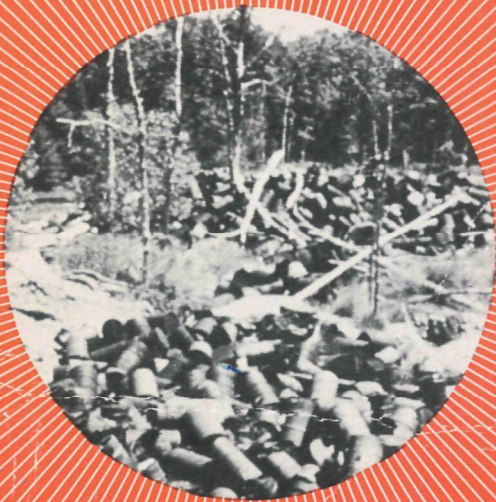


# **MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES**





**NATIONAL CONFERENCE ON**

**MANAGEMENT OF  
UNCONTROLLED  
HAZARDOUS  
WASTE SITES**

**NOVEMBER 29-DECEMBER 1, 1982  
WASHINGTON, D.C.**

**AFFILIATES:**

- *U.S. Environmental Protection Agency*
- *Hazardous Materials Control Research Institute*
- *U.S. Corps of Engineers*
- *U.S. Geological Survey*
- *American Society of Civil Engineers*
- *Association of State and Territorial Solid Waste Management Officials*



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U.S. Environmental Protection Agency  
Hazardous Materials Control Research Institute  
U.S. Corps of Engineers  
U.S. Geological Survey  
American Society of Civil Engineers  
Association of State and Territorial Solid Waste Management Officials

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# ELECTROMAGNETIC RESISTIVITY MAPPING OF CONTAMINANT PLUMES

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## FACTORS AFFECTING SOIL RESISTIVITY

The electrical resistivity of a soil is a measure of the relative difficulty encountered in causing an electrical current to flow in it; the more resistive the soil, the smaller the current flow for a given voltage. Surprisingly, most physical constituents of a soil are electrical insulators of such high resistivity that no appreciable current flows through them. What does allow significant current to flow is the relatively conductive soil moisture; it is this parameter which often controls the soil bulk resistivity.

An electrical model of soil where it is considered to consist of a large number of insulating particles immersed in a conductive fluid is shown in Fig. 1. The mixture resistivity should be affected both by the resistivity of the conductive soil moisture and also by the fact that the insulating particles act to impede the current flow. Empirically it has been established that Archie's Law often gives the correct behavior of soil resistivity:<sup>1,2</sup>

$$\rho_{\text{sample}} = \rho_{\text{moisture}} \times \frac{1}{\sqrt{(\text{soil porosity})^3}} \quad (1)$$

and, as expected, there is a linear relationship between soil resistivity and the resistivity of the included water. Now the water resistivity is determined mainly by the ionic content since it is the movement of ions that carries the electrical current. For a given voltage more ions permit greater current flow, i.e. reduced resistivity; it is on this principle that the use of resistivity surveys to outline contaminated areas is based.

However, other factors also affect the measured soil resistivity. For example, it is evident from Eq. 1 that soil porosity has a somewhat greater effect on soil resistivity than the soil moisture, so that variations in soil type, which result in changes in porosity can cause incorrect interpretation of resistivity surveys carried out to map contaminants. Clay content (and the type of clay) can additionally affect soil resistivity because of a "surface conduction"

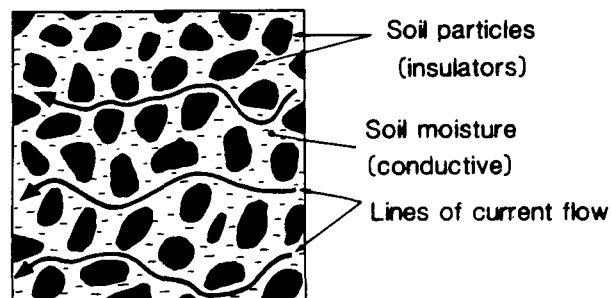


Figure 1.  
Electric model of soil sample

phenomenon which occurs in clay. Furthermore since resistivity measurements are influenced by the vertical distribution of resistivity, which is in turn influenced by the vertical distribution of soil moisture, variations in the moisture profile (such as changes in the level of the water table) will affect survey results.

Since geological and hydrogeological factors can affect soil resistivity, surveys intended to delineate a contaminant area must include a sufficient density of measurements both over the suspect region and also beyond into the surrounding area so that the possible influence of any of the above factors can be determined. Furthermore, the survey interpreter must always bear in mind the various factors other than soil water resistivity that can influence the survey results.

## CONVENTIONAL RESISTIVITY SURVEY TECHNIQUES

Conventional resistivity surveys are carried out by inserting four metal electrodes in the ground in one of a number of arrays. The theory of such techniques is well covered in the literature.<sup>2</sup>

In general, a voltage applied across two of the electrodes causes a current to flow in the soil, and the resulting voltage measured across the two other electrodes is a measure of the soil resistivity. The Wenner array, commonly used for geotechnical surveys, is shown in Fig. 2. The depth to which resistivity is sensed is determined essentially by the inter-electrode spacing, and for the Wen-

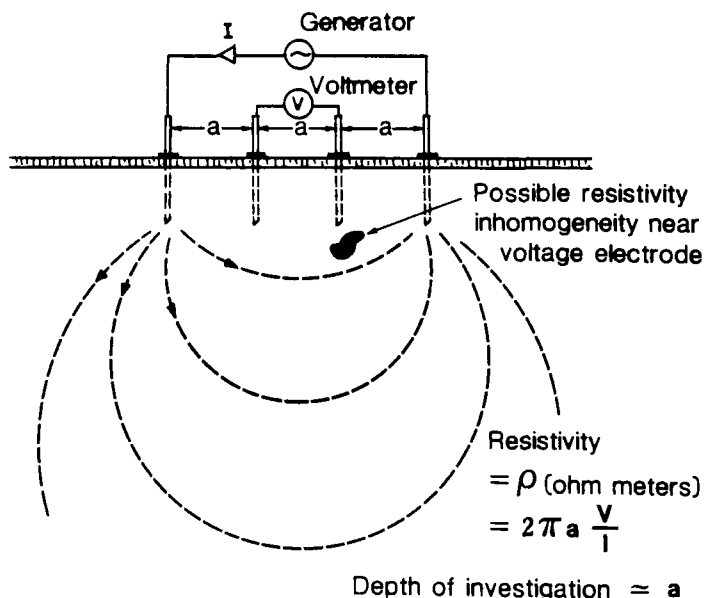


Figure 2.  
Conventional resistivity (Wenner array)

ner array it is usually considered to be approximately  $a$ . The resistivity of the ground for the Wenner array is given as:

$$\rho = \frac{2\pi a^2 V}{I} \quad (2)$$

where  $\rho$  = resistivity ( $\Omega\text{m}$ )  
 $a$  = inter-electrode spacing (m)  
 $I$  = current flowing through outer electrodes (amps)  
 $V$  = voltage across inner electrodes (volts)

Although widely used for resistivity surveys, there are several disadvantages related to the use of electrodes:

- It may be difficult or impossible to drive electrodes into compact earth. It is impossible to survey in the winter when the ground is frozen.
- The presence of resistive inhomogeneities (for example, rocks) near the voltage electrodes can cause large measurement errors, even though the physical size of the inhomogeneity is much smaller than the anticipated depth of exploration. Reconnaissance surveys are usually carried out by making a series of measurements along the survey line at constant inter-electrode spacing to achieve essentially constant depth of exploration. The survey data are plotted as a profile of measured resistivity along the survey line. Such profiles can be quite "noisy" due to electrical inhomogeneities with the result that the presence of subtle changes in resistivity caused by a contaminant, might be missed by the interpreter.
- In order to make a measurement the four electrodes must be accurately spaced (Fig. 2) and a total length of wire equal to  $4a$  must be connected between the electrodes and the instrumentation. Thus the process is laborious and progress is slow. Even for the most organized surveys the survey costs on a line-mile basis are high.

These high costs lead in turn to several important consequences:

- Within the presumed anomalous area, insufficient measurements may be carried out to accurately characterize the plume.
- Outside of the anomalous area, insufficient measurements may be carried out to accurately characterize the background against which the plume is to be contrasted or to determine the existence and nature of other anomalous regions which may exist and which may or may not be caused by contaminants.
- In areas of complex hydrogeology a time-consuming and expensive survey may be performed, to learn, at the conclusion, that the data are inconclusive. The contaminant may simply not be present in sufficient quantities to produce a marked and unambiguous anomaly over the survey geological noise. Since such cases do occur, the inclination to carry out further resistivity surveys can be greatly tempered by a few such failures, which is unfortunate since resistivity measurement is often the single most successful method in delineating contaminant plumes.

It was in recognition of the usefulness of resistivity and the high cost of the conventional methods that inspired the research staff at Geonics Limited to examine the application of electromagnetic techniques for making resistivity measurements.

## ELECTROMAGNETIC SURVEY TECHNIQUES

Let a small transmitter coil be situated on or close to the earth, as indicated in Fig. 3. An alternating voltage, typically at an audio frequency, is applied to the terminals of this coil, causing a current to flow. This current generates an alternating magnetic field which, through Faraday's Law, causes electrical currents to be induced in the earth (no such current is induced in the air, which is effectively infinitely resistive).

The induced currents in the earth generate a secondary magnetic field. Both the primary and the secondary fields are detected by a receiver coil located near the transmitter coil, as shown in Fig. 3, and, in principle, measurement of the ratio of the secondary to the

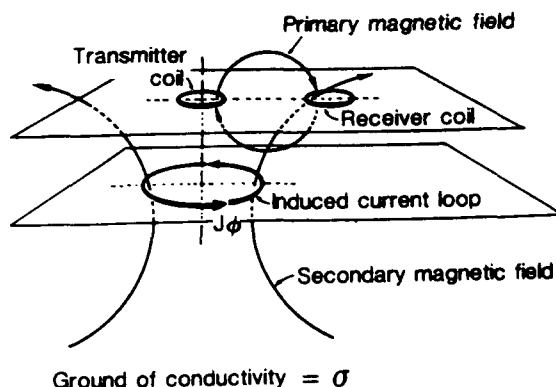


Figure 3.  
Inductive electromagnetic fields

primary magnetic field strength can be used to determine the electrical resistivity of the earth. In general, however, this ratio is an extremely complicated function of the resistivity, the distance between the transmitter and receiver coils, and the frequency of the transmitter current, so that interpretation of the results in terms of the resistivity is quite involved.<sup>2,3</sup> Furthermore, the depth of investigation is also a complicated function of the same three parameters.

Fortunately a substantial simplification in the response function results when the energizing frequency is chosen to be sufficiently low so that the condition known technically as "operation at low values of induction number" is fulfilled.<sup>3</sup> For the remainder of this paper all reference to the use of inductive electromagnetic techniques assumes that the condition of a low induction number has been met.

For example, for low values of induction number the ratio of the secondary to primary magnetic field at the receiver becomes simply:

$$\frac{H_s}{H_p} = \frac{i2\pi f \mu \sigma s^2}{4} \quad (3)$$

where  $f$  = operating frequency (Hz)  
 $s$  = intercoil spacing (m)  
 $\sigma$  = ground conductivity which is the reciprocal of resistivity (mho/m)  
 $\mu$  = permeability of free space (a constant)

and the quantity  $i (= \sqrt{-1})$  indicates that the magnetic field arising from the induced currents in the ground is phase shifted by  $90^\circ$  with respect to the primary magnetic field, greatly simplifying measurement of the small ratio given by Eq. 3.

For the four-electrode resistivity measurement, Eq. 2 indicates that the ratio of the voltage across the inner two electrodes, divided by the current through the outer electrodes, is linearly proportional to the terrain resistivity. For the electromagnetic measurement, Eq. 3 shows that the magnetic field ratio is linearly proportional to the ground conductivity rather than resistivity, since, subject to the constraint of operation at low induction number, the more conductive the ground the larger the current flow in the ground, and the larger the resultant secondary field. Instruments based on this principle are therefore called ground conductivity meters.

There are further advantages and some disadvantages to measurement of terrain conductivity using the principles outlined. The advantages fall into two main groups; ease of calculation of system response to a layered earth and operational simplicity.

## Calculation of Layered-Earth Response

In general, the resistivity or conductivity of the earth varies with depth; for example in a typical vertical profile the conductivity will initially increase with depth due to increasing soil moisture, becoming essentially constant at the water table due to saturation. If the underlying bedrock has very low porosity, the conductivity would now decrease. Such a continuous conductivity profile, shown



schematically in Fig. 4, would be approximated by the engineer/geologist as a three-layer geometry also indicated in Fig. 4.

Suppose further, that in a certain region the groundwater may be sufficiently contaminated to double the groundwater conductivity, that is, through Eq. 1 to double the conductivity of the intermediate layer of Fig. 4. The question arises: "With a conventional resistivity array of fixed interelectrode spacing 'a' or an electromagnetic system with fixed intercoil spacing 's' how is the instrumental response calculated over such 'layered earths' so that the difference in response between the contaminated and uncontaminated areas can be determined?"

If the earth resistivity was uniform with depth, Eq. 2 shows that the Wenner array, for a given current I, would give an inner electrode voltage  $V_u$  related to the resistivity by:

$$V_u = \frac{\rho I}{2\pi a} \quad (4)$$

If now the earth is layered, as indicated in Fig. 4, a different value of voltage  $V_x$  will be measured for the same current I and inter-electrode spacing a, and an apparent resistivity can be defined by:

$$\rho_a = 2\pi a \frac{V_x}{I} \quad (5)$$

For a layered earth the apparent resistivity so defined will reflect the influence of the various resistivities at the different depths.

To return to the contaminant problem, the question can now be rephrased as "for a given fixed inter-electrode spacing how does the apparent resistivity vary in going from the uncontaminated to the contaminated region?" Unfortunately, for conventional resistivity techniques, such a calculation requires a reasonably complicated computer program (although it can now be performed on the most advanced programmable pocket calculators). The calculation for an arbitrarily layered earth cannot be performed by hand.

For electromagnetic measurement of terrain conductivity at low induction number, the concept of apparent conductivity is entirely analogous. Equation (3) is inverted to yield:

$$\sigma_a = \frac{4}{2\pi f \mu s^2} \frac{H_s}{H_p} \quad (6)$$

which, for the case of a uniform earth gives the correct terrain conductivity, and for the case of a layered earth gives an apparent conductivity which also depends on the layering.

A major difference between the conventional and the electromagnetic survey techniques is that for the latter it is a simple matter to calculate the apparent conductivity (by hand) for any type of layering. The reason for this difference is that for conventional resistivity measurements, the current distribution at any point in the layered earth is a complicated function of the parameters of all of the layers. In the case of the electromagnetic surveys, the local current flow is determined by the local conductivity—changed in any given layer do not affect (to the low induction-number approximation) the current flow in other layers.

It is thus possible to generate the curve in Fig. 5 which shows, for

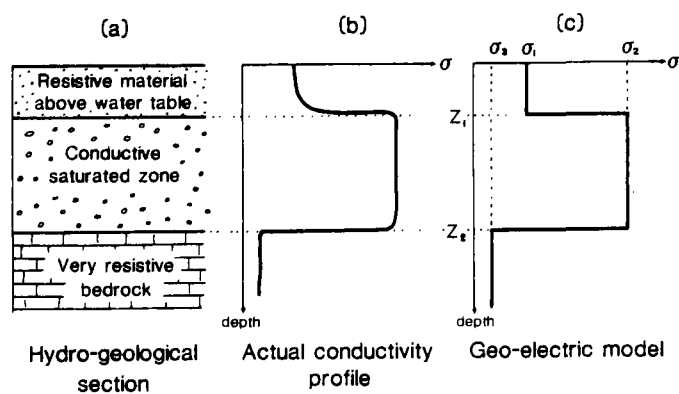


Figure 4.

Typical ground conductivity profile

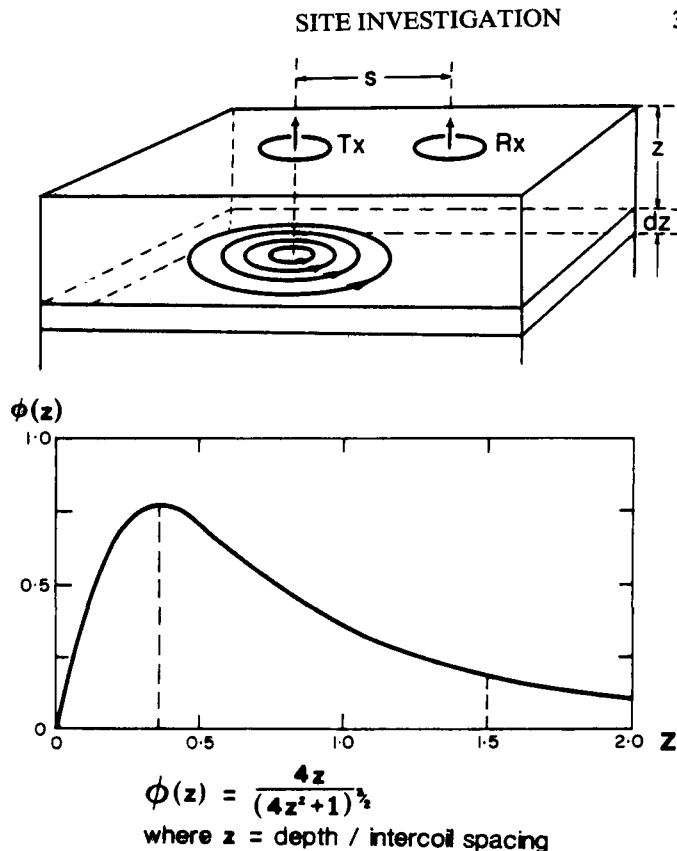


Figure 5.

Relative sensitivity to ground at various depths

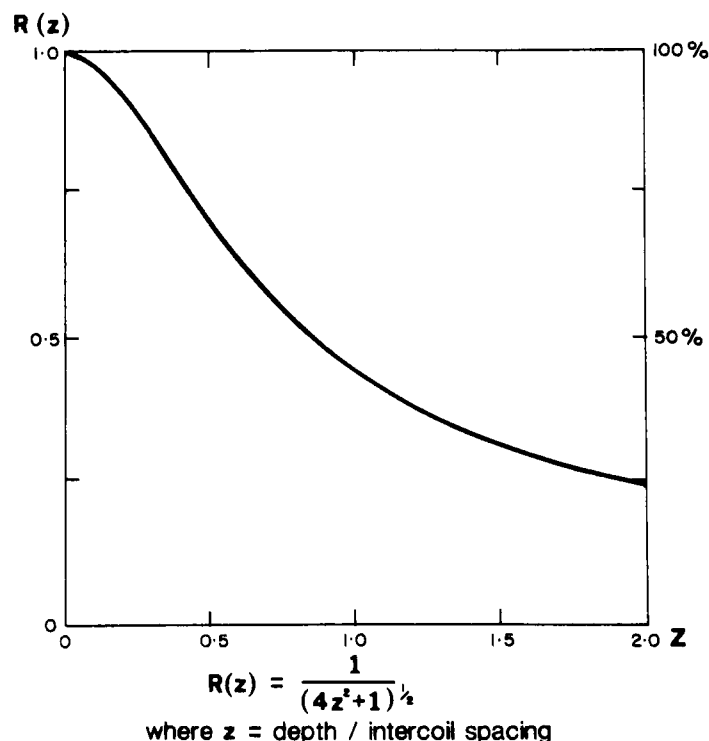


Figure 6.

Cumulative sensitivity to ground at various depths

a uniform earth, the relative contribution to the meter reading from a thin horizontal layer of thickness  $dz$  at any depth  $z$ , (where  $z$  is the real depth normalized with respect to the intercoil spacing). The figure shows that this relative response is very small near the surface, that it increases with depth, becoming a maximum at 0.4 intercoil spacings (i.e. at 4 m if the intercoil spacing is 10 m) and then gradually decreases again. There is still appreciable response at 1.5

intercoil spacings. To construct such a response curve for conventional resistivity techniques is not possible due to the interaction of current flow at different depths.

Knowing the relative response to material at any given depth, it is possible to generate from Fig. 5, the curve of Fig. 6 which gives the cumulative contribution to the meter reading from all material below any depth "z" (again normalized with respect to the intercoil spacing). This curve can be used to quickly calculate the apparent conductivity from a layered earth as follows,<sup>1</sup> using the data from Table 1.

**Table 1.**  
**Postulated Geoelectric Section (Fig. 4)**

Uncontaminated Area			Contaminated Area		
$\rho_1$	2000m	$\sigma_1 = 5$ mmho/m	$\rho_1 = 2000m$	$\sigma_1 = 5$ mmho/m	
$t_1$	5 m	$z_1 = 5$ m	$t_1 = 5$ m	$z_1 = 5$ m	
$\rho_2$	500m	$\sigma_1 = 20$ mmho/m	$\rho_2 = 250m$	$\sigma_2 = 40$ mmho/m	
$t_2$	10 m	$z_2 = 15$ m	$t_2 = 10$ m	$z_2 = 15$ m	
$\rho_3$	10000m	$\sigma_3 = 1$ mmho/m	$\rho_3 = 10000m$	$\sigma_3 = 1$ mmho/m	

where  $\sigma$  (mmho/m) =  $1000/\rho$  ( $\Omega m$ )

and  $t_i$  is the thickness of the  $i$ th layer

and  $z_i$  is the distance from the surface to the bottom of the  $i$ th layer.

Assuming the intercoil spacing is 10 m, all of the material below 0 meters produces 100% of the instrumental response, all the material below 5 m produces 70% of the instrumental response and all below 15 m produces 31% of the response. Therefore, the material between 0 and 5 m produces  $100-70 = 30\%$  of the total response and the material between 5 and 15 m produces  $70-31 = 39\%$  of the response. Since each layer produces its own contribution independently of that from the other layers, regardless of their conductivity, to obtain the apparent conductivity one simply adds the relative contribution from each layer, weighted according to its own conductivity:

$$\sigma = \sigma_1 \times 0.30 + \sigma_2 \times 0.39 + \sigma_3 \times 0.31$$

or, more generally :

$$\sigma_a = \sigma_1 (1-R(z_1)) + \sigma_2 (R(z_1)-R(z_2)) + \sigma_3 (R(z_2)) \quad (7)$$

where  $R(z)$  is the function given in Fig. 6.

For the uncontaminated area:

$$\begin{aligned} \sigma_a &= 5 (1-0.70) + 20 (0.70-0.31) + 1 (0.31) \\ &= 1.50 + 7.80 + 0.31 \\ &= 9.61 \text{ mmho/m} \end{aligned}$$

whereas for the contaminated area:

$$\begin{aligned} \sigma_a &= 5 (1-0.70) + 40 (0.70-0.31) + 1 (0.31) \\ &= 1.50 + 15.60 \\ &= 17.41 \text{ mmho/m} \end{aligned}$$

Because of the contributions from the first and third layers, the apparent conductivity has less than doubled.

The equation for  $R(z)$  is extremely simple (Fig. 6), so the calculation of the apparent conductivity for any number of layers can be carried out with the simplest pocket calculator or, using the graph, by hand. The contribution from each layer to the total is immediately apparent, and it is simple to calculate the variation caused by changes within any given layer.

In the example, a 2/1 change in the middle layer conductivity produced a 1.8/1 change in the overall apparent conductivity. If, however, the conductivity of the first layer increased from 5 to 25 mmho/m, for example, by encountering a region with high clay content, the contribution from this layer would increase from 1.5 to 7.5 mmho/m which could be confused as an increase in the contaminant in the second layer. The provision for quick and simple

calculations of this type facilitates both the planning of surveys and estimating the probability of their success.

### Operational Advantages of Electromagnetic Conductivity Measurement

- Resistivity inhomogeneities of a size much less than the anticipated depth of exploration would, if they were located near the voltage electrodes, produce an anomalous measurement which is truly "geological noise" since without further measurements it is not possible to determine the resistivity contrast, the physical location, or the size of the anomaly. In the case of the inductive conductivity technique it can be shown\* that the current concentration in the ground is highest in the vicinity of the transmitter coil and one might anticipate that this technique would be especially sensitive to inhomogeneities in this location. However, these high amplitude current loops have a small radius and their effect on the relatively distant receiver is negligible. The net result is that in the inductive technique, once the intercoil spacing has been selected to be approximately equal to the desired depth of the exploration, the system is quite insensitive to small, local variations in conductivity, and an accurate measurement of the bulk conductivity is obtained. This is particularly important in studies for groundwater contamination where the changes in the apparent conductivity due to the presence of the contaminant may be rather small. Fortunately variations in the apparent conductivity of 20% are quickly and reliably measured.

- The presence of a highly resistive upper layer offers no barrier to measurements with inductive electromagnetic systems and surveys can be carried out when the upper layer is frozen, through desert sand, and even through concrete (assuming that there are no reinforcing bars).
- With the electromagnetic measurements, the effective depth of exploration is given approximately by one and a half times the intercoil spacing, whereas for conventional resistivity measurements the exploration depth is only one third the array length. There is no necessity to lay out lengths of wire on the ground which are much greater than the exploration depth and there is no requirement for electrodes.
- It is a simple matter to incorporate circuitry which automatically indicates the correct intercoil spacing, thus doing away with the requirement of physically measuring the distance.
- The equipment is lightweight and readily portable. A "two-man" instrument achieves an exploration depth of up to 60 m.

### Instrumental Disadvantages of Electromagnetic Conductivity Measurement

The disadvantages of the inductive electromagnetic terrain conductivity meters are instrumental in nature:

- At levels of conductivity below about 1 mmho/m, there simply is not enough response from the small currents induced in the ground to obtain an accurate measurement. At high levels of conductivity, the "low induction number" approximation breaks down and the instrument response becomes increasingly non-linear with conductivity. This constraint also makes it difficult to design an instrument for large depths of exploration.
- The measured ratio of secondary to primary magnetic field is typically 0.3% and often less (Eq. 3). To achieve precision at these levels requires sophisticated electronic design, which results in instruments that are significantly more expensive to manufacture than conventional resistivity equipment.
- Ideally the instrument "zero" would be set by removing the instrument from the influence of all conductive material, including the earth. Obviously this is not possible and it is difficult to establish and maintain this zero to better than a few tenths of a mmho/m over the wide ranges of temperature, humidity, and mechanical shock to which geophysical equipment is routinely exposed. This feature further limits the accuracy in highly resistive ground.
- In principle conductivity sounding with depth can be carried out



in a manner completely analogous to that for conventional resistivity equipment, i.e. measurement is made over a wide range of intercoil spacings. Technical problems associated with the dynamic range of the received signal make this difficult and expensive to do, and currently available instrumentation has a maximum of three switch-selectable intercoil spacings of 10, 20 and 40 m.

In summary, inductive electromagnetic techniques are most suited to rapid reconnaissance-type surveys, where the relatively high initial cost of the equipment can be offset by the speed and low cost with which surveys can be carried out, and where the resolution in conductivity, whereby small variations can be accurately mapped, is a prime consideration in the survey objectives.

For those situations where very high or very low conductivities are to be mapped, or where an accurate profile of the vertical distribution of resistivity is the objective, conventional resistivity techniques will still be required.

### SURVEY INSTRUMENTS

Instrument design conforming to the condition of operation at low values of induction number, forms the basis of the patented Geonics EM31, EM34-3 and EM38 terrain conductivity meters. The EM31, a one-man portable instrument with a fixed intercoil spacing of 3.7 m and a depth of exploration of about 6.0 m is shown in Fig. 7. Basically designed as a rapid reconnaissance instrument the EM 31 can be effectively used with a chart recorder to provide continuous profiles of ground conductivity. In addition this instrument is very effective in detecting and mapping the location of buried metallic drums.<sup>5</sup> Finally, by laying the instrument on the ground and making two measurements, one with the device in

normal position and a second on its side (vertical and horizontal dipole modes), it is possible to detect a two-layered earth and to ascertain whether the more conductive material is near surface or at depth.<sup>5</sup>

The EM34-3 (Fig. 8) is a two-man instrument with switch-selectable intercoil spacings of 10, 20, or 40 m to permit maximum depths of 15, 30 and 60 m. It too can be operated in either the vertical or horizontal dipole mode to vary the instrumental sensitivity with depth. The two coils are connected by a flexible cable: the receiver console has two meters—one of which electronically indicates the intercoil spacing.

To make a measurement the transmitter operator stops at the survey mark: the receiver operator then moves his coil with respect to the transmitter until this meter indicates that the correct intercoil spacing has been achieved, whereupon he reads the terrain conductivity on the second meter. The whole procedure takes about 20 sec.

The EM 38 is a 1.0 m long instrument (depth about 1.5 m) designed for soil salinity measurements.

### SURVEY CASE HISTORY

A case history<sup>6</sup> will illustrate some of the features of surveys carried out using inductive electromagnetic techniques.

The survey area, shown in Fig. 9, is described by Greenhouse and Slaine<sup>6</sup> as follows:

"A variety of waste chemicals from herbicide and pesticide manufacturing were deposited in lined lagoons situated on glacial overburden during the 1970s. One or more of the lagoon liners has leaked into an unconfined aquifer, producing groundwater conductivity anomalies proportional to total dissolved solids (primarily chloride and sodium). The contamination threatened a nearby creek but the pattern of movement was unknown. Geophysical surveys were requested to assist in locating a drilling program."

This is a typical application for a geophysical survey.

During the planning stages of a conductivity survey, Greenhouse and Slaine obtain all of the available hydrogeological data on the



Figure 7.  
EM 31

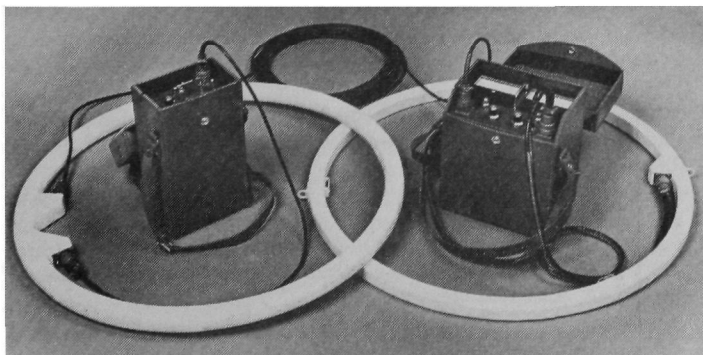


Figure 8.  
EM 34-3

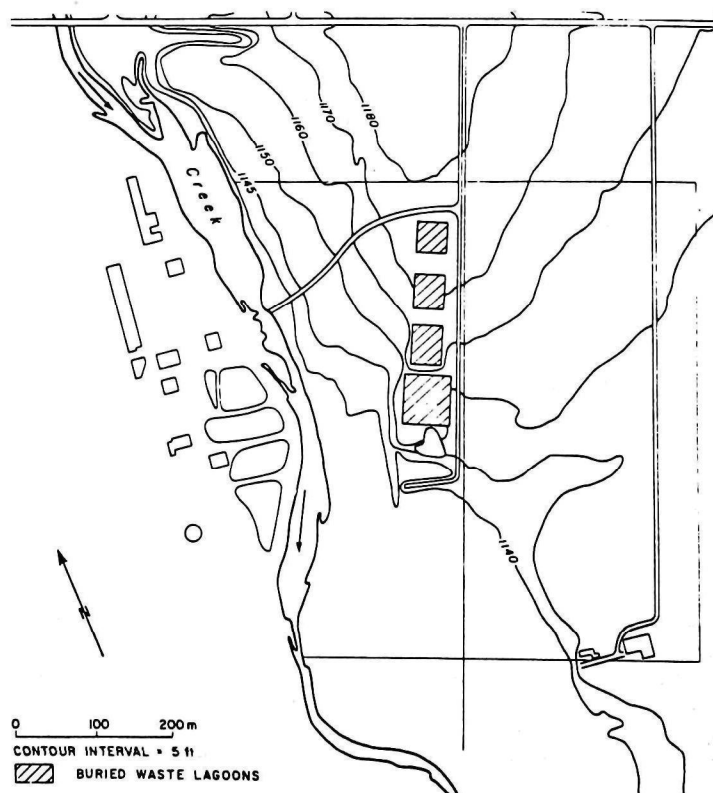


Figure 9.  
Survey case history area

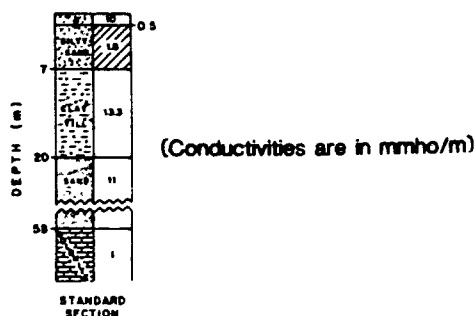


Figure 10.  
Hydro-geological and geo-electric section

site. These data are used to construct a hydrogeological model such as that shown in Fig. 10. Alongside each geological unit an estimate is made (generally from previous survey experience) of the electrical conductivity of that unit in order to make a geo-electric section. Next those formations whose conductivity might change due to contamination are identified. For example, in Fig. 10 "the unconfined sand aquifer is apparently isolated from the lower regional sand aquifer by a clay till. Groundwater flow in the upper sand was expected to be horizontal and towards the creek."

In order to determine which instrument, coil orientation, and intercoil spacing is most suitable for the survey, calculations of the type outlined above are performed to obtain the apparent conductivity measured by each instrument or spacing as the conductivity of the postulated contaminated section is allowed to increase. From such calculations the optimum instrument or spacing can be selected, and, furthermore, estimates made of the survey success, since as shown it is a simple matter to vary the conductivities in the geo-electric section (to account for possible errors in their estimated magnitude) and to determine whether these will mask the anticipated anomaly. For this survey site, such calculations suggested that for the EM31, any increase in conductivity of the silty sand formation of more than a factor of about 1.8 would produce a detectable anomaly over the usual background variations, and that for the EM34-3 (used in the horizontal dipole mode) this factor would be about 2.2, both of which would indicate a successful survey since a higher change in conductivity could be anticipated from the contaminant.

"Measurements were made on a basic 50 m grid covering a 500 x 500 m area centered on the southernmost lagoon...The grid was refined to 25 m for much of the western half of the survey, for a total of 150 stations per instrument. Establishing the grid required 14 man hours; the...EM 31 and EM34 surveys required 10 and 20 man hours respectively."

Greenhouse and Slaine chose a logarithmic base for their data presentation. More specifically, they plotted contours of decibels:

$$20 \log_{10} \frac{\sigma_a(x, y)}{\sigma_a(\text{background average})} \quad (8)$$

where  $\sigma_a(x, y)$  = measured values of  $\sigma_a$  over the survey area

$\sigma_a(\text{background average})$  = average background conductivity (i.e. average value measured off the anomaly).

Thus, the zero db contour outlines the background, and their contour interval of 4 db portrays successive factors of about 1.6 over the background. They suggest three advantages for this technique:

- Logarithmic contours do not cluster close to the course and thus do a better job of defining the plume
- Non-dimensional contour units with a zero background put all instruments on an equal basis
- The procedure is easily automated once  $\sigma_a(\text{background average})$  is identified.

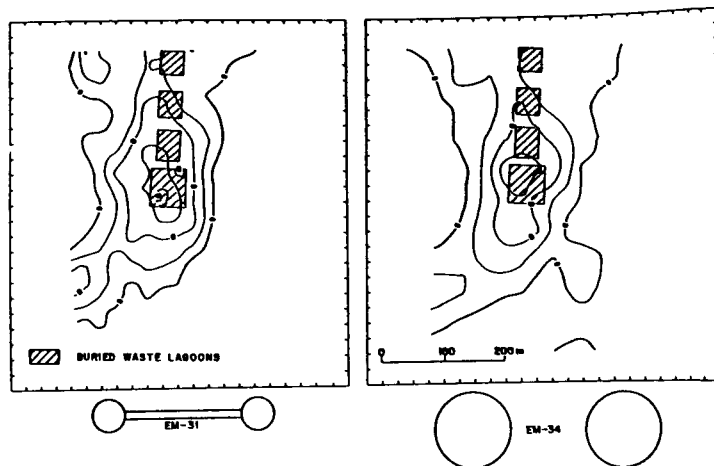


Figure 11.  
Survey data

The survey data, shown in Fig. 11, clearly indicate a well-defined plume-like anomaly heading toward the creek from the two southern lagoons. As anticipated by the calculations, the anomaly is somewhat larger on the EM31 survey since it is situated more closely at the depth of maximum response for this instrument. Apparently the two northern lagoons were excavated and replaced with clear fill several years ago, explaining the lack of a conductive anomaly at their location. Unfortunately insufficient test well control is available to confirm that the conductivity plume is due to contaminant, as however, seems probable.

## CONCLUSIONS

The case history illustrates the important features of the inductive electromagnetic technique viz.—the ease of estimating the survey response, the speed with which surveys can be carried out, and the ability to detect small changes in conductivity. Many conventional resistivity surveys fail to produce convincing results since the high cost usually results in too little data with inadequate resolution and an anomalous region that is not convincingly contrasted against the background. Inductive electromagnetic techniques, while also having disadvantages as discussed previously, do offer features which are particularly well suited to the rapid and accurate mapping of contaminant plume.

## ACKNOWLEDGEMENT

Grateful appreciation is extended to J.P. Greenhouse and D.D. Slaine at the University of Waterloo for interesting discussions concerning survey data obtained using electromagnetic techniques.

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# FIELD INVESTIGATION OF AN ABANDONED PESTICIDE FORMULATION PLANT

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## INTRODUCTION

Between 1974 and 1981, a pesticide formulating plant operated within the floodplain of the Missouri River, 11.3 km south of Council Bluffs, Iowa. A sequence of events, beginning with a fire in 1976, led to the investigation of the site by the Region VII United States Environmental Protection Agency (USEPA). In 1981, Ecology & Environment, Inc. (E&E) was authorized by Region VII to perform a field investigation to determine the extent of contamination at the site.

In this paper, the author discusses the design, implementation and the data obtained in the various phases of this investigation. At the time of the investigation, this site was being considered for inclusion on the first Interim Priorities List.

## BACKGROUND

### Physical Setting

The plant site is located at the eastern edge of the Missouri River floodplain, directly adjacent to the loess covered bluffs that border the valley (Fig. 1). The site has a minimal slope of 0-5 percent and is located 3.0-6.1 m above the normal level of the Missouri River, located 5 km to the southwest. The surface drainage in this agricultural section of the floodplain is controlled through artificial drainage ditches.

The alluvial sediments underlying the surface soils consist of sands, silts and clays, with coarse sand and gravel near the base of the alluvial sequence. The highly dissected loess bluffs bordering

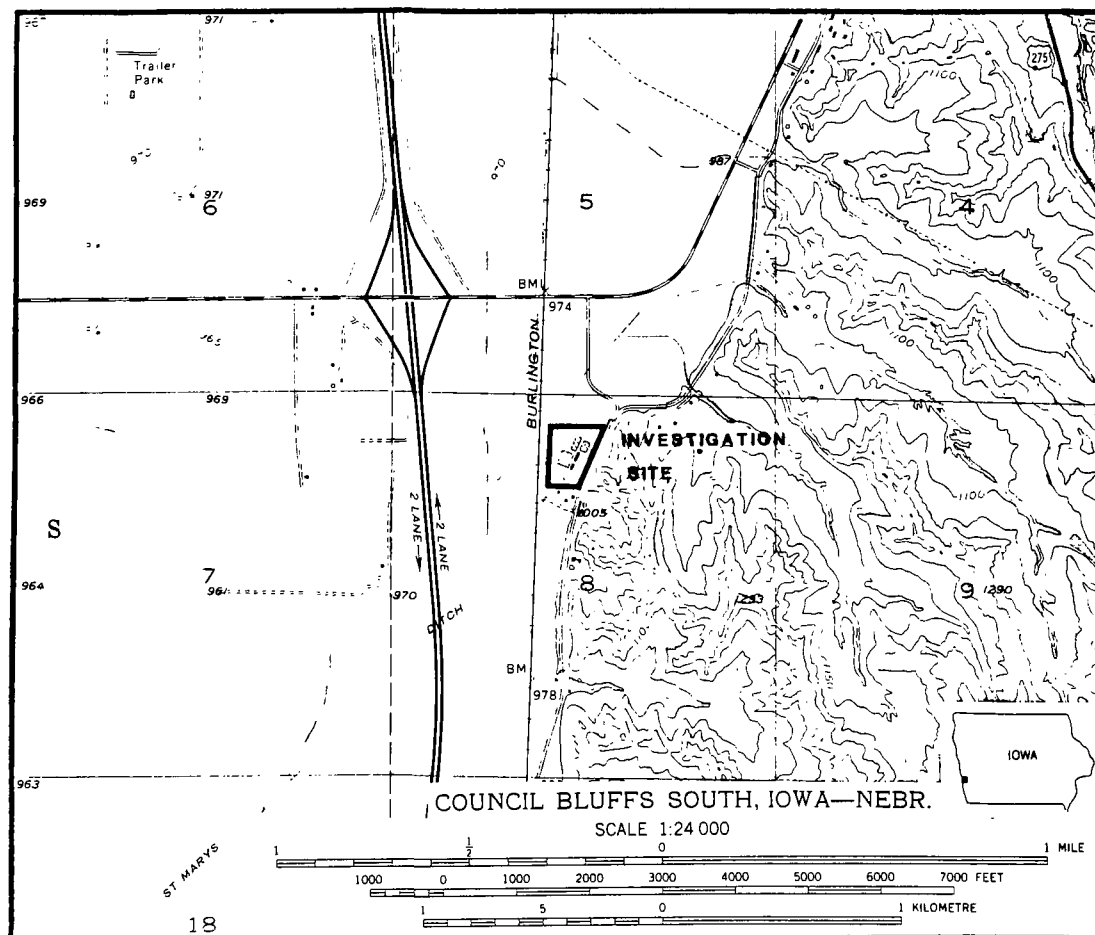


Figure 1.  
Site Location Map



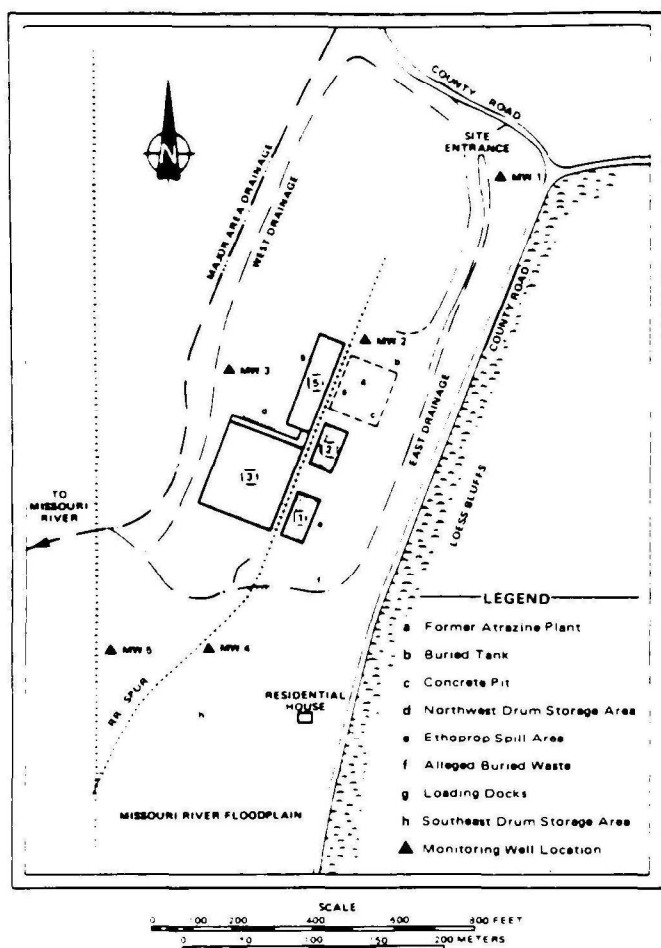


Figure 2.  
Site Map

the Missouri River valley are composed of windblown silts of glacial origin and rise 30.5-91.4 m above the floodplain.

The alluvial aquifer of the Missouri River provides the major drinking and industrial water supply in the area. The drinking water wells surveyed in the vicinity of the site range from 5.5-30.5 m in depth. Two wells located at the site average 27.4 m in depth.

#### Past History

Prior to 1974, this company operated a pesticide formulating facility in Omaha, Nebraska. This facility was destroyed in a fire and subsequently the operation was moved to its present site, south of Council Bluffs, Iowa. This new facility (Fig. 2), which encompasses 8 ha, was located in a rural area to minimize exposure to the population should a similar incident occur (Fig. 3).

The company operated as both formulators and packagers of various organochlorine, organophosphate and s-triazine pesticides and herbicides. Two divisions of the company were also located at the site and handled the dry and wet formulations. The two major products were ethoprop, an organophosphate pesticide, and atrazine, a triazine herbicide, along with small volume and pilot project formulations.

In November of 1976, a fire destroyed the atrazine formulation plant at the Council Bluffs facility. Following this fire, production at the plant was greatly reduced and in 1980 the firm filed for reorganization under Chapter 11 of the Federal Bankruptcy Act. In August 1981, a bankruptcy sale was held at the site to liquidate the assets of the company.

#### Contamination at the Site

During the process of extinguishing the 1976 fire that destroyed the atrazine formulation plant, it was estimated that 110 m<sup>3</sup> of

water were used. Chemical contamination of the sediments and water in the plant's drainage system was documented at this time by Region VII, with prometon (60-357 mg/kg) and atrazine (13-840 mg/kg) being the major pesticides detected.

An investigation by Region VII in March 1980 showed concentrations of atrazine in the drainage sediments of 32 mg/kg. In August of 1980, an investigation by the National Enforcement Investigations Center (NEIC) of USEPA detected seven pesticides in subsurface sediments with concentrations greater than 1 mg/kg: atrazine, heptochlor, chlorodane, phorate, disulfoton, chlorpyrifos and toxaphene. At the same time, a buried tank located north of the former atrazine plant was sampled and found to contain lindane, malathion, toxaphene, and methoxychlor in concentrations of 20, 320, 1,200, and 3,200 mg/kg respectively. During each of the sampling efforts described above, the two onsite wells were sampled and found not to be contaminated with pesticides.

The final sampling effort occurred in August 1981, prior to the E&E investigation and following the bankruptcy sale. During the sale, a spill of ethoprop baghouse dust occurred. As a result of this accident, two workers were admitted to the hospital with organophosphate pesticide poisoning. At the same time, several large metal atrazine storage tanks, sold as scrap, were drained into a concrete basin at the site. Personnel from Region VII USEPA coordinated the cleanup of this spill.

From the samples taken during these four investigations it became clear that there were certain areas of concern that needed to be addressed. The four investigations conducted at this site, although limited in scope, documented contamination of the surface soils, subsurface soils and drainage sediments. A buried tank contained approximately 30 m<sup>3</sup> of wastes from numerous pesticide manufacturing processes. An open pit contained atrazine process wastes. During those investigations, greater than 1,500 drums, many in deteriorated condition, were being stored outdoors at the site. An additional 1,200 fiber drums of baghouse dust were being stored indoors. There were also allegations by former plant employees and nearby residents of drummed waste buried at the site. The E&E investigation was initiated to determine the extent of the contamination and assess the potential for migration of contamination via the air, soil and groundwater pathways.

#### FIELD AND LABORATORY INVESTIGATIONS

In order to assess the extent of pesticide contamination on and around the site, a multi-phase analytical study was undertaken. A description of a field investigation procedure similar to the one followed at this site is found in a prior conference paper by Hagger and Clay in 1981.<sup>1</sup>

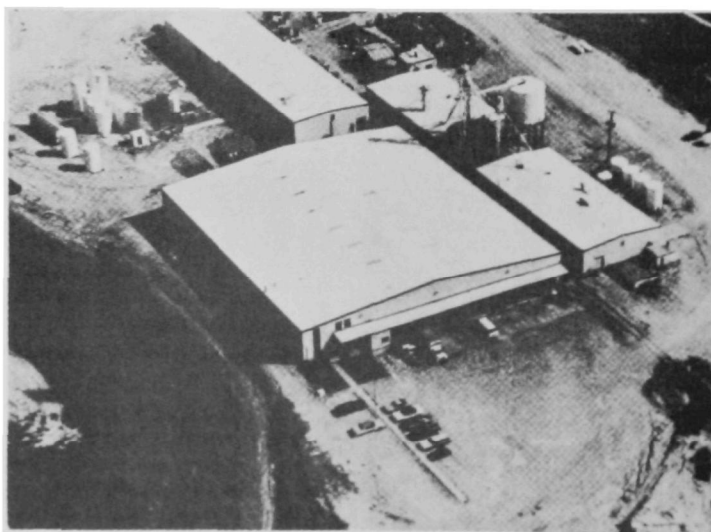


Figure 3.  
Aerial Photograph of Site  
(see Fig. 2 for identifying features)

Analyses of airborne particulates, surface soil, subsurface soil, subsurface sediments and groundwater samples were used to delineate the most highly contaminated areas of the site. A metal detector survey was also performed to locate areas of suspected waste disposal. The following sections will describe the rationale behind the design of each of these monitoring schemes.

Due to the public access to the site, Region VII USEPA personnel had a security fence constructed, financed by Superfund Immediate Removal funds.

### Air

As a Superfund candidate, it was necessary to determine the air pollution release potential. Due to the chemical odors originating from the site, an initial organic vapor survey was performed prior to any field sampling.

Pesticides are not generally volatile and would therefore not be recorded by an organic vapor analyzer. However, solvents used during the formulation of pesticides are volatile and will be detected by the analyzer.

High-volume air sampling was also conducted to qualify the existence of airborne particulate pesticides on- and off-site. A quantification of values was not possible, because pesticide may volatilize while being pulled through the pressure differential created in the high volume sampler.

### Surface Soil

An extensive soil sampling study was conducted to produce data on surface contamination resulting from spillage, leaking drums and containers, and poor housekeeping practices at the plant. The three grid sampling patterns chosen for the soil survey were designed to cover all of the major areas of the plant used during its operation, as well as areas of waste disposal and alleged debris burial. The major drainageways outside the site were sampled to document any migration of contaminants offsite. Within the grid pattern, 89 samples were collected to a maximum depth of 7.6 cm.

Because of the large number of samples to be analyzed, and time and budgetary constraints, a method was used to identify those samples which were most contaminated. This procedure of screening out non-contaminated samples consisted of analysis in a capillary gas chromatograph with an electron capture (EC) detector. Total pesticide concentration estimates were calculated using a standard mixture of several of the suspected organochlorine pesticides. The concentrations measured may be substantially lower than actual total concentrations of pesticides due to the greater response of the EC to organochlorine compounds relative to organophosphate and s-triazine compounds. However, these concentrations are useful in comparing the concentrations of samples from different locations and identifying those samples that were significantly contaminated.

Based on the results of preliminary chemical analysis on the 89 samples, 20 samples were selected for further analysis. These samples included uncontaminated background as well as onsite contaminated samples. Thermionic specific detectors allowed quantification of the organophosphorus and organonitrogen pesticides. Gas chromatography/electron capture techniques were used to quantify the organochlorine compounds. The pesticides which were quantified are listed in Table 1.

### Composite Soil Samples

Subsurface composite soil sampling was conducted to determine the vertical extent of contamination in areas identified as having surface contamination. Four composite samples were collected to a depth of about 15.2-30.5 cm. These samples were analyzed using the same techniques described for the surface samples.

### Subsurface Sediments

During the drilling of the groundwater monitoring wells, subsurface sediment samples were collected at 1.5 m intervals with a split spoon sampler. A total of 33 samples were collected to a depth of 10.7 m. The analysis of these samples, which was performed using

**Table 1.**  
**Pesticides Determined During Site Analysis**

Priority Pollutants Pesticides:	Additional Pesticides:
Aldrin	Atrazine
Dieldrin	Chlorpyrifos
Chlorodane	Disulfoton
4,4'—DDT	Ethoprop
4,4'—DDE	Methoxychlor
4,4'—DDD	Phorate
alpha-Endosulfan	Prometone
beta-Endosulfan	
Endosulfan sulfate	
Endrin	
Endrin aldehyde	
Heptachlor	
alpha-BHC	
beta-BHC	
gamma-BHC (Lindane)	
delta-BHC	
Toxaphene	

the methods described above for surface soil samples, determined the extent to which pesticides had migrated vertically into the subsurface.

### Groundwater

A five-well groundwater monitoring system was installed to monitor the shallow groundwater for pesticide contamination; included were a background well and wells adjacent to areas of buried wastes, the buried tank, and drum-storage areas. The wells were installed in a blue-gray, silty, clay deposit overlying the alluvial aquifer, with the purpose being to monitor the initial water-bearing strata. They were constructed of 7.6 cm diameter PVC threaded-joint pipe and designed to prevent any downward migration of surface contaminants. Each well was screened and gravel packed for 6.1 m. A bentonite seal was placed above the gravel and the remainder of the column was sealed with cement grout. Concrete pads at the surface and locking well covers completed the wells. The groundwater samples were analyzed using electron capture and thermionic specific detection for the pesticides listed in Table 1.

In conjunction with the onsite groundwater monitoring, 17 off-site drinking wells in the vicinity of the site were sampled. Analyses for the acid, base/neutral, pesticide, and volatile fractions of the priority pollutant list were performed. Analyses for the seven additional pesticides were not determined.

### PERSONNEL SAFETY AND DECONTAMINATION

The guidelines used to determine the appropriate levels of protection are outlined in the following manuals developed by E&E for USEPA:

- Personnel Protection & Safety Training Manual<sup>2</sup>
- Hazardous Waste Site Investigation Training Manual<sup>3</sup>

Due to the odors at the site, the amount of pesticide spillage, and the chlorinesterase-inhibiting nature of the organophosphate pesticides, it was important to protect the sampling and drilling crews. All personnel were required to wear air-purifying respirators with combination cartridges for organic vapors and particulates. Disposable coveralls, neoprene boots and neoprene gloves were also worn.

In order to avoid cross-contamination between samples, strict decontamination procedures were followed. Whenever possible, as in the surface soil samples, disposable equipment was used. When this was not possible, as during the composite soil sampling and the subsurface sediment sampling, a five-step soap and water wash and solvent rinse procedure was followed. All drill equipment was steam cleaned between holes.

## FIELD AND LABORATORY RESULTS

## Air

Only those readings taken in close proximity to drums which had contained solvents had significantly higher concentrations of organic vapors than background levels of 1 to 3 ppm. There were odors present at the site, caused by mercaptan compounds used in organophosphate formulations; however, mercaptans are detectable at concentrations less than 1 ppm, which is the lower limit of the organic vapor analyzer in the survey mode.

## Surface Soil

Based on the results of preliminary chemical screening of the 89 surface soil samples, 20 samples (Table 2) were further analyzed to identify specific pesticides and develop background values for comparisons. The results of the analyses are presented in Table 3.

Table 2.  
Locations of Surface Soil Samples

Sample No.	Location
03	Ethoprop spill (east of building #1)
06	East of building #1
09	East of building #2
16	East of Atrazine building (#4)
29	Southeast Drum Storage Area
36	Southeast Drum Storage Area
44	West of building #5
48	Loading dock at building #5
50	Northwest Drum Storage Area
53	Loading dock at building #5
59	North of Atrazine building #4
60	North of Plant (north of plant)
65	Along railroad tracks
79	West Drainage

Table 3.  
Concentrations of Pesticides in  
Surface Soil Samples (mg/kg)

Pesticide	Site Number															
	03	06	09	16	29	36	44	48	50	53	59	60	65	79		
Promethion(e)	TR	40	180	30	2			180	190	400	200	120	140	1100		
Atrazine					6		6									
Phorate			17			100					5					
Disulfoton	70															
Chlorpyrifos		80														
Heptachlor				13.5		3600										
Endosulfan Sulfate										670						
alpha-Endosulfan										940						
Dieldrin			1.1		0.6		550	1.0								
Aldrin			0.5		3.2	0.1	1530	2.1								
gamma-BHC (Lindane)				2.25												

One soil sample collected near a loading dock showed high concentrations (> 500 mg/kg) of aldrin, dieldrin, alpha-endosulfan, endosulfan sulfate and heptachlor. The two major products of the formulating plant, ethoprop and atrazine, were not detected in this sample. Similarly, no ethoprop was detected in the area of the ethoprop spill. However, several other pesticides were identified at the following concentrations: disulfoton (70 mg/kg), prometon (40 mg/kg) and 4,4'-DDT (4.36 mg/kg). In the southeast drum storage area, 100 mg/kg of phorate were detected near drums identified as containing phorate. These results agree with the data obtained during the NEIC investigation.

Two piles of unidentified material dumped within the plant grounds and thought to be pesticide products were found to be

primarily clay, with less than 1 mg/kg of pesticide. However, a reddish material dumped in the west drainage contained 110 mg/kg of prometon. This was the only significant contamination detected in the plant drainages.

## Composite Soil Samples

Pesticides were found in all four composite soil samples taken at a depth of 15.2-30.5 cm below the surface (Table 4.) Heptachlor was found in all four areas tested, while atrazine, ethoprop, and phorate were detected in all locations except the northwest drum storage area. In the southeast drum storage area, the major contaminant found was heptachlor (47 mg/kg). In the area of the ethoprop spill, the following concentrations were detected: ethoprop (23.8 mg/kg), phorate (44.1 mg/kg) and atrazine (1,600 mg/kg). The organochlorine pesticides heptachlor, methoxychlor, and toxaphene were detected in the area north of the atrazine plant and the northwest drum storage area.

Table 4.  
Concentrations of Pesticides in  
Subsurface Composite Samples (mg/kg)

Pesticide	Ethoprop Spill Area	North of Atraz. Pt.	Northwest Drum-Stg	Southeast Drum-Stg
Atrazine	1600	1.60		0.49
Phorate	44.1	0.20		0.025
Ethoprop	23.8	0.524		0.40
Disulfoton	2.44			0.072
Toxaphene		32.0	35.0	
Methoxychlor	1.29	18.7	16.7	
Meptachlor	1.40	25.0	16.0	47.0
Dieldrin	0.055			
Aldrin		0.43		5.0
alpha-BHC			4.0	
beta-BHC	0.12			
gamma-BHC (Lindane)	0.76	1.60	1.55	

## Subsurface Sediments

Subsurface sediment samples were collected at 1.5 m intervals to a depth of 10.7 m in four locations. The results are given in Table 5. Atrazine, heptachlor, and gamma-BHC were detected at depths of 10.7 m near the former atrazine formulating building. In this same area, methoxychlor was detected to depths of 3.5 m.

Table 5.  
Concentrations of Pesticides at Various Depths  
in Monitoring Wells (mg/kg)

	Monitoring Well #2							Monitoring Well #4						
Pesticide	5	10	15	20	25	30	35	5	10	15	20	25	30	
Atrazine	18	8.5	6.4	5.3		15.3	0.35	0.5		0.22	2.7	0.3		
Disulfoton								9.0	5.9	0.52	1.1	0.13		
Toxaphene												0.06		
Methoxychlor	0.31	0.40	0.66							0.03				
Heptachlor	1.32	0.46				0.023								
Endosulfan Sulfate								2.0	0.02	0.035				
Aldrin								0.135						
alpha-BHC								1.6	0.73		0.665			
gamma-BHC (Lindane)	0.15	0.144	0.063	0.150		0.06								

The subsurface data correlate with the composite soil data for this area. Seven pesticides, including disulfoton, heptachlor, atrazine, beta-BHC, aldrin, toxaphene and methoxychlor were detected in the sediments underlying the southeast drum storage



area. Neither ethoprop nor phorate were detected at depth. Except for the concentrations of disulfoton in the southeast drum storage area, there was no correlation between increasing depth and pesticide concentrations.

### Groundwater

Five wells were installed onsite: one well was up-gradient of the plant operations and four wells were down-gradient. Atrazine was detected in all down-gradient wells, with concentrations ranging from 1.1 mg/l in well MW #2, located near the former atrazine formulation building, to 0.005 mg/l in well MW #5, located furthest down-gradient from the plant. No pesticide contamination was detected in any of the offsite residential wells. Therefore, groundwater contamination is not a major concern at this site at this time. However, continued monitoring is recommended.

### Buried Waste

During the metal detector survey, two areas of buried metal were located, both of these being located near the area marked by dead trees. Following this survey, interviews with former plant employees indicated that wastes had been buried in the areas indicated by the metal detector. These wastes consisted of 2% ethoprop baghouse dust, buried from 1976 to 1978.

Allegations have been made that drums of parathion were also buried along with the ethoprop. Above background readings in the air of 300 ppm were recorded during a subsurface survey of this area with a photonionizer. These data suggest that volatile solvents are also present. To date, these drums have not been excavated and tested.

### SUMMARY AND CONCLUSIONS

The organic vapor survey did not indicate a significant level of volatile organic compounds in the ambient air. The results of high volume air sampling did not indicate the presence of pesticide particulates in the ambient air. The odors at the site are probably due to residual mercaptan compounds.

The analytical results from the different soil surveys revealed extensive soil contamination by numerous pesticides in several areas of the plant. The areas which were identified as being most highly contaminated were:

- Northwest drum storage area, particularly west of building #5
- Railroad tracks between buildings and north of buildings
- Loading dock area north of former atrazine plant #4
- Area east of building #2
- Area between buildings #1 and #2
- Area east of ethoprop spill (near building #1)
- Southeast drum storage area

Organophosphate, organochlorine and s-triazine pesticides were detected in the soils of the plant. The compounds of greatest and immediate concern are the organophosphates, due to their high mammalian toxicity. Because of the cholinesterase-inhibiting nature of the organophosphates, a human health hazard will exist at the site in the form of discarded waste products and contaminated soil until removal activities are completed. The organochlorine pesticides, while being less toxic, are more persistent in the environment, and less subject to biodegradation.

The on-site groundwater sample analyses revealed atrazine contamination in the four down-gradient wells, the concentrations ranging from 0.005 to 1.1 mg/liter. Contamination at these levels does not constitute a serious hazard at the present time, though the groundwater should be monitored periodically. Off-site residential wells are not contaminated at the present time.

Any waste buried on-site will need to be excavated, analyzed, and disposed of properly. Two areas have been identified as having

been areas of buried drummed waste. Since these drums are buried below the high water table level, they may constitute a threat to groundwater quality.

### RECOMMENDATIONS

Based on the conclusions of this field investigation, it was recommended that the following areas of contamination be addressed as part of the first phase of cleanup activities:

- Containment of onsite drums
- Removal of concrete basin contents
- Removal of buried tank contents and disposal of tank
- Excavation of areas of buried waste
- Removal of contaminated soil

These activities are described below.

□Containment of drums—An estimated 500 drums are now stored outdoors and may be in advanced stages of deterioration. The cleanup tasks must include the characterization, segregation and containment of these drums. The 1,200 drums stored indoors must be either recycled or disposed of properly.

□Concrete basin—Two large metal tanks had been drained into a concrete basin located in the former atrazine building. The main components of this liquid are liquid atrazine and water. Removal of the contents of this basin should be conducted in the first phase of cleanup.

□Buried tank—In discussions with former employees of the plant and review of Region VII USEPA records it was determined that a buried tank filled with methoxychlor, malathion, lindane, atrazine and toxaphene is located onsite. The exact dimensions are unknown. However, its current capacity is estimated at 300m<sup>3</sup>. The cleanup activities shall include removal of the tank's contents along with removal and disposal of the tank.

□Trenches—With the information obtained during interviews of former plant employees and local residents it was indicated that trenches containing drums of ethoprop wastes and possibly parathion are present on the site. The cleanup will have to include the uncovering, characterization, removal, and disposal of the contents of these trenches.

□Soil contamination—The extent of soil contamination was determined from surface sampling and composite subsurface sampling. The total volume being considered for removal is estimated at 5400 m<sup>3</sup>. Removal of this soil will constitute removal of the majority of the moderately to highly contaminated soil. Reduced levels of contamination will still exist at the site. Back filling of these areas will reduce the pathway for contact with remaining subsurface contamination. The backfill material should be capped with gravel to prevent erosion and allow the site to sustain traffic.

### ACKNOWLEDGEMENTS

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# USE OF NDT METHODS TO DETECT BURIED CONTAINERS IN SATURATED SILTY CLAY SOIL

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## INTRODUCTION

There are estimated to be 30,000 to 50,000 existing dump sites in the United States containing various amounts and types of hazardous materials. Furthermore, many new sites are discovered on a regular basis. One of the first pieces of information needed in the cleanup process is the physical extent of the dump site and the resulting polluted area. This is very difficult to do when hazardous materials (often in metal and plastic containers) are buried beneath the ground surface. Since traditional methods of core borings and excavation of test pits are dangerous, discontinuous, and expensive, the use of non-destructive testing (NDT) methods is often suggested. Many of these methods, including those of the authors,<sup>1,2</sup> have been described in the literature.

In an earlier study,<sup>3</sup> we evaluated use of the various NDT methods to locate buried metal and plastic containers in a uniform dry sandy soil. In that study, the metal and plastic containers were buried at known locations and depths in various patterns and seven NDT methods used for detection. The results indicated that the metal detector, very low frequency electromagnetic, magnetometer and ground probing radar techniques are of definite value in delineating the drums. Continuous wave microwave techniques were less successful, and seismic refraction and electrical resistivity were unsuccessful under those particular conditions.

Since the soil and the site of that study<sup>3</sup> represented nearly ideal conditions, it was decided to repeat the entire project by burying the metal and plastic containers in a saturated fine grained soil which was eventually located in a construction contractor's storage yard.

Following this section is a description of the NDT techniques used, details of the site and specific results obtained.

## DESCRIPTION OF EXPERIMENTAL METHODS

Since the continuous wave microwave technique was only marginally successful and seismic refraction and electrical resistivity techniques were unsuccessful on the previously described nearly ideal site,<sup>3</sup> they were not attempted for this more difficult situation. Commercially available metal detector (MD), very low frequency electromagnetic (VLF-EM), magnetometer (MA) and ground probing radar (GPR) were used.<sup>4-10</sup>

The metal detector (sometimes called a pipe locator or eddy current method) and very low frequency electromagnetic methods operate on essentially the same principle. They will be discussed together. Both of the instruments used had two coils; many of the less expensive metal detectors are single coil/inductance change instruments. A transmit coil generated an electromagnetic field and a

receiving coil in the vicinity picks up the resulting field. Some of the field arrives via the air and some via the subsurface material. The field through the air is essentially constant for a given transmitter-to-received distance, but the field arriving from the subsurface materials depends on the subsurface electrical conductivity and magnetic permeability. If a conducting body is present in the subsurface material between the two coils, the total detected field is altered and the anomaly noted.

A magnetometer measures changes in the earth's magnetic field. Any magnetic object, e.g., an iron ore deposit or a buried steel object, will alter the earth's magnetic field locally and thus can potentially be detected. The most commonly used magnetometer employs proton nuclear magnetic resonance. The nuclear spin of the proton processes at a frequency which is linearly proportional to the total magnetic field at the nucleus. If the total magnetic field changes because of an anomaly, the precession frequency change can be read accurately, and hence the magnetic field change can be determined precisely.

In the ground probing radar technique, a few cycles of electromagnetic radiation (100 MHz to 900 MHz) are sent into the ground from a highly damped antenna. A reflection occurs when a medium of different dielectric constant is encountered. The time it takes for the pulse to travel down and back given an indication of the depth of the object. Lateral surveying gives an indication of the spatial extent of the objects.

## SITE DETAILS

The containers were buried in a heavy construction contractor's storage yard in North Wales, Pa. The 150 ft by 120 ft area was bounded by trees and a drainage ditch to the north, a chain link fence to the east and south and miscellaneous forms, tanks and trailers to the west.

Disturbed and undisturbed samples indicated that the soil was a dense sandy silty clay of 128 lb/ft<sup>3</sup> unit weight and 19% water content. This is equivalent to a 98% relative density (via standard Proctor compaction test) and 100% saturation. Other physical properties of the soil showed that the specific gravity was 2.54, the liquid limit was 32%, the plastic limit was 23% and the shrinkage limit was 11%. Regarding gradation characteristics, 21% was in the silt size range and 4% was the clay size range. Thus, the soil is classified as ML-CL by the Unified Soil Classification system. Being near the high point of the local topography, the soil was only about 4 ft to 6 ft thick above bedrock which was observed to be decomposed red shale, fractured at 4 ft but rapidly became sound at a depth of about 6 ft.

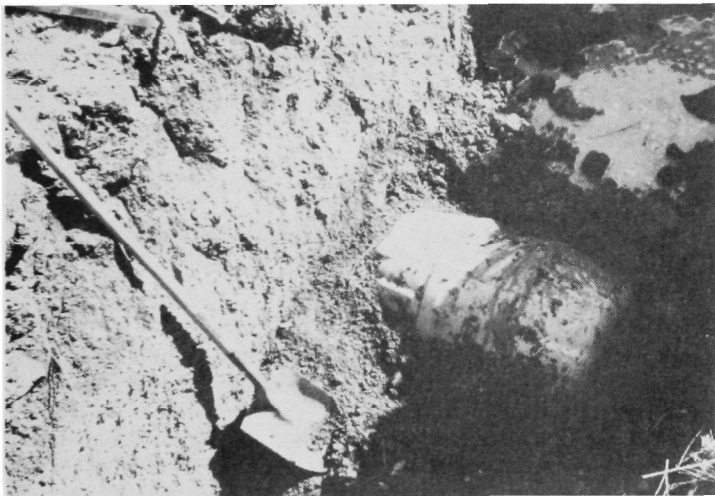
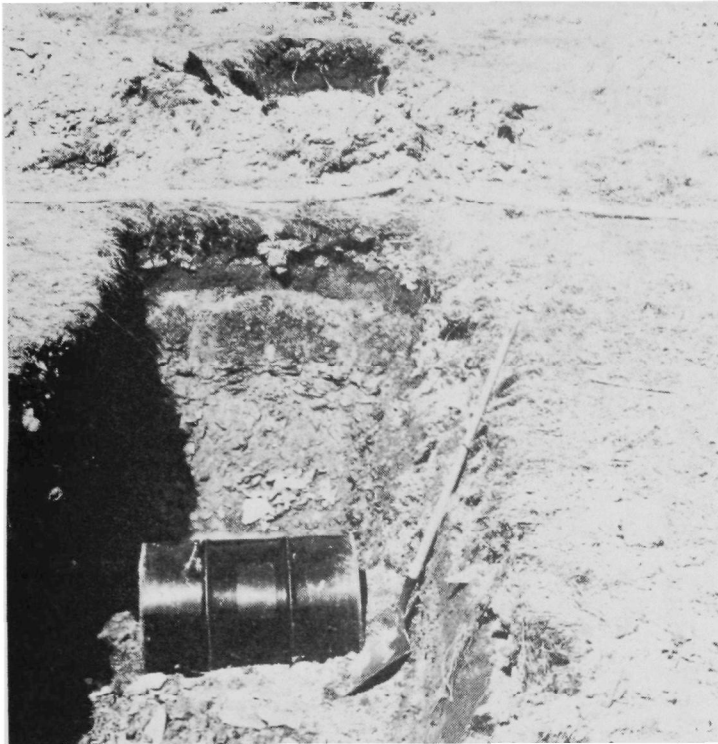


Figure 1.

Photographs of Containers After Placement and During Backfilling. Upper is a 30 Gallon Steel Drum; Lower is a 40 Gallon Plastic Drum.

Eighteen (18) steel and plastic containers were placed in backhoe excavated holes that varied from 2 ft to 6 ft deep (see Fig. 1). The soil cover over the containers varied from 1 ft to 4 ft. The container burial patterns were as follows:

- Four 30 gal steel containers buried with 1 ft, 2 ft, 3 ft and 4 ft of cover.
- Three steel containers (5 gal, 30 gal and 55 gal) buried at 3 ft of cover. (The 30 gal drum was included in the previous pattern.)
- Four 40 gal plastic containers buried with 1 ft, 2 ft, 3 ft and 4 ft of cover.
- Four 30 gal steel containers buried with 3 ft of cover. Three of the containers were adjacent to one another and the fourth was separated by 16 ft.
- Four 30 gal steel containers with 1 ft of cover were each oriented at 90°, 60°, 30° and 0° with the horizontal.

In general, all containers were cylindrical, placed with their long axis horizontal (except where noted), placed empty, placed approx-

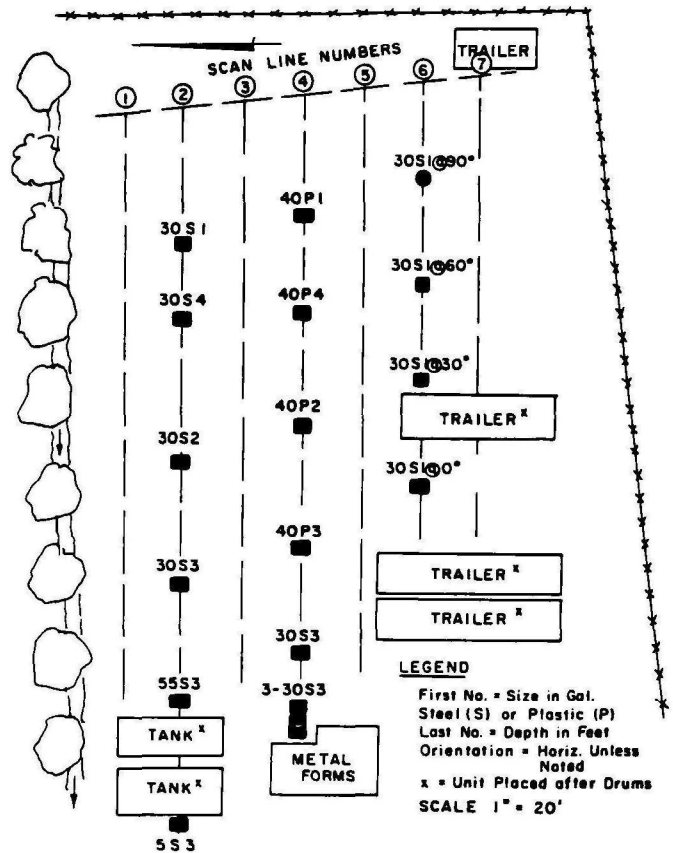


Figure 2.

Plan View of Site Boundaries and General Conditions, Buried Container Deployment and Survey Scan Lines for Various NDT Techniques.

imately 25 ft from each other (except where noted) and backfilled with the same soil that was excavated at the particular location involved. After hand backfilling and tamping soil around the drums, the site was further backfilled and compacted by a heavy dozer, graded off to a level condition and allowed to stabilize for approximately four months. During this time period the contractor brought additional equipment onto the site which made the area more representative of conditions at an actual site. Fig. 2 is a plan of the site, the containers and other relevant items.

## RESULTS

Each of the aforementioned NDT techniques were used at the site by making a series of seven parallel scans about 10 ft apart (see Fig. 2), with data being taken at 2 ft intervals along each scan. Fig. 3 contains photographs of two of the techniques during monitoring. Results were transferred from profiles along each scan (results not shown due to paper size limitations), to generalized plan views. These generalized results are presented in this paper.

The metal detector (commercially available from Fisher Company, Model M-Scope)\* gave results shown in Fig. 4. The cross hatched areas along scan lines show where the device gave a positive indicate that each metal container was accurately located, but that none of the four plastic containers was located. Positive location of a buried object by the device is given by pinning of the dial indicator and by an audible signal. Positive signals were observed on scan lines where no containers were purposely buried. This is understandable since the site had numerous metal objects (old cans, reinforcing bars, fencing, springs, etc.) very near to the

\*Mention of trademarks or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency or Drexel University.

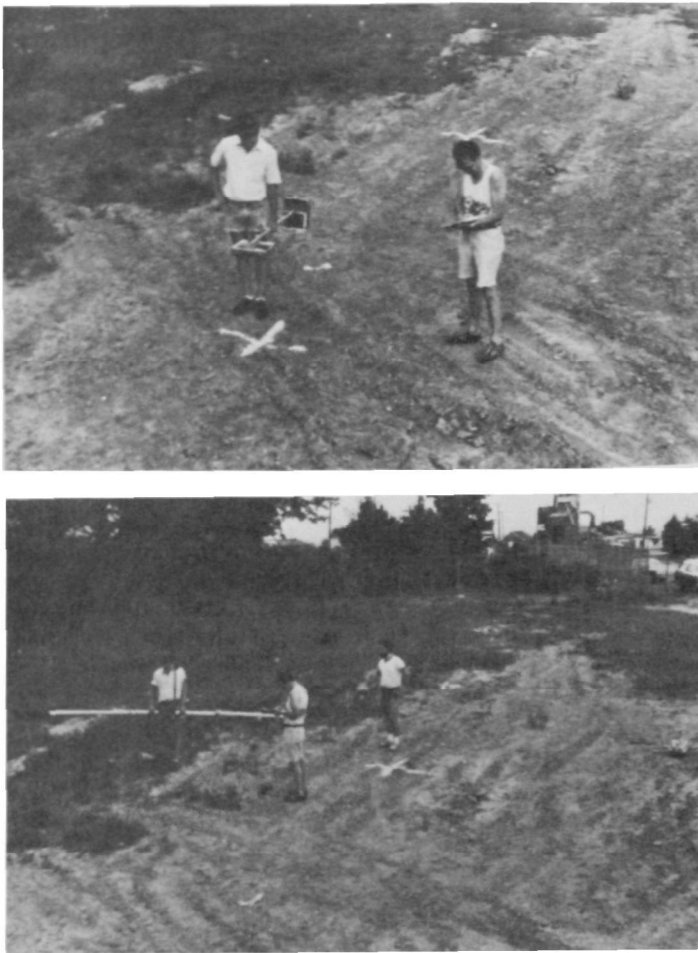


Figure 3.

Photographs of Site Showing Metal Detector (upper) and Very Low Frequency Electromagnetic (lower) Techniques for Detecting Buried Containers. Crosses Mark Locations Where Containers are Buried.

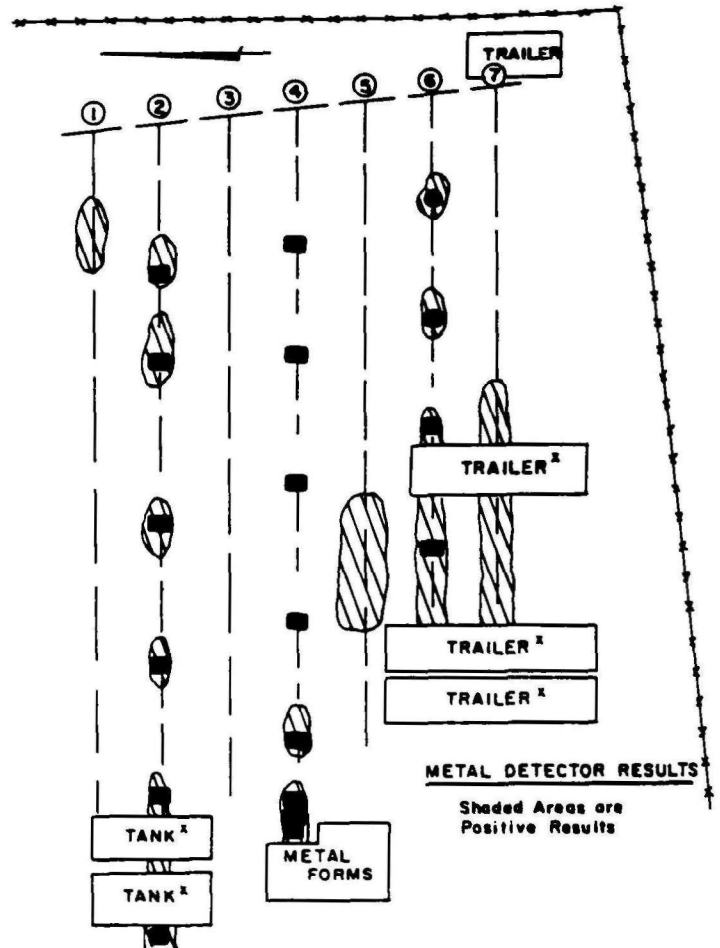


Figure 4.

Plan View of Site Showing Results of Metal Detector (MD) Survey. See Fig. 2 for Actual Container Identification.

ground surface before the containers were buried. In the vicinity of the trailers and metal forms, the metal detector remained pinned continuously.

The results of the very low frequency electromagnetic device (commercially available from Geonics Ltd., Model No. EM-31) are given in Fig. 5. Similar to the previous results, the system accurately located all metal containers, but no plastic ones (Fig. 5). The possible exception was the plastic container buried 1 ft deep along scan line #4. Anomalous spots were also seen along scan lines where no containers were buried but, as described before, quite possibly for the same reason. At a few of these locations the MD and VLF-EM readings were in agreement, e.g., along scan line #5 at 90 ft west of the base line.

The magnetometer results (commercially available from EG and G Geo-Metrics, Model No. F-856) are shown in Fig. 6. The individual scan lines showing magnetic field data were interpreted and plotted for this figure. Correlation with actual containers locations was very poor for the steel drums (which was unexpected) and for the plastic drums (which was expected). The westerly portion of each scan line became swamped due to the heavy magnetic metal (i.e., steel) concentration of the tanks, forms and trailers on the ground surface.

Results from the ground probing radar (commercially available from Geophysical Survey Systems, Inc., Model No. SIR-7) scans are not shown in the same format as the preceding techniques because results were very negative. A typical GPR trace along scan line #2 is shown in Fig. 7. The trace was made over the four 30 gal steel drums buried at 1 ft, 4 ft, 2 ft and 3 ft, respectively, and then

over the 55 gal drum at a 3 ft depth. No discernible return signal was noted at the proper locations. This was typical of all GPR scans over the site.

Four separate scan trips were made to the site, one before drum placement and three afterwards. Perhaps a GPR system with signal enhancement capabilities would have shown the expected parabolic shapes indicating a curved object, but it was not obvious in this situation.

## CONCLUSIONS AND RECOMMENDATION

In contrast to the earlier study of container detection in a dry sandy soil, most NDT techniques worked quite well; at this site conditions were much more formidable. The major differences between the sites were the:

- High clay content of the soil
- Complete saturation of the soil voice
- Closeness of the bedrock to the ground surface
- The fact that the bedrock surface was not abrupt but weathered from highly decomposed to very hard within a 2 ft thickness
- Relatively confined area where background noise is present.

In spite of the above difficulties, this is typical of a real site having buried containers.

For this situation, the metal detector and very low frequency electromagnetic methods worked equally well in locating metal containers. On the basis of equipment cost, the authors would favor the metal detector (\$600 versus \$8,000). The VLF-EM has a deeper penetration depth and lateral scan sensitivity as determined



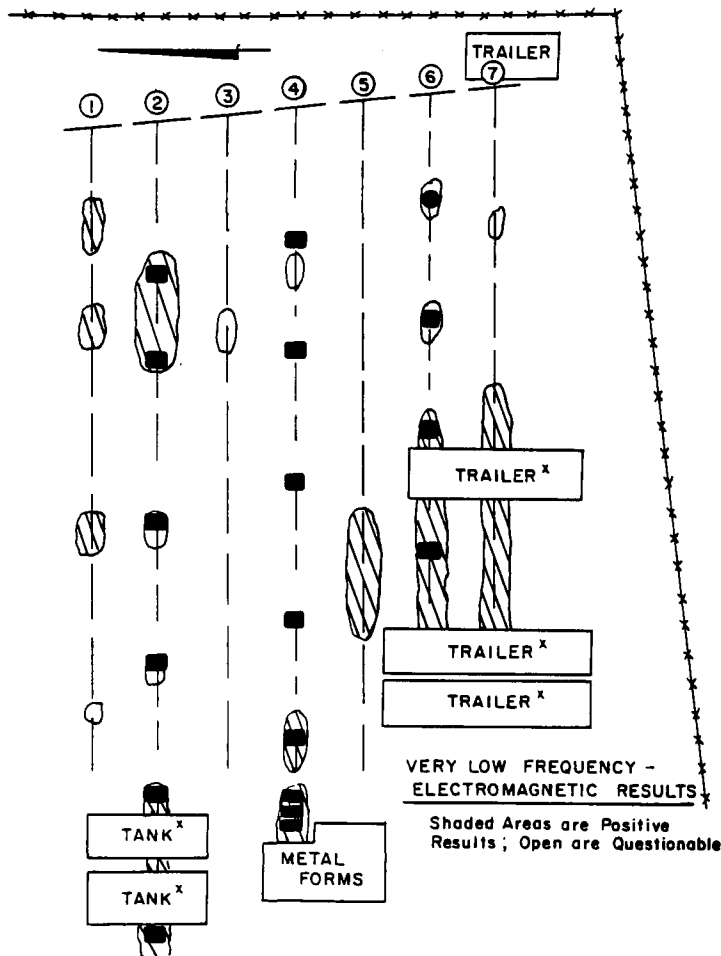


Figure 5.

Plan View of Site Showing Results of Very Low Frequency Electromagnetic (VLF-EM) Survey. See Fig. 2 for Actual Container Identification.

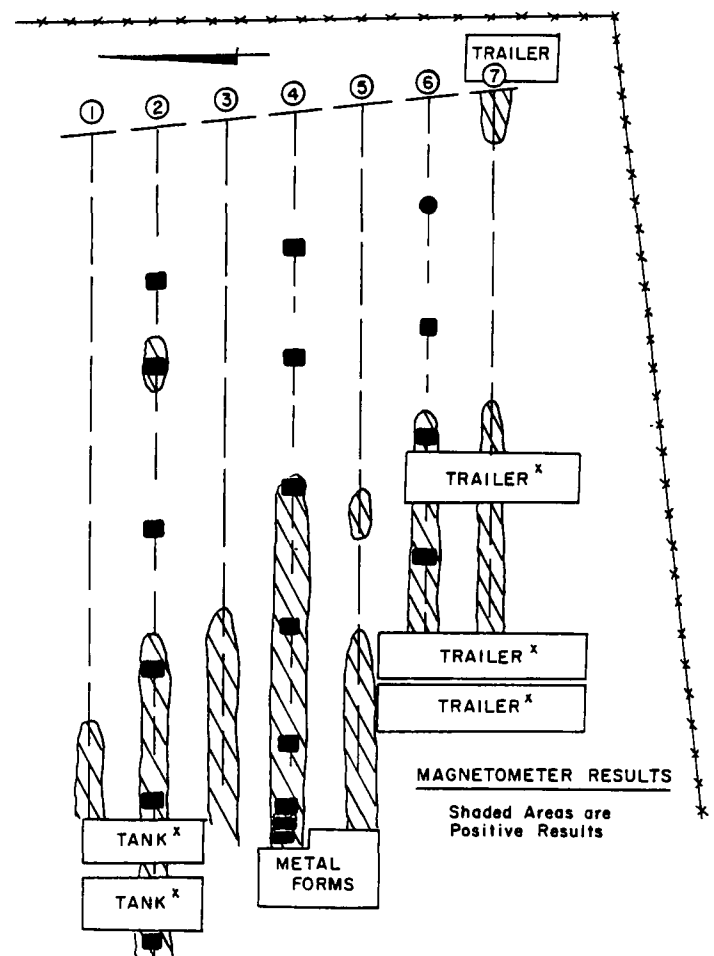


Figure 6.

Plan View of Site Showing Results of Magnetometer (MA) Survey. See Fig. 2 for Actual Container Identification.

from the earlier study.<sup>3</sup> However, neither the MD nor the VLF-EM will give the depth to the reflecting object.

The magnetometer was unsuccessful because of the abundance of buried metal objects. This conclusion was expected and confirmed by this work.

Somewhat surprising was the failure of the ground probing radar to detect even the shallow buried containers. Neither steel nor plastic could be located—a marked departure from the earlier study.<sup>3</sup> Probably the saturated clay soil attenuated the signal before any significant penetration occurred or the background conditions submerged the signal in noise. GPR is the preferred technique known to the authors to give a specific depth to a reflecting object, but in this case was simply not successful.

Other NDT techniques that were marginally successful or unsuccessful at the sandy soil site<sup>3</sup> were not deployed at this saturated clay soil site for the reasons stated earlier.

On the basis of these two studies (reference 3 in dry sandy soil and this one in saturated clay soils), the authors recommend that a high quality metal detector be the first NDT method to be used at a suspect site. Only metal objects, at relatively shallow burials, can be detected, but this is very often the actual situation. The device is inexpensive (about \$600), can be obtained from a number of equipment manufacturers, is easy to use, gives both meter and audible inductions of a buried object and is instantaneous. It obviously has drawbacks. Such limitations as only being able to locate metal objects and poor penetration depth are the most pronounced, however, its use as the first method to be deployed is highly recommended.

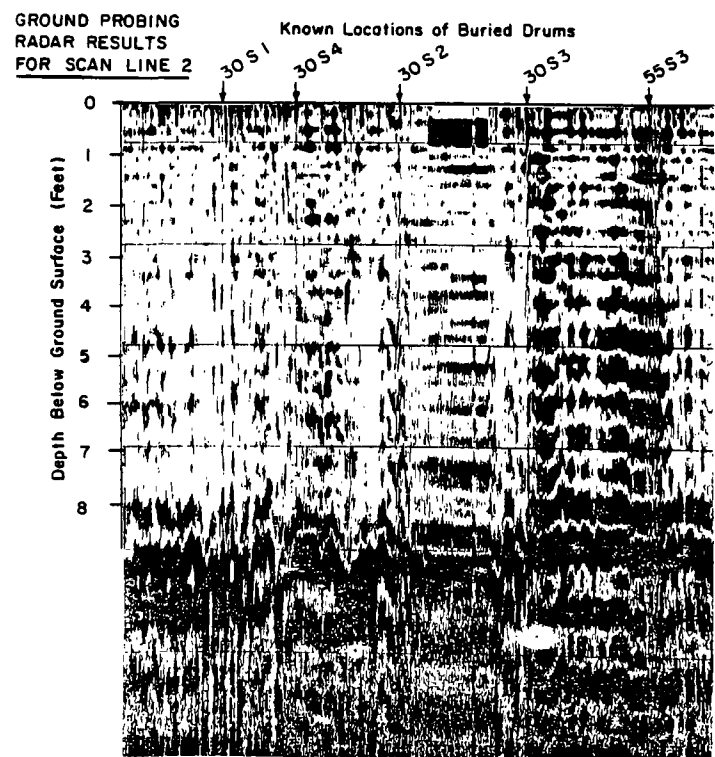


Figure 7.

Ground Probing Radar (GPR) Trace Over Scan Line #2 Showing Arrows Where Five Containers Are Actually Located.

## ACKNOWLEDGEMENTS

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# SYSTEMATIC HAZARDOUS WASTE SITE ASSESSMENTS

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## INTRODUCTION

The National Contingency Plan gives the objectives of preliminary site assessment as: (1) evaluating the magnitude of the hazard, (2) identifying the source and nature of the release, and (3) evaluating the factors necessary to make the determination of whether immediate removal is necessary.<sup>1</sup> For this paper, these objectives can be restated in terms of the following goals for subsurface characterization: (1) determining the hydrogeologic characteristics of the site, (2) locating and mapping leachate plumes, and (3) locating and mapping buried wastes.

### Systematic Assessments

In the past, investigations of hazardous waste sites were usually dependent on drilling to obtain information about the geological setting, on monitoring wells for samples of groundwater, and on laboratory analyses of groundwater, soil, and waste samples. This costly approach may fail to adequately characterize the site setting, location of buried wastes, and the extent of groundwater contamination.

There are several reasons why a network of monitoring wells may poorly define a contaminant plume or produce an incomplete picture of site hydrogeology, but probably the chief cause is that the subsurface is rarely homogeneous. Substantial variations in permeability or hydraulic conductivity can be produced by a change of only a few percent in the silt or clay content of a sandy aquifer. Fig. 1<sup>2</sup> illustrates the effect of small-scale heterogeneities on the migration of a contaminant in a sandy medium. Such heterogeneities complicate the siting of monitoring wells. Other sources of error include well construction, sampling techniques, and even improper logging of soil and rock samples. Ironically, the groundwater samples collected from well networks can be analyzed for trace contaminants in the part-per-million or part-per-billion range with great accuracy. In many groundwater contamination investigations, the accuracy of such analyses may be much better than the interpretation of the subsurface afforded by the well networks.

During the past decade, extensive development in geophysical survey equipment, field methods, analytical techniques, and associated computerized data processing has greatly improved the characterization of hazardous waste sites. Some geophysical techniques can detect contaminant plumes and flow direction. Some are applicable to measurements of contaminants and direction of flow within the vadose zone; others offer detailed information about subsurface geology. The capability to characterize the subsurface directly without disturbing the site offers benefits in terms of less cost and less risk. It can also achieve a more complete understanding of the subsurface by filling gaps in data in the areas between exploratory sampling wells.

Cost-effective preliminary assessments of hazardous waste sites involves an integrated, three-phased approach:

- Review of available data, including the use of aerial photography, on-site inspections, and review of readily available literature and

local information to characterize the site geology, hydrogeology, and possible waste composition

- Geophysical surveys combined with exploratory drilling and sampling
- Design and implementation of a monitoring program including monitoring wells

This systematic approach defines the areas of contamination and thus supports necessary planned removal of wastes or other remedial action.

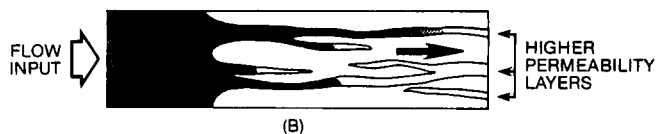


Figure 1.

The Effect of Small Scale Heterogeneities on the Pattern of Contaminant Migration

**Table 1.**  
Some Typical Sources of Data Useful in a Systematic Assessment of Waste Disposal Sites (from Le Grand, 1980)

Type of Data	Typical Sources
Property Survey	County Records, Property Owner
Well Drillers Logs	Well Driller, Property Owner, State Records
Water Level Measurements	Well Owners Observations, Well Drillers Logs, Topographic Maps, Ground Water Maps (Reports)
Topographic Maps	U.S. Geological Survey and Designed State Sales Offices
Air Photos	U.S. Dept. of Agriculture, U.S. Forest Service, etc.
County Road Maps	State Agencies
Ground Water Reports	U.S. Geological Survey, State Agencies
Soil Surveys of Counties	U.S. Dept. of Agriculture
Geologic Maps	U.S. Geological and State Surveys
Climatological Data	U.S. National Oceanographic and Atmospheric Agency

## REVIEW OF AVAILABLE DATA

Much data are commonly available for sites in a variety of documents, reports, maps, etc. Some of the data sources are found in Table 1.<sup>3</sup> This information should be used first to gain an overview of the site's relationship to the regional setting. This can be accomplished by a review of topographic maps, geologic maps, aerial photographs and federal and state geohydrologic publications. Nel-

son, *et al.*<sup>4</sup> described in detail a methodology for inventorying and prioritizing possible uncontrolled waste disposal sites based on available data. This methodology includes a systematic approach to compiling, reviewing, and interpreting available data.

Aerial photography is a valuable tool for preliminary hazardous waste site assessments; both current aerial photos and historical imagery are useful. Historical (archival) photographs may date back 40 years or more and can play a vital role in assessing specific sites. They can often trace the life of a waste disposal site from its creation to the present. Locations of old landfills or disposal ponds now covered by subsequent land use or vegetation growth can be determined from historical photographs. The history of one disposal site is traced in Fig. 2 from 1945 through 1979 and shows the construction of residential neighborhoods over and around the former site.<sup>5</sup>

Archival imagery can be obtained from the National Archives, the data center of the U.S. Geological Survey, and other sources such as city, county, or state agencies. Usually imagery taken at three or more dates from the late 1930s to the present is examined. If necessary, current photography is obtained from overflights as part of the preliminary assessment. The history of the land use around a site and drainage patterns should be carefully studied. The potential exposures to nearby residences and direct and indirect environmental pathways to them must be evaluated. Frequently, detailed imagery analysis is coupled with ground investigations to provide a more complete picture of potential environmental problems. The end product<sup>7</sup> of a detailed analysis is shown in Fig. 3.

#### Waste Characterization

Waste characterization prior to beginning field work is highly desirable. Valuable information about waste composition, assuming legal considerations are not involved, can be obtained from the property owner and/or those responsible for transporting or disposing of the waste. Where a manufacturing or processing facility was involved in the generation of the wastes of interest, the spe-

cifics of waste characteristics may sometimes be obtained from a variety of corporate records, disposal logs, and conversations with technical personnel. Wastes related to military bases can be characterized as to their shape, size, construction and chemistry. The military usually maintains this type of documentation.

#### SELECTING THE APPROPRIATE GEOPHYSICAL TECHNIQUE

Contemporary geophysical techniques and their advantages and limitations have been extensively described in many recent publications. A few of these key references are cited in the bibliography. A brief description of the theory of operation and the application of the primary geophysical techniques which have regularly and successfully been applied for waste site assessments follows:

Ground Penetrating Radar (GPR) is designed to detect the presence and depth of subsurface features using radar waves transmitted from a small antenna moved across the ground's surface. This analysis results in a continuous cross-sectional "picture" or profile of shallow, subsurface conditions. The responses are caused by radar wave reflections from interfaces of materials having different electrical properties. The reflections are often associated with natural hydrogeologic conditions such as bedding, cementation, moisture and clay content, voids, fractures, and intrusions as well as man-made objects. GPR has been used at numerous hazardous waste sites to evaluate natural soil and rock conditions and to detect buried wastes.

The Electromagnetics (EM) method measures the electrical conductivity of subsurface soil, rock and groundwater. Electrical conductivity is a function of the type of soil and rock, its porosity, and the conductivity of the fluids which fill the pore space. In most cases, the conductivity (or specific conductance) of the pore fluids will dominate the measurement. The EM method is applicable to both the assessment of natural geohydrologic conditions and mapping of many types of contaminant plumes. Trench boundaries, buried wastes and drums, as well as metallic utility lines can also be located with EM techniques.

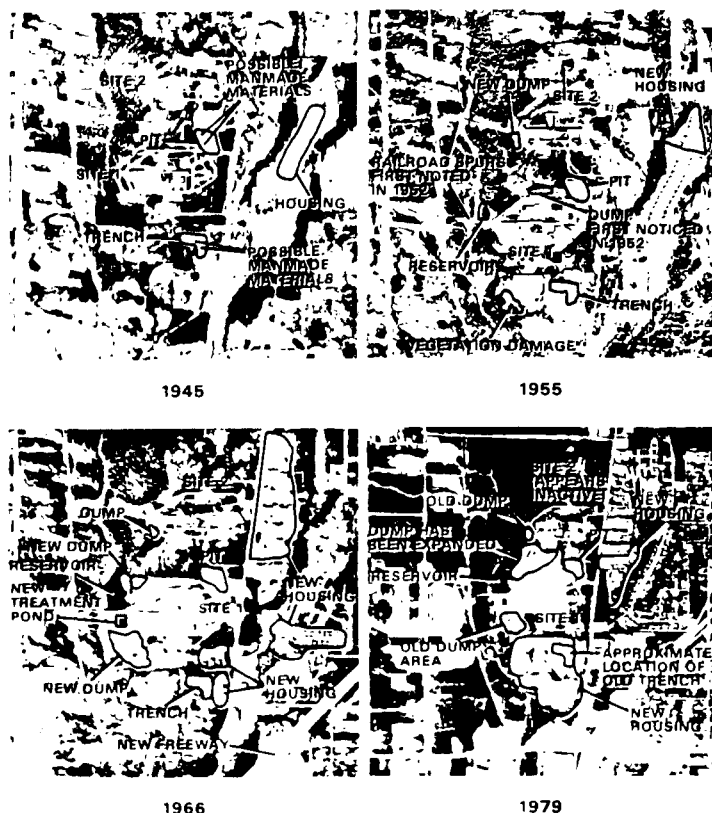


Figure 2.

Overhead Imagery Used to Trace the History of One Site

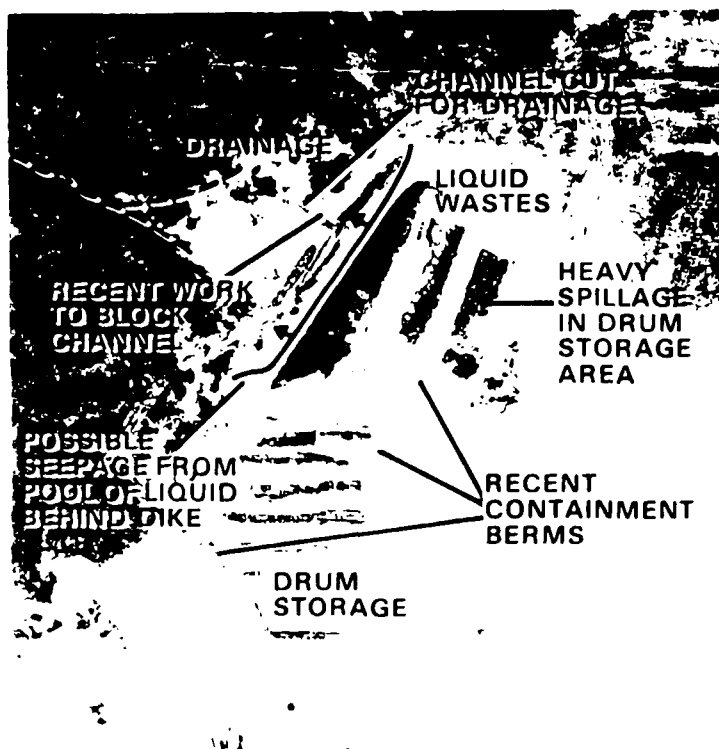


Figure 3.

Typical End Product of an Aerial Site Investigation

The Resistivity method measures the electrical resistivity of the geohydrologic section which includes soil, rock and groundwater. Interpretation of these measurements provides depth and thickness of geologic strata as well as lateral changes in the subsurface. Usually the presence, quantity and quality of groundwater are the dominating factors influencing the resistivity value. The method may be used to assess lateral and vertical changes in natural geohydrologic settings as well as evaluate contaminant plumes at hazardous waste sites. The method may also be used to locate buried wastes.

Seismic Refraction techniques are used to measure the depth and thickness of geologic strata using acoustic waves transmitted into the ground. Seismic methods also provide measurements of rock density and are often used to map depth to specific horizons such as bedrock, clay layers and water table. Secondary applications of the seismic method include location and definition of burial pits and trenches at hazardous waste sites.

Metal Detectors (MD), commonly used by treasure hunters searching for coins and by utility crews for locating buried pipes and cables, are used to locate buried metallic objects. They can detect metallic materials, including ferrous objects (iron and steel) and non-ferrous metals such as aluminum and copper. In hazardous waste site investigations, metal detectors are useful in detecting buried drums and in delineating trench boundaries containing metallic containers at shallow depths.

A Magnetometer responds to distortion in the earth's natural magnetic field. These distortions can be caused by the presence of buried ferrous metals (iron or steel); a magnetometer will not respond to non-ferrous metals. It will respond to variations of iron-oxide concentrations in soil and rock as well as nearby cultural features made of iron or steel. Magnetometers are regularly used in locating buried drums, estimating their numbers, and in determining the boundaries of trenches containing drums.

When selecting the appropriate geophysical technique to meet a mission objective, it should be recognized that more than one technique can usually be applied. The complementary nature of data obtained from combining geophysical techniques can reduce the errors in interpretation that have been common in the past.

The typical objectives of preliminary waste site assessments and the geophysical techniques which can be applied are summarized in Table 2. The reader is referred to "The Use of Selected Geophysical Remote Sensing Methods in Hazardous Waste Site Investigations"<sup>6</sup> for a more thorough treatment of the use of geophysics.

### Interpretation

While geophysical surveys can sometimes stand alone, field investigations will usually require additional quantitative data. In-

formation from drilling logs and groundwater samples, obtained from existing data and/or supplemental newly-acquired data can provide the additional information needed for interpretation. The following examples highlight the use of ground truthing information.

The radar "picture" shown in Fig. 4 resulting from a field survey does not indicate the soil type—only that differences in soils have been seen. A drilling log will provide the means to correlate the radar data with actual soil type (Fig. 4).

Similarly, an EM record and the drilling logs which allowed correlation of the EM data and permitted definition of the soils in the area (Fig. 5).

The correlation of the direct sampling with the geophysical data will allow the investigation to proceed with the design and subsequent installation of two monitoring well networks.

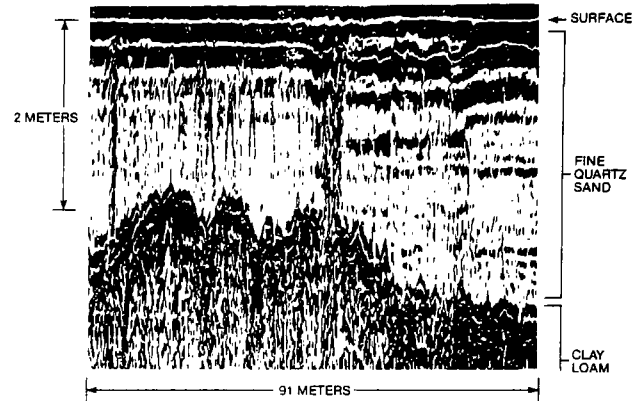


Figure 4.  
Radar Profile of Soil Section<sup>11</sup>

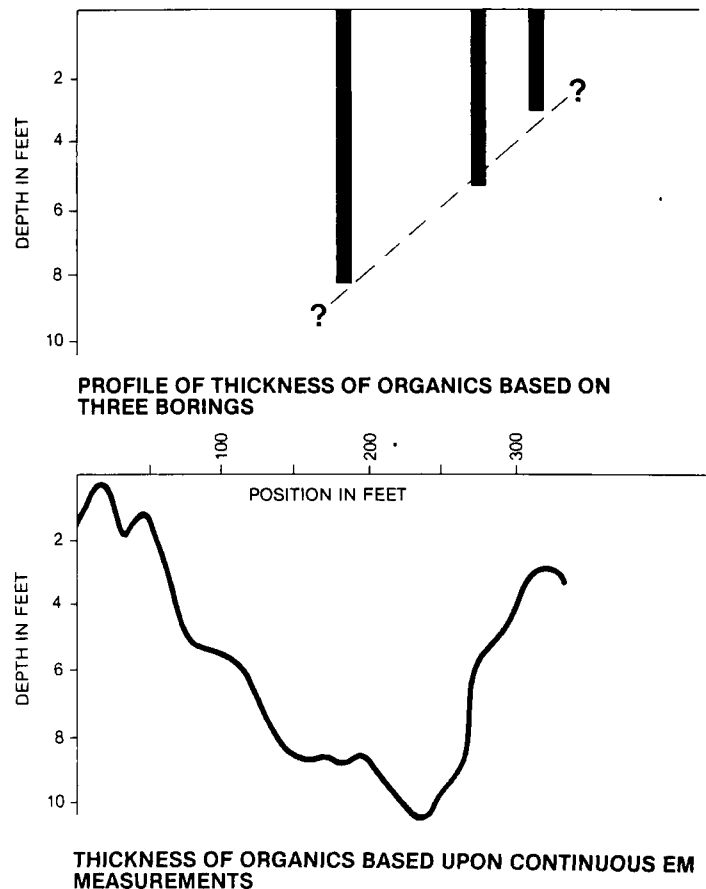


Figure 5.  
Comparison of Continuous Electromagnetic Data with Three Test Borings

Table 2.  
Potential Applications of Geophysical Methods

Application	Radar	Electro-Magnetics	Resistivity	Seismic	Metal Detector	Magneto-Meter
Mapping of geology and hydrogeologic features	1	1	1	1		
Mapping of conductive leachates and contaminant plumes (e.g., landfills, acids, bases)	2	1	1			
Location and boundary definition of buried waste trenches—without metal target	1	1	2	2		
Location and boundary definition of buried trenches—with metal targets	1	1	2	2	2	2
Location and definition of buried metallic objects (e.g., drums, ordinance)	2	2			1	1

1—Primary method—indicates the most effective method  
2—Secondary method—indicates an alternate approach



## GROUNDWATER MONITORING

The objective of groundwater monitoring in hazardous waste site assessment is to provide long term information about the areal extent of groundwater contamination and the concentrations of contaminants, for the purposes of insuring the safety of water supplies or measuring the effectiveness of corrective action. The design of a monitoring well network should consider many variables, including direction and rate of groundwater flow, soil permeability, and background water quality, all of which may interact in a complex fashion.

Discussions of monitoring well placement are available in the literature.<sup>7</sup> One set of guidelines states:

"In order to detect and evaluate potential or existing groundwater contamination at a landfill, a minimally acceptable monitoring well network should be implemented and consist of the following:

- One line of three wells downgradient from the landfill and situated at an angle perpendicular to groundwater flow, penetrating the entire saturated thickness of the aquifer
- One well immediately adjacent to the downgradient edge of the filled area, screened so that it intercepts the water table
- A well completed in an area upgradient from the landfill so that it will not be affected by potential leachate migration

The size of the landfill, hydrogeologic environment, and budgetary restrictions are factors which will dictate the actual number of wells used. However, every effort should be made to have a minimum of five wells at each landfill and no less than one downgradient well for every 250 ft of landfill frontage."

Additional consideration must be given to the effects of the aquifer characteristics. The reference publication does on to say:

"When considering the design of the monitoring system, aquifers can be subdivided on the basis of permeability and porosity. Although the design previously described could generally be applied to all aquifers, aquifer parameters should dictate the following:

- monitoring well density, depth, construction, and drilling methods
- probability of successful detection of the contaminant plume
- sampling methods

For the monitoring network to be effective, the basic network design at a particular site will require modification according to geologic conditions."

Ideally, the extent and location of the plume would be known prior to construction of the well network. In practice, monitoring well locations are generally chosen on the basis of limited knowledge of the site geology and hydrogeology and the professional judgment of the investigator. The accuracy and effectiveness of this approach is limited by the implicit assumption that subsurface conditions are uniform in the horizontal direction, which is usually not true. This assumption can lead to poorly located wells, with inaccurate interpretations of the subsurface conditions.

Geophysical surveys offer a means of obtaining beforehand estimates of the natural hydrogeologic conditions and/or the extent of contaminant plumes. The vertical configuration of the plume to be monitored and the subsurface geology defined in the previous phases of the program should dictate well construction specifications. For example, clay lenses would not provide the optimum location for well sampling screens. If present, permeable sand layers would be more suitable.

Limiting the vertical extent of well screening (zone of completion) to the zone of contamination would yield more accurate estimates of actual contaminant concentrations in groundwater. As geophysical techniques are capable of developing a comprehensive picture of the hydrogeologic site conditions both laterally and vertically, a well can be screened to the proper depth for sampling.

The location and completion depths of existing monitoring wells can also be put into perspective.

This is a brief description of the systematic approach to hazardous waste site assessments. Implementation of this approach must typically be modified to suit the actual conditions of each site. Economics, legal implications, local reaction, schedule, site access, and lack of existing information are some of the considerations which can and do constrain and modify a systematic approach.

The following case studies illustrate a systematic approach applied to a number of site assessments and further show the typical areas of compromise in actual projects. Each example is based on a project completed by the co-authors' firm in the past two years.

### EXAMPLE 1—BULK CONTAMINANTS

A large playground was suspected of containing buried hazardous waste materials. The type of contaminant materials, their exact location and quantity were all unknown. Six soil sampling and monitoring well locations were in place. The size of the total area of investigation was 25 acres, resulting in a sample density of approximately four acres per hole. There were indications of contaminants in the soil, groundwater, and a nearby stream. Aerial photos provided the overall setting picture and showed old buried stream channels in the immediate area of the site. No indication of dumping was noted. The objectives of the subsequent survey were to locate the precise boundaries of the contaminants, estimate their volume and nature, provide a design for a monitoring well program and, if possible, estimate local groundwater flow direction and speed.

When the size of the target and location are unknown, discrete sampling via drilling is a very uneconomical approach to the target location problem. Therefore, non-destructive geophysical methods were selected (see reference 8 for a more complete treatment of drilling and geophysics costs).

Shallow EM measurements were used to locate the bulk contaminants and define their exact perimeter. Further EM soundings at the site provided the approximate thickness of contaminants and their maximum depths. Ground penetrating radar was used to evaluate the soil cover over the contaminants and further confirm the contaminant perimeter. A magnetic survey indicated that only a few steel objects were present in this rather large site. This information suggested that the waste material was bulk-dumped rather than containerized within steel drums.

The survey indicated that the ratio of the total site area to the area of the contaminants was approximately 10:1. This ratio requires that more than ten drilling locations or sample points are needed to yield a detection probability of greater than 95%. Not surprisingly, the six existing exploratory holes had all missed the contaminated area (Fig. 6). Additional holes would be required to define both the boundary and the vertical extent of the contaminants. Fifteen to twenty sample points would only approximate the geophysical data net shown in Fig. 6.

3-D REPRESENTATION  
OF CONDUCTIVITY DATA SHOWING  
BURIED HAZARDOUS MATERIALS

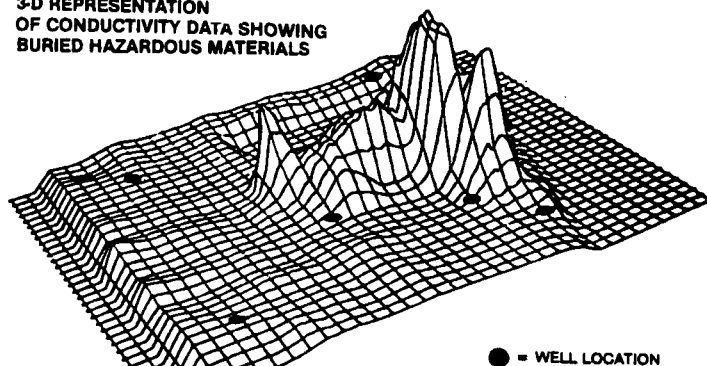


Figure 6.  
Monitoring Wells Located Prior to Electromagnetic Survey Miss  
Buried Waste Site

This survey provided the location, boundaries, depths and estimated volumes of the bulk contaminants. The contaminants were identified as highly electrically conductive and subsequently identified by drilling and sampling as a fly-ash material with a heavy metal content.

Conductive plumes were detected in the immediate site area, indicating minimum migration of conductive contaminants from the site. Further, locations for the installation of monitoring wells were suggested by the presence of a stream on one side and a buried stream channel on the opposite side of the site. The most probable migration paths were either into the adjoining stream channels or downward into underlying strata.

This information improved the reliability of the evaluation of the site location, contents, and potential for contamination. It also provided guidance for location of subsequent monitoring wells and cost estimating and planning of remedial action.<sup>9</sup>

### EXAMPLE 2—LANDFILL PLUME

A landfill approximately one square mile in area had been in use for 29 years. An extensive network of near-field monitoring wells was installed in and around a landfill to evaluate groundwater contamination. The total depth of the aquifer in this location is about 90 ft. The plume was sampled to a maximum depth of approximately 50 ft. The monitoring wells had characterized the plume from the landfill along the vertical plane defined by the line of monitoring wells, and detailed water chemistry was available from groundwater samples. The initial 1974 data from the monitoring wells are shown in Fig. 7.

The spatial extent of the plume, however, was unknown. There was no information to the north or south or farther downgradient beyond the monitoring wells. The objectives of an initial geophysical survey in 1977 were to define and map the spatial extent

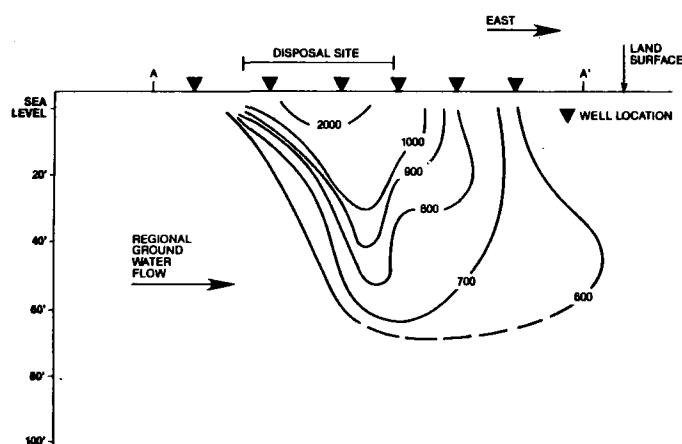


Figure 7.  
Isopleths of Specific Conductance ( $\mu$  mho/cm) from 1974 Well Data  
(locations shown in Figure 8)

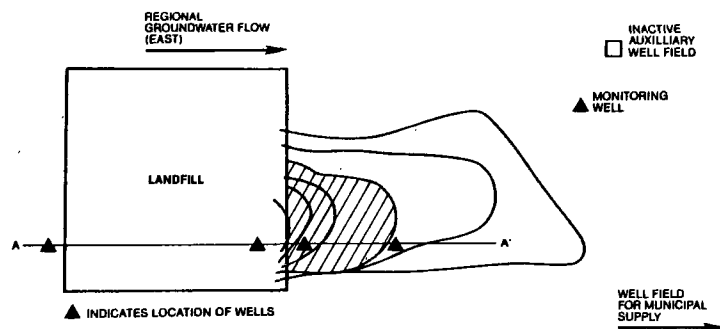


Figure 8.  
Plume Configuration Estimated from 1977 Resistivity Survey  
(See resistivity cross-section A-A' on Figure 7)

of the plume and to provide recommendations for additional monitoring wells if required. The results of the 1977 resistivity survey are shown in Fig. 8.

A few years after the resistivity survey, a new auxiliary well field was installed nearer the landfill—approximately 1.5 miles in an approximate downgradient groundwater flow direction. This well field had been pumping intermittently for approximately two years (1979-1981) when a second geophysical survey was requested. The landfill had been identified by USEPA as one of the major hazardous waste sites in the country because of its proximity to the local well field supplying drinking water to a large city.

The objectives of the subsequent 1981 survey were to evaluate any changes in the plume and the influence of the new water well field.

Monitoring well data were again reviewed. The contaminant plume inferred from the 1981 well data alone is shown in Fig. 9. Inspection of aerial photographs showed that during the four year period between the first and second surveys, considerable development had taken place in the area, and potential auxiliary sources of contaminant were present. Available areas that could be readily surveyed with geophysical techniques were identified at this time.

Resistivity was again selected as the survey method so that the new survey measurements could be correlated with the earlier measurements. The electromagnetic technique was used to provide a more extensive and detailed data base and to improve the statistical validity of the survey. The new survey area was extended beyond the earlier survey to cover more area down gradient. The results of the new survey, plotted in Fig. 10, showed the plume after a four-year period. There are important differences between the plume inferred from the monitoring well data alone and the plume inferred from the geophysical survey. The contamination observed in the well to the south was found to originate from a source not related to the landfill.

A resistivity transect (line B-B' in Fig. 10) runs through the plume and the well which was indicating contamination can put the

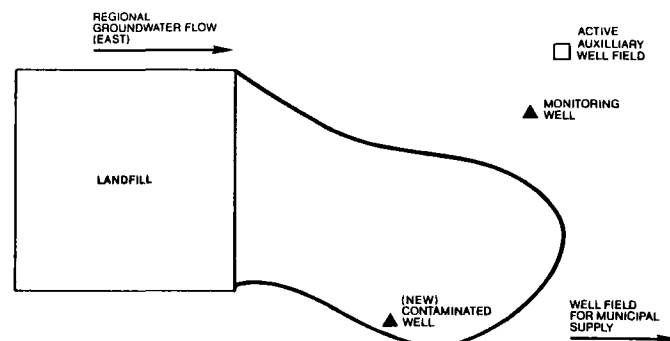


Figure 9.  
Plume Configuration Estimated from 1981 Well Data Only

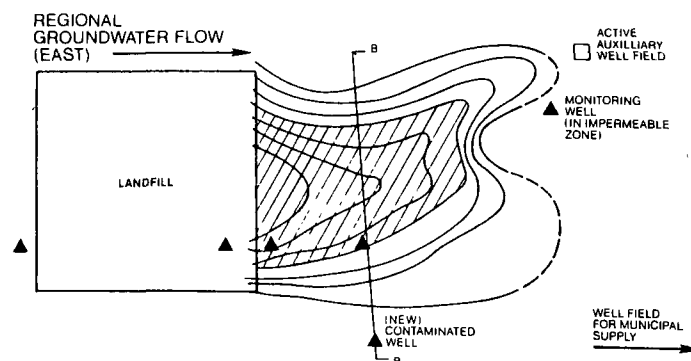


Figure 10.  
Plume Configuration Estimated from 1981 Electromagnetics Survey  
(B-B' indicates location of resistivity cross-section)

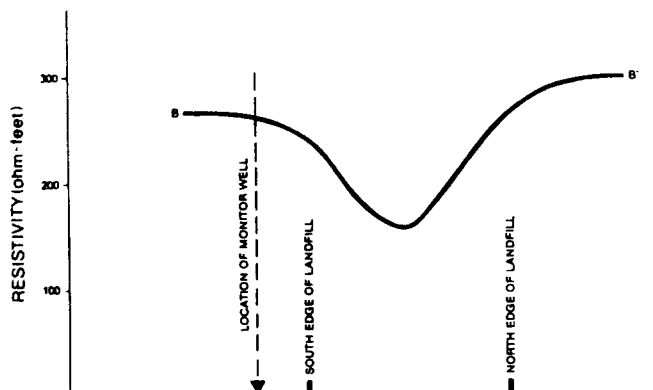


Figure 11.

Resistivity Transect (Along cross-section B-B' in Figure 10)

existing well data and the geophysical data in perspective. The data obtained along the transect are shown in Fig. 11. The main contaminant plume clearly does not reach the well in question. This well is contaminated from other sources which were identified.

The node bisecting the outer edge of the plume was created by a low permeability zone in which leachate was not penetrating. Most importantly, the plume was clearly responding to the pumping of the new auxiliary well field to the northeast.

The plume, as shown in Fig. 10, is representative of the conservative parameters measured by the electrical methods. For landfill contaminants, these boundaries will typically represent a worst-case condition. Most contaminants of a hazardous nature will lie within these boundaries and often will have migrated less distance than these conservative parameters. The locations for additional monitoring wells can be precisely determined after these plume configurations are defined. In addition to accomplishing this objective, the survey identified a number of other point sources which were contributing to the contamination of the aquifer (not shown in the data).

Probably, the most significant result of this work was the demonstrated ability to measure, through successive geophysical surveys, the migration of the contaminants over the four-year study period.<sup>10</sup>

### APPLYING THE SYSTEMATIC APPROACH

The case examples have illustrated the systematic approach in practice. It is important to understand the organizational structure and tools needed to correctly implement the systematic approach (Fig. 12). None of the technical tools or skills taken by itself is a panacea.

Project success will be achieved through the proper selection, combination and balance of all of these elements. When these elements are combined properly, a synergism results which can significantly improve understanding of site conditions.

### CONCLUSIONS

Relative costs and benefits of an integrated approach have been discussed by Benson, *et al.*<sup>8</sup> The use of geophysics considerably reduces the total cost of most hazardous waste site assessments. As site complexity increases and/or sites get larger, particularly relative to the area of interest, geophysical-assisted projects become increasingly more cost effective. Further geophysics may be the only reasonable alternative when there is risk of puncturing waste containers during drilling.

Knowledge gained in initial literature and aerial photography review will aid in focusing a cost-effective systematic site assessment.

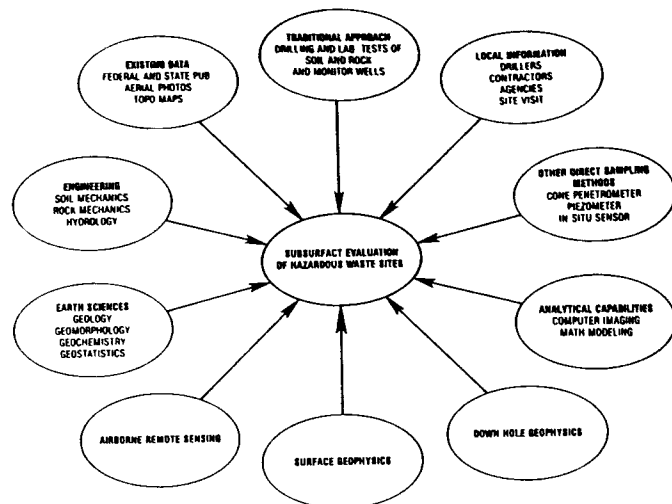


Figure 12.

Technical Resources and Tools for Subsurface Investigations of Hazardous Waste Sites

There is increasing recognition that hazardous waste site assessments are complex. Shortcuts or elimination of essential elements in a systematic approach will often result in failure to accurately or effectively characterize the site. Therefore, all available technical resources and tools should be considered in a subsurface investigation of a hazardous waste site.

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# DETERMINATION OF RISK FOR UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

The development of risk assessment at both controlled and uncontrolled hazardous waste sites is perhaps the fastest growing area of environmental investigation. Various federal and state agencies as well as private consulting firms have become involved in the determination of risk through initiating legislation, developing rules and regulations, conducting site searches and investigations, as well as developing new and more sophisticated risk assessment models. Risk is usually defined as a function of the probability of an event occurring and the magnitude or severity of the event should it occur,<sup>1</sup> while risk assessment has been defined as, "the identification of hazards, the allocation of cause, the estimation of probability that harm will result, and the balancing of harm with benefit."<sup>2</sup>

Frequently, the assessments also include the cost of risk reduction compared to the public benefit. Risks associated with hazardous waste disposal include threats to public health and safety due to environmental degradation of air, water and land resources, fire and explosion, exposure to carcinogenic, mutagenic or teratogenic chemicals, as well as socioeconomic and legal risks due to the loss of property value and potential liability suits.

The type and extent of a risk determination should be based upon a general series of assessment criteria as well as an understanding of the ultimate purpose of the investigation. The nature of the program will vary depending upon whether the assessment will be used to distinguish priorities among numerous uncontrolled sites, to initiate emergency removal, to evaluate sites for insurance purposes, or to recommend long-term remedial measures. The purpose of this paper is to illustrate how general risk assessment methodology can be used in conjunction with a detailed analytical and mass balance program in order to develop appropriate remedial action recommendations.

## THE NATIONAL CONTINGENCY PLAN

Section 105 of the Comprehensive Environmental Response, Compensation and Liability Act, P.L. 96-510 (known as CERCLA or Superfund) requires that the National Contingency Plan (NCP) be revised to include the removal of oil and hazardous substances and "shall establish procedures and standards for responding to releases of hazardous substances, pollutants, and contaminants."<sup>3</sup> According to the Act the plan shall include:

- Methods for discovering and investigating facilities
- Methods for evaluating and remedying releases or potential releases
- Methods and criteria for determining extent of removal or remedy
- Means of assuring cost effective remedial action measures.

CERCLA goes on to say,

"Criteria and priorities under this paragraph shall be based upon relative risk or danger to public health or welfare or the environment...taking into account, to the extent possible, the population at risk, the hazard potential of the hazardous substances at such

facilities, the potential for contamination of drinking water supplies, the potential for direct human contact, the potential for destruction of sensitive ecosystems..."<sup>3</sup>

On July 16, 1982, the NCP Rules and Regulations were published in the *Federal Register*.<sup>4</sup> In compliance with CERCLA, the NCP provides direction on the criteria for conducting preliminary assessment, undertaking immediate removal, evaluating planned removal and undertaking remedial action including determination of the appropriate extent of the response. Specific actions described by the NCP for the preliminary assessments are: the evaluation of the hazard magnitude, identification of the nature and source of the release, determination of responsible parties, and evaluation of background information.<sup>4</sup>

Once it has been determined that a site does not require immediate remediation, the more detailed process of evaluation to determine appropriate response would begin. The general areas of concern are: whether there is a population at risk, the amount and form of hazardous substances, the hazardous properties of those substances, the hydrogeologic factors affecting the site and the climate. Based upon the NCP, the appropriate response to such a site upon discovering that a threat exists includes:

- Collecting and analyzing data
- Developing a limited number of alternatives
- Screening the alternatives based on cost, environmental, health, and engineering criteria
- Refining the alternatives and performing detailed analysis (including engineering implementation, constructibility, extent of migration, detailed costs, and environmental impacts)
- Selecting the most cost-effective alternative that will mitigate the danger and provide adequate protection
- Balancing the need for protection against the amount of money available in the Superfund

Although the NCP was designed for uncontrolled sites where the federal government has become involved, it can serve as an outline for appropriate response at numerous hazardous waste sites which are not on the national priorities list. The assessment criteria, however, should be considered minimum requirements. The criterion of selecting the most cost-effective alternative which "effectively minimizes and mitigates the danger and provides adequate protection of public health, welfare and the environment" should be recognized as a general standard. Time and cost constraints are usually the limiting factors for all types of remedial action whether cleanup is being undertaken by industry or government agencies. Although the same type of balancing of protection against monies available in the fund would not apply, it should be accepted that industries will apply the most cost-effective alternative when designing and implementing remedial measures.

## GENERAL RISK ASSESSMENT METHODOLOGY

The type and extent of risk determination undertaken will depend upon the intended ultimate use of the assessment. The purpose would shape the data requirements, the methodology, the

rigor of the assessment, as well as the eventual value of the assessment for secondary purposes. Potential objectives include establishing priorities among various uncontrolled waste sites, assessing imminent health or environmental hazard, determining legal and/or insurance liability, and evaluating remedial action requirements. Normally, the last of these objectives would require the most extensive assessment.

General criteria have been developed which would apply to all types of preliminary investigations. These are usually based upon an investigation of available information related to essentially four characteristics: receptors, pathways, waste characteristics, and waste management practices.<sup>3</sup> The labels may differ depending upon the particular risk assessment model, but the basic areas of concern remain the same. In the Rating Methodology Model these factors are defined as follows:

- Receptors—humans and other organisms that may be exposed to hazards from the site
- Pathways—the routes or media by which hazardous materials may escape from the site
- Waste characteristics—the hazardous properties of the waste including quantity, mobility, toxicity, ignitability and persistence
- Waste management practices—the design characteristics and procedures used in managing and containing wastes<sup>5</sup>

The relationship between pathways and receptors in a simple schematic diagram (Fig. 1).<sup>6</sup> The general information requirements for a risk assessment at either a controlled or uncontrolled hazardous waste site are listed in Table 1, which has been designed to correspond to the receptor—pathway—waste characteristics—waste management practices mode. Standard matrix forms are utilized to evaluate the risk associated with specific sites based on available data. Each evaluation parameter is rated on a numerical scale, and multiplier factors are applied to obtain the site parameter score. The final site rating is obtained by adding the products of all the factors and normalizing the results on a percentage basis.<sup>5</sup>

In actual fact, most of the information listed in Table 1 is not readily available during a preliminary assessment. Frequently, investigators are compelled to rely upon previously gathered data and the available literature in combination with a preliminary site

**Table 1.**  
**Risk Assessment Information Requirements**

- |  |   |
|--|---|
| <p>I. Identification of Facility</p> <ol style="list-style-type: none"> <li>1. Owner and Operator</li> <li>2. Type/Function of Facility</li> <li>3. Location</li> </ol> <p>II. Receptors</p> <ol style="list-style-type: none"> <li>1. Description of Region               <ol style="list-style-type: none"> <li>a. surrounding facilities</li> <li>b. surrounding population</li> </ol> </li> <li>2. Land and Water Use               <ol style="list-style-type: none"> <li>a. regional characteristics</li> <li>b. surrounding land uses</li> <li>c. drinking well data</li> </ol> </li> <li>3. Critical Habitats               <ol style="list-style-type: none"> <li>a. endangered or threatened species habitats</li> <li>b. environmentally sensitive areas (e.g., floodplains, earthquake zones)</li> <li>c. state or federal preserves</li> </ol> </li> <li>4. Off-Site Dose Assessment               <ol style="list-style-type: none"> <li>a. dose exposure for surrounding population</li> <li>b. specific demographic and agricultural data</li> <li>c. biota monitoring</li> </ol> </li> </ol> <p>III. Pathways</p> <ol style="list-style-type: none"> <li>1. General Description               <ol style="list-style-type: none"> <li>a. site location and surrounding geography</li> <li>b. site description</li> <li>c. off-site discharges</li> <li>d. potential natural and man-made pathways</li> </ol> </li> <li>2. Meteorology               <ol style="list-style-type: none"> <li>a. regional climatology</li> <li>b. local climatology</li> <li>c. air monitoring data</li> </ol> </li> <li>3. Geology               <ol style="list-style-type: none"> <li>a. regional geology</li> <li>b. site geology</li> <li>c. soil sampling data and boring logs</li> </ol> </li> </ol> | <p>4. Hydrology               <ol style="list-style-type: none"> <li>a. surface water hydrology</li> <li>b. groundwater hydrology</li> <li>c. drainage patterns</li> <li>d. water quality monitoring data</li> </ol> </p> <p>IV. Waste Characteristics</p> <ol style="list-style-type: none"> <li>1. Site Characteristics               <ol style="list-style-type: none"> <li>a. quantity of waste</li> <li>b. condition of waste containment</li> <li>c. facility characteristics</li> <li>d. facility capacity</li> </ol> </li> <li>2. Waste Characteristics               <ol style="list-style-type: none"> <li>a. mobility</li> <li>b. toxicity</li> <li>c. ignitability</li> <li>d. reactivity</li> <li>e. corrosivity</li> <li>f. carcinogenicity</li> <li>g. volatility</li> <li>h. radioactivity</li> <li>i. solubility</li> <li>j. persistence</li> </ol> </li> </ol> <p>V. Waste Management Practices</p> <ol style="list-style-type: none"> <li>1. General Description of Facility               <ol style="list-style-type: none"> <li>a. location and layout</li> <li>b. facility description</li> <li>c. closure procedures</li> </ol> </li> <li>2. Structural and Mechanical Design</li> <li>3. Description of Operations</li> <li>4. Training and Safety Procedures</li> <li>5. Pollution Control Methodology</li> <li>6. Monitoring and Record-keeping Procedures</li> <li>7. Quality Assurance</li> <li>8. Government Relations               <ol style="list-style-type: none"> <li>a. applicable regulations</li> <li>b. permit applications</li> <li>c. consent decrees</li> <li>d. fines</li> </ol> </li> </ol> |
|--|---|

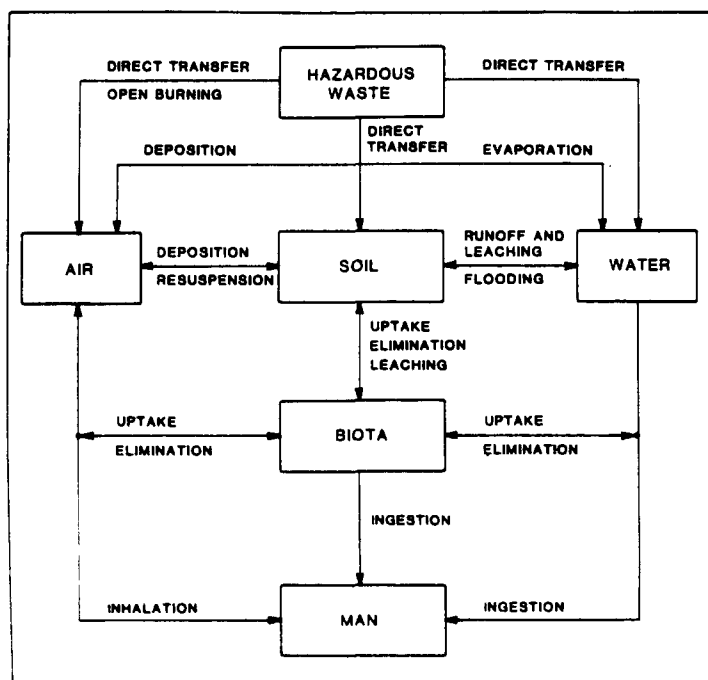


Figure 1.

Major Physical, Biological Transport Pathways of Hazardous Waste

visit to complete the risk assessment. This is particularly true if the investigator does not have the cooperation and approval of the facility operator and/or owner.

Standard risk evaluation is a valuable tool for determining priorities among numerous sites, for determining emergency situations or for evaluating sites for insurance purposes; however, in order to develop cost-effective remedial action alternatives for long term cleanup of a site, a detailed analytical program must be undertaken. The data gathered during the preliminary assessment should be directed toward determining the optimum location, parameters and frequency of sampling.

The first stage of the analytical program would involve the utilization of preliminary screening procedures such as determination of pH, conductivity, total organic carbon, heavy metals, methylene blue active substances and phenol. In addition, such techniques as halogenated organic scans, organic nitrogen/phosphorus scans, volatile halogenated/non-halogenated scans and organic scans have proven extremely valuable in formulating a general conception of site contamination.<sup>7</sup> In addition, where some information is available as to previous disposal activities analytical parameters would be selected based upon:

- Chemicals which may have been deposited at the site in very large quantities
- Chemicals which may be present in small quantities, but are known to be extremely toxic even in low doses
- Chemicals commonly found at waste sites which behave in a manner characteristic of many other contaminants<sup>8</sup>

This analytical program, combined with such tools as mass balance calculations and general risk assessment, can then be mean-



ingfully applied to develop remedial action alternatives. Without analytical results, the most a risk assessment can achieve is a qualitative ranking between sites and a general conception of the nature of potential problems.

## TECHNICAL APPROACH

### Environmental Background

Selecting an effective remedial technique involves the balancing of the need to contain contaminants within acceptable levels against the costs associated with the cleanup measures. The fulcrum of the balance is risk. The following example is intended to illustrate the way in which remedial action alternatives can be determined based upon a balancing of risk, environmental setting and cost.

The particular site is an uncontrolled hazardous industrial landfill located in Niagara Falls, New York along the north shore of the Niagara River.<sup>9</sup> The site was utilized from mid-1948 until Sept. 1970 for the disposal of chemical waste by-products. Almost the entire landfill is covered by waste material ranging from 8 to 17 ft and averaging 12 ft in thickness. Closure was originally accomplished by covering the waste with a final soil cover, establishing vegetation, and constructing a retaining wall along the river.

A detailed preliminary examination of the geology, hydrology, environmental setting, surrounding community, waste characteristics and past industrial disposal practices was undertaken at this site. Potential receptors of the contaminants included aquatic life in the river and associated biota, recreational users and, to some extent, communities taking treated drinking water from the river. General information concerning waste characteristics and past disposal practices was supplied by the company involved in the remediation.

Using the Rating Methodology Model, the risks associated with the site were considered to be high. This determination was based upon the waste characteristics of the material disposed of at the site, the previous waste management practices and the hydrogeologic pathways by which contaminants were leaving the site. However, the overall risk from the site was deemed to be medium when the dilution factor of the river was included in the assessment because dilution effectively reduced the hazardous constituents reaching potential receptors.

In order to determine remedial action alternatives, a detailed hydrogeologic investigation, an analytical sampling program and mass balance calculations were used to supplement previously gathered information. These were the key elements to development of alternatives and eventually remedial recommendations.

Briefly, the hydrogeologic investigation identified three water bearing zones. First, the groundwater table, or unconfined saturated one was located within the waste itself. Second, a semi-confined aquifer was located within sandy Recent alluvial deposit. Third, a confined to semiconfined aquifer existed within the Lockport Dolomite.

The analytical program suggested that chemical constituents attributable to the landfill existed in the former two water bearing zones and to a lesser extent in the Lockport Dolomite. Downward migration of groundwater from the landfill was restricted by a stratum of highly impermeable glacial lake deposits (permeability  $2.1 \times 10^{-6}$  cm/sec). However, the stratum was not continuous across the site, and varied in thickness from 26 ft to less than 2 ft. The geology and groundwater flow patterns are represented in Fig. 2.

The objective of the water balance was to quantify, to the extent possible, each of the mechanisms of groundwater inflow and

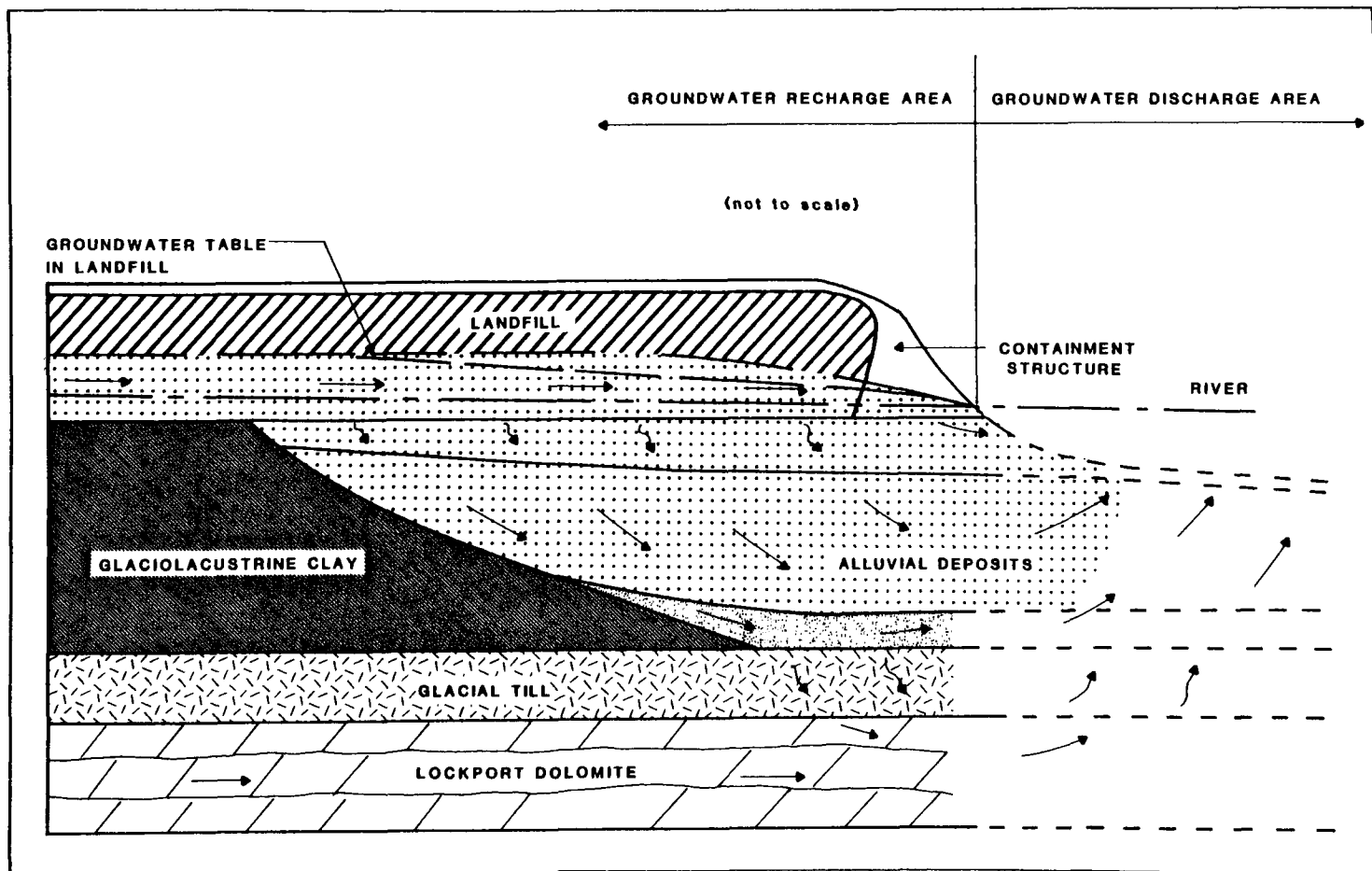


Figure 2.  
Generalized Groundwater Discharge Pathways

outflow from the landfill. Further, by incorporating the chemical character of the leachate into the assessment it became possible to quantify each of the principal avenues of contamination in terms of contaminant migration from the landfill. The finished water balance/contaminant analysis was an invaluable tool in evaluating potential remedial measures in terms of their need and cost effectiveness. The components of the water balance for the Niagara Falls site are shown in Fig. 3. Calculations were based upon local climatological and sampling data. The inflow component was 8,871 gal/day based upon inputs of 7,800 gal/day from precipitation percolation into the landfill and 1,071 gal/day from lateral groundwater inflow. The outflow component was calculated to be 9,504 gal/day, with 70% derived from the migration of leachate into the Recent alluvium aquifer, predominantly in the form of lateral groundwater movement beneath the retaining wall to the Niagara River. Other pathway components were infiltration to a storm sewer, and lateral outflow around and through the containment structure.

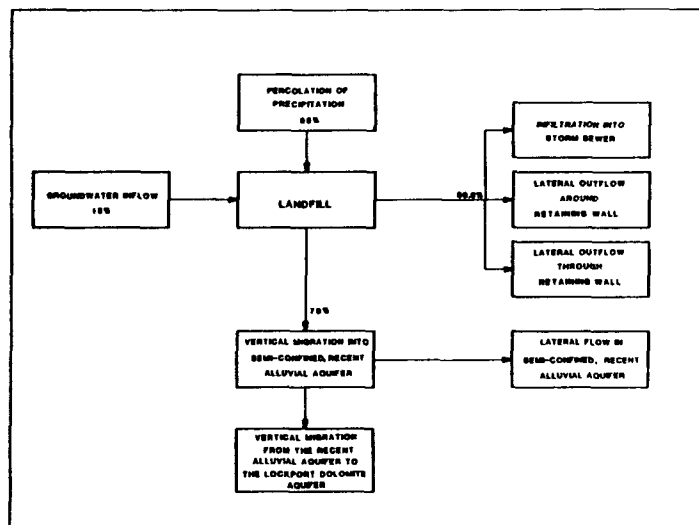


Figure 3,  
Schematic of Water Balance

Analysis of groundwater samples from piezometers was used in conjunction with water balance information to calculate off-site discharge loadings from the landfill. Samples were taken in the saturated fill zone and the alluvial zone. Bedrock well data, surface water data, and river sediment data were used for conceptual confirmation of the calculated loadings. These data were then applied to the water volumes based upon the water balance predictions. Loadings were estimated to be: 50 lb/yr chlorinated organics, 6.0 lb/yr volatile non-halogenated organics, 10 lb/yr phenol and 14 lb/yr toxic heavy metals.

The distribution pattern of halogenated organics suggested two discharge mechanisms. First, groundwater was migrating beneath the containment structure and entering the river near the top of the sediments along the base of the retaining wall. Second, off-site sources and/or ground water via infiltration from the site was also being carried into the river by the sewer line. After reaching the river, the constituents appeared to move outward and downstream from the landfill.

#### Remedial Action Alternatives

In order to reduce loadings of chemical constituents to the Niagara River a corresponding reduction in the inflow component of the water balance was necessary. Initially four remedial action alternatives were suggested:

- Excavation
- Total encapsulation with leachate collection and treatment
- Three-sided cutoff wall with an impermeable clay cap
- Impermeable clay cap

Based upon the mass balance calculation, the environmental setting, the risk associated with the site and the cost, alternative four was selected as the most appropriate remedial action. The calculated water balance indicated approximately 85% of the inflow component to be a function of precipitation percolation. An impermeable clay cap would reduce this component by at least 90% and the resulting inflow component to 780 gal/day, combined with other inflow constituents this equals a total of 1851 gal/day or 20% of the present situation. Assuming the outflow component would be proportionally reduced, the loading to the river would then be: 10 lb/yr chlorinated organics, 1.2 lb/yr volatile non-halogenated organics, 2.0 lb/yr phenol and 2.8 lb/yr heavy metals.

Examining the environmental setting of the area, it was determined that the diminished loadings would reduce the risk to low/acceptable levels. The additional inputs from this landfill site were considerably lower than that of existing industrial loadings to the Niagara River. Secondly, current water quality standards would not be contravened by these inputs. Finally, the risk associated with the landfill to public health and the environment was considered minimal. Therefore, the costs associated with excavation and total encapsulation was deemed to be prohibitive based upon the potential environmental benefit. A three-sided cutoff wall would assist in the reduction of the remaining inflow parameter to the water balance; however, costs combined with potential adverse environmental impacts when the landfill groundwater level reached equilibrium with the Niagara River eliminated this alternative from consideration. Consequently, it was recommended that an impermeable clay cap be placed over the landfill.

#### ACKNOWLEDGEMENTS

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# ASSESSMENT OF HAZARDOUS WASTE MISMANAGEMENT CASES

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## INTRODUCTION

USEPA's Office of Solid Waste (OSW) is responsible for promulgating hazardous waste management facilities regulations under the Resource Conservation and Recovery Act (RCRA). In addition to developing the necessary data base to support these regulations, OSW must also develop Regulatory Impact Analyses (RIAs), as required by Executive Order 12291, issued Feb. 18, 1981. In order to achieve these objectives, USEPA identified the need to develop and compile a data base on damage case histories associated with land and non-land based hazardous waste disposal facilities. Fred C. Hart Associates, under contract to the USEPA, subsequently completed the study and analysis upon which this paper is based.

The information generated by this project will provide: (1) a compilation of damage information on a large number of both active and inactive disposal sites meeting certain criteria, (2) information of the kinds of environmental damage associated with certain contamination events, and (3) some measure of the overall extent of contamination and damage resulting from the mismanagement of hazardous wastes. The OSW intends to submit the compiled information for incorporation into the Administrative Record prior to finalization of the RIA process. The data, as well, will be useful in preparing regulations tailored to specific facility types, evaluating alternative regulatory scenarios, and for use as background information in resolving a variety of other technical issues.

## WORK OUTLINE

Fred C. Hart Associates, Inc. completed a number of specific tasks in accomplishment of the overall project objectives:

- Identification, review and assessment of existing potential sources of information on damage from hazardous waste disposal sites. These sources include USEPA's Site Tracking System (STS), the Superfund Notification System (NOTIS), the Hazardous Waste Data Management System (HWDMS), the Surface Impoundment Assessment files (SIA), the Center for Disease Control files, the Eckhardt Report, Regional USEPA files, and the Regional Field Investigation Team (FIT) files
- Selection of the FIT and USEPA Regional Office files as having the data most suitable and readily available for the intended purpose
- Development of site selection criteria to best meet the technical information requirements of USEPA and to most efficiently utilize available contract dollars. These criteria, which were utilized to select those active and inactive land disposal and non-land disposal sites that were to be evaluated in this study, included:
  - preferential selection of all sites scoring with the MITRE Superfund model (The interim list of 175 Mitre Scored sites, "rescored" under the direction of USEPA in September-October 1981), and
  - preferential selection of any site associated with waste storage.
- Selection of a total of approximately 1,000 sites for preliminary file review

- Development of a Damage Incident Summary Form (DISF) to record the data to be collected from the individual site files
- Development of review criteria to insure uniformity of DISF responses regarding the identification of contamination and damage events, rating of damage severity, determination of the level of file documentation required to support given responses, etc.
- Review of the selected damage incident cases at each of the FIT and USEPA regional offices to complete the DISF survey form
- Analysis of the data findings and preparation of the report entitled "Assessment of Hazardous Waste Mismanagement Damage Case Histories" (Sept. 1982) upon which this paper is based

## EVALUATION PROCESS

### Case Selection Criteria

The final six criteria developed to select damage case histories contained in the FIT and regional USEPA files are summarized in Table 1. Files or sites conforming with these criteria were identified as the most suitable from the perspective of the project goals. Since site selection was not a random process, the reader is cautioned against making generalizations based upon the findings of this specific analysis.

Files associated with sites for which sampling and analytical data were available are identified in criteria 1 and 4. These files generally were those sites inspected, investigated and sampled by FIT and/or USEPA survey teams. FIT files for which sampling data were not available usually were not sufficiently detailed to support damage case assessments.

Criteria 2 and 5 identified files associated with hazardous waste storage, such as tank and container facilities. Criteria 5 was further refined to include only those sites for which there was preliminary evidence of damage in order to generate a data base consistent with project goals and resources.

Criteria 3 and 6 targeted sites identified under the Superfund program as the 175 highest MITRE scored sites. These sites were

Table 1.  
Summary of Case Selection Criteria for Evaluated Sites  
for FIT and S&A Files

USEPA Field Investigation Team (FIT) Files			
Criteria Number	1	2	3
Criteria Description	Files having sampling data	Files associated with waste storage	Files associated with MITRE scored sites (a)
USEPA Survey and Analysis (S&A) Files			
Criteria Number	4	5	6
Criteria Description	Files having sampling data	Files associated with waste storage for which there is evidence of damage	Files associated with MITRE scored sites (a)

(a) The interim list of 175 Mitre Scored sites, "rescored" on September/October 1982 under the direction of USEPA.

included in the survey based on the assumption that environmental damage could potentially be most readily documented at these locations.

### Evaluation Procedures

Files in each region were evaluated by a study team consisting of a project director, team leader and four to five technical assistants. Guidelines, definitions and criteria used by the study team in making the interpretations and judgments needed to complete the DISFs are discussed in detail in the project report.

In summary, the evaluation procedure consisted of a two-phase effort. The first phase consisted of visiting regional FIT and Survey and Analysis (S & A) offices, screening files according to the selection criteria, and transferring the appropriate information to the DISFs. This effort was accomplished during a noncontinuous nine-week period beginning in Nov. 1981 and ending Feb. 1982. The second phase consisted of reviewing the completed DISFs for consistency, format and editorial standards, tabulating the conformed DISFs and summarizing the information in the report. This effort was accomplished over a period of several weeks beginning in late Mar. 1982 and ending with the submission of the report.

The DISF was used to assess damage case histories and associated site characteristics. After the study team reviewed the file information, appropriate responses were made on the DISF (Sections I through XII) and the case was summarized in a brief narrative (Section XIII), which was attached to the DISF form.

- |                                 |                              |
|---------------------------------|------------------------------|
| I. Site Identification          | VII. Epidemiological Studies |
| II. Site Description            | VIII. Event Causing Incident |
| III. Date of Incident/Discovery | IX. Waste Characterization   |
| IV. Status of Operations        | X. Status of Response        |
| V. Exposed Media                | XI. Source of Information    |
| VI. Affected Areas              | XII. Severity of Damage      |
| XIII. General Comments          |                              |

### Evaluation Criteria

DISF responses for Sections I, II, III, IV, VII, X and XI were prepared from information available in the files according to the definitions and instructions accompanying the DISF. DISF responses for Sections V, VI, VIII, IX and XII required value judgments based on evaluation criteria developed for each value judgment question. For example, the study team was frequently required to assess whether contamination had occurred, what media had been exposed, what event caused the incident, and what waste resulted in contamination. Finally, the study team was required to assess the severity of damage which had occurred to either human health and/or the environment. In order to ensure that the study team rated sites uniformly, specific evaluation criteria were developed for use as guidance in:

- identifying contamination and damage events,
- rating the severity of damage, and
- determining the file documentation required to support a given response (i.e., documented versus suspected).

For example, in this study, "contamination" is defined as the presence of pollutants in groundwater, surface water, soil or air, as identified by present standard sampling and analytical techniques. "Pollutants" are defined as substances not naturally found in the site-specific environment which may interfere with the best use of, or cause environmental harm to, the affected resource. "Identified" is defined as positive contaminant verification at concentrations above the detection limits of the sampling and analytical techniques applied. Verifiable concentration levels varied, but in most cases were in the  $\mu\text{g/l}$  range.

Contamination was considered to be "documented" if the event was substantiated by a direct investigative action by a regulatory office or other recognized agency. File information required to support documentation included:

- Sampling data

- Excerpts from relevant documents (engineering reports, environmental impact statements, NPDES, and RCRA permits, enforcement actions, etc.
- Professional evaluations, expert witness testimony, etc.

"Damage" was defined as the presence of pollutants at concentrations causing interference with, loss in quality of or harm to human health, drinking water, the food chain, flora, fauna or property. Damage was considered to be documented according to the same evaluation criteria discussed previously, with certain additional criteria:

- DISF responses indicating documented damage to human health were to be based on authoritative references in the file correlating sickness, injury or death to contamination events occurring at the site. These references would typically include hospital reports, OSHA citations, regulatory agency reports, facility operating reports and, in certain limited cases, epidemiological data.
- DISF responses indicating documented damage to drinking water were to be based on authoritative references in the file correlating excessive contaminant concentration levels in the water supply with contamination events occurring at the site. Excessive contaminant concentration levels were defined as constituent concentrations exceeding USEPA National Interim Primary or Secondary Drinking Water Standards or USEPA Human Health Criteria for Maximum Contaminant Levels (MCLs) in water supplies.
- DISF responses indicating damage to food chain and flora were to be based on authoritative references correlating visible vegetation stress with contamination events occurring at the site.
- DISF responses indicating documented damage to fauna were to be based on authoritative references, usually bioassay studies, correlating fish and wildlife damage with contamination events occurring at the site.
- DISF responses indicating documented property damage were to be based on authoritative references correlating property damage with contamination events occurring at the site. These references would typically include insurance claims, regulatory reports, OSHA citations and enforcement actions restricting residential property, drinking water well or other site/facility usages.

Damage was considered to be "suspected" if the responses to Section VI were based only on citizen allegations, newspaper reports or inconclusive scientific studies.

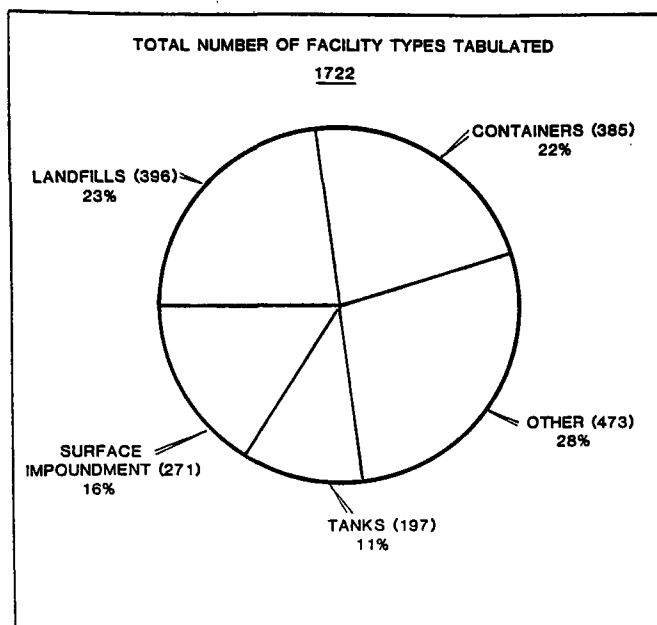
The study team also rated each site according to the severity of human health and environmental damage. The broad guidelines developed by the study team to rate site severity of damage are given in Table 2. High human health damage ratings were assigned to sites where incidents resulted in deaths, whereas low damage ratings were associated with minor, short-term injuries. High environmental damage ratings were typically associated with sites correlated with substantial fish or animal kills, and/or groundwater contamination incidents in which contaminant concentrations exceeded ten times the drinking water criteria discussed previously. Low environmental damage ratings were usually associated with sites where soil or vegetation contamination were limited to relatively restricted areas.

### NATIONAL SUMMARY

The study team evaluated and completed DISFs for a total of 929 sites nationwide. Many of the sites contained multiple facilities. A total of 1,722 individual facility types were used in describing the 929 sites in the ten regions. Of the 1,722 facility types evaluated, 23% were landfills, 22% were containers, 16% were surface impoundments and 11% were tanks. The remaining 28% of the facilities were described by various other categories (Fig. 1).

Contamination, either documented or suspected, was identified in 834 sites, or at 90% of the sites evaluated. At 555 of the sites, or 60%, contamination was documented. Most of the contamination, (Fig. 2) occurred in groundwater 32%, with the remaining incidents occurring to soil (31%), surface water (29%) and air (8%).

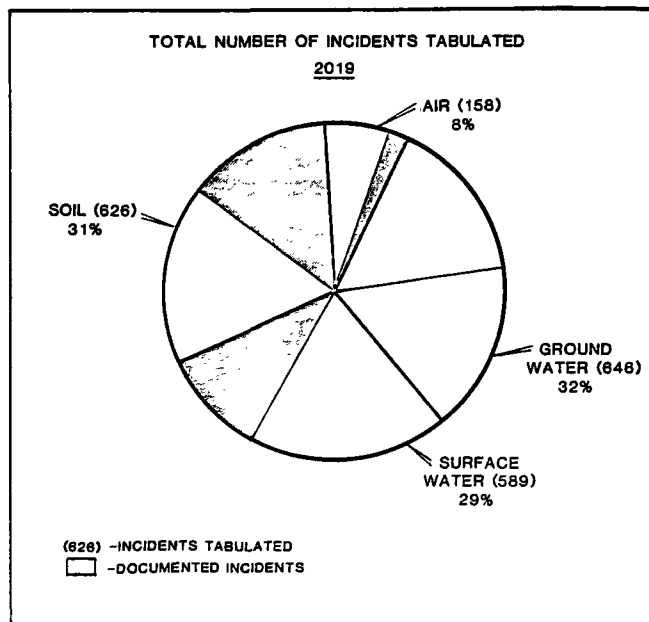
### SITE DESCRIPTIONS BY FACILITY TYPE



<sup>1</sup>Sampled sites were not randomly selected. Site selection criteria and the implications of this criteria are discussed in detail in the report.

Figure 1.  
Hazardous Waste Sites DISF Summary of Evaluated Sites<sup>1</sup>

### MEDIA CONTAMINATED



<sup>1</sup>Sampled sites were not randomly selected. Site selection criteria and the implications of this criteria are discussed in detail in the report.

Figure 2.  
Hazardous Waste Sites DISF Summary of Evaluated Sites<sup>1</sup>  
Media Contaminated

Of the 2,019 responses originally indicating contamination, only 856 (42%) could be documented using the evaluation criteria previously developed.

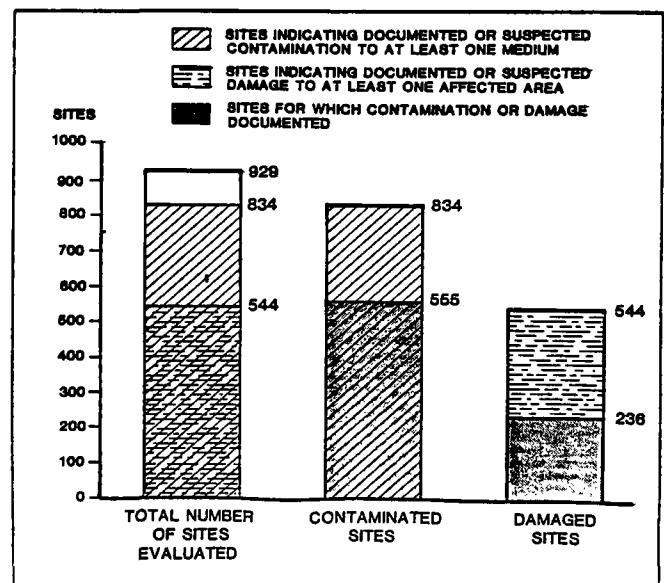
Each site was also evaluated for damage occurring to life, property and various natural resources. This evaluation focused on six potentially affected areas, including drinking water, food chain,

Table 2.  
Summary of Guidelines Used in Rating Severity  
of Damage at Evaluated Sites

Category	Severity		
	High	Medium	Low
Human Health	Damage incident to at least one person resulting in... ...death	...severe injury	...minor injury.
		Contamination of groundwater resulting in closure or restriction of drinking water in a... ...community water supply.	...single private well.
Environmental	Contamination incident where sampling indicates the presence of pollutants in concentrations... ...at levels greater than 10 times applicable standards.	...at levels equal to applicable standards.	...at detectable levels, but less than applicable standards.
	groundwater, surface water & air		
food chain, flora	Contamination incident resulting in stress to vegetated or food crop area... ...greater than one acre.	...greater than ½ acre.	...in limited areas only.
fauna	Damage incident confirmed by... ...massive kills	...limited kills	...bioassay studies confirming tissue contamination.
soil			...contamination incident confirmed by sampling data.

<sup>1</sup>Higher levels of damage were typically identified via use of evidence in the other categories.

### TABULATION OF SITES CONTAMINATED AND DAMAGED



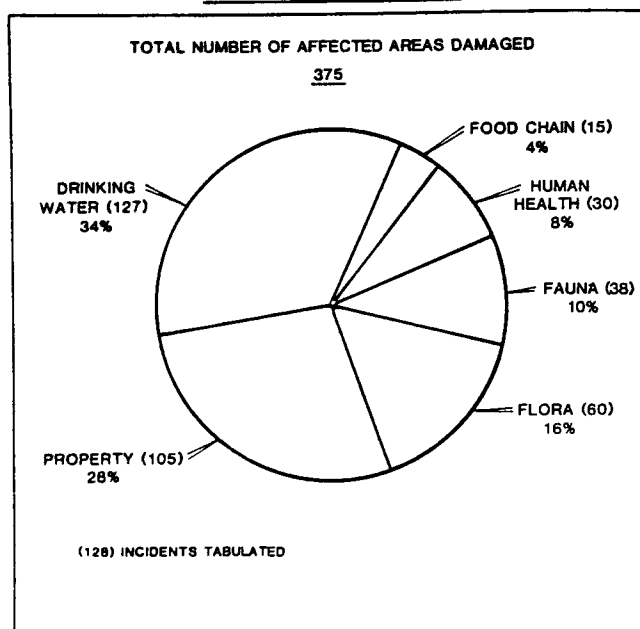
<sup>1</sup>Sampled sites were not randomly selected. Site selection criteria and the implications of this criteria are discussed in detail in the report.

Figure 3.  
Hazardous Waste Sites DISF Summary of Evaluated Sites<sup>1</sup>  
Tabulation of Sites Contaminated and Damaged

flora, fauna, human health and property. Damage (either documented or suspected), was identified in at least 544 sites, or 59% of the sites evaluated. The total number of evaluated sites is compared to the total number of sites rated as "contaminated" and/or "damaged" in Fig. 3. ("Contaminated sites" means sites causing contamination to at least one medium; "Damaged sites" are those



### AFFECTED AREAS DAMAGED DOCUMENTED CASES



<sup>1</sup>Sampled sites were not randomly selected. Site selection criteria and the implications of this criteria are discussed in detail in the report.

Figure 4.

#### Hazardous Waste Sites DISF Summary of Evaluated Sites<sup>1</sup> Affected Areas Damaged Documented Cases

sites resulting in damages to one affected area.) The fraction of contaminated sites and damaged sites associated with the files having the appropriate documentation are also shown in Fig. 3. Of the 1,171 affected areas indicating damage, only 375 (32%) could be documented using the evaluation criteria.

Approximately 34% of the documented damage incidents occurred to drinking water (Fig. 4), with the remaining incidents occurring to property (28%), flora (16%), fauna (10%), human health (8%) and food-chain (4%). The subsequent figure (Fig. 5), indicates that 72% of the incidents causing the damage or contamination described above were due to leachate (32%), leaks (22%), or spills (17%). These incidents involved contamination caused by metals, volatile halogenated organics, volatile non-halogenated organics, acid compounds or base neutral extractables in 70% of the incidents tabulated.

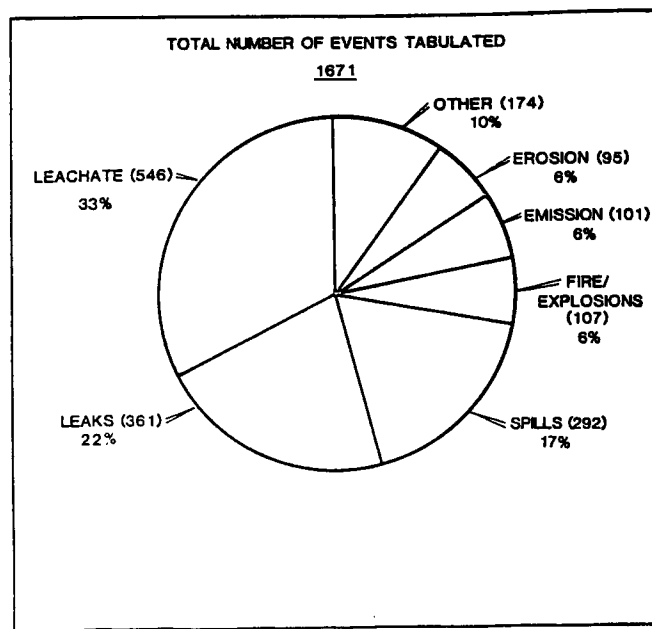
The test of the report provides additional data along these lines on a facility by facility type basis, as well as on an USEPA region by region basis. Specific information is also provided on the sources of the data, facility type profiles, the events causing contamination, the types and ranges of concentrations of chemicals recorded in the files, the status of remedial responses indicated in the files, etc.

## CONCLUSIONS

As a result of the data base review, the site history reviews, and the subsequent data analysis, the study team reached the following conclusions:

- The FIT and regional USEPA files contain the most readily accessible data base on potential damages from hazardous waste disposal facilities of the data bases examined in this study.
- For those sites that met the selection criteria, the facility types most commonly identified with potential contamination or damage included landfills, containers, tanks and open pumps.
- Of the 929 sites evaluated, 41% were identified as active facilities, and 43% as inactive facilities. The remaining 16% could not be identified using the information available in the files.

### EVENTS CAUSING CONTAMINATION



<sup>1</sup>Sampled sites were not randomly selected. Site selection criteria and the implications of this criteria are discussed in detail in the report.

Figure 5.

#### Hazardous Waste Sites DISF Summary of Evaluated Sites<sup>1</sup> Events Causing Contamination

- Approximately 90% of these sites had evidence of suspected or documented contamination.
- Approximately 60% of the sites indicating the potential presence of contamination had documented evidence of contamination.
- Groundwater, surface water and soil were the media that were contaminated most often and at approximately the same number of sites.
- The events most often associated with contamination included leachate, leaks, spills, fire/explosion, toxic gas emissions and erosion.
- The most commonly identified contaminants included metals, volatile halogenated organics and volatile non-halogenated organics.
- Damage was suspected or documented at 59% of the sites evaluated, or at 63% of the sites involving contamination; in total approximately 25% of the sites evaluated have documented evidence of damage to human health or the environment.
- Suspected damage was most often reported to drinking water, human health, fauna and flora; documented damage was most often reported to drinking water and property.
- While remedial programs varied on a case by case basis, various legal actions and/or remedial activities have been initiated at a significant number of sites evaluated in this study. For example, legal or enforcement activities have occurred at 19% of the sites, while 55% of the sites have had or are currently completing additional environmental investigations. At approximately 30% of the sites, remedial activities of some type have been initiated.
- It is particularly important for the reader, throughout this analysis, to be cognizant of the fact that the 929 sites evaluated were selected based on specific criteria. This criteria included preselection of active and inactive hazardous waste disposal sites associated with cases having sampling data, cases associated with waste storage and MITRE scored sites. In view of this preselection process, it should be noted that these cases are not necessarily representative of all damage cases on file at USEPA or in actual existence. As a consequence, it difficult to apply the findings of this analysis to other data bases on hazardous waste facilities, abandoned sites, etc., or to develop more generalized conclusions based upon the efforts of this study.

# ELECTRICAL RESISTIVITY TECHNIQUES FOR LOCATING LINER LEAKS

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## INTRODUCTION

An important aspect of hazardous waste treatment and disposal in landfills or surface impoundments is the prevention of surface and groundwater contamination by fluids containing hazardous constituents. Relatively impervious flexible membrane liners have been used to establish the facility boundaries and to prevent fluids from migrating into the surrounding water resources.

Research and evaluation projects are underway to investigate the effectiveness of waste containment liner materials, including the long-term deterioration of liners exposed to various waste products. Early landfill liners consisted of clay hardpans, and wood or metal barriers. Improved liners have been developed more recently using flexible polymeric materials to provide lower liquid permeability and longer waste containment lifetimes.

While these newer liner materials are demonstrating improved resistance to prolonged waste exposure, no methods are presently available to nondestructively test their physical integrity in service environments. A tear or rupture in a liner system will allow fluid to migrate from the facility and thus violate the original intent of the liner. The work reported herein has been directed toward developing a nondestructive electrical system which can be used for detecting and locating leaks in waste containment liners while the facility remains in service.

Since the philosophy of impervious liners is to contain rather than absorb or filter contaminants, the physical characteristics of the liner materials will usually differ significantly from the underlying soil and the contained hazardous waste. In particular, liners made of impervious plastics and rubbers will exhibit very high electrical resistance which will act as an electrical insulator between the internal and external liner surfaces. If the liner is physically punctured or separated so that fluid passes through the liner, the electrical conductivity of the fluid and saturated underlying soil will form a detectable electric current path through the liner by which the leak may be revealed. Electrical methods are attractive because they can be applied on the surface of the landfill or fluid impoundment. The methods are completely nondestructive in operation and, by means of automated field equipment, can be made very efficient and cost-effective for facility monitoring operations. The resulting method, when fully developed, will be useful for surveying existing as well as new facilities where electrically resistive membrane liners are installed.

Two- and three-dimensional computer models were used to examine the current distribution in the cross sections of several simulated liner geometries having different leak locations. In addition to these analytical model studies, a three-dimensional physical scale model was also constructed using a plastic liner in a wooden frame. Soil was placed inside the model to simulate a landfill. Water was used to simulate a fluid impoundment. Electrical potential distributions on the surface of the soil and water were measured to determine the effects of punctures in the liner. The effects of multiple leaks as well as those caused by subsurface anomalies contained within the liner were studied. Based upon these application

concept studies, the most promising electrical testing methods have been identified and subsequent project activities are now directed toward the design and fabrication of an appropriate experimental field instrumentation system. Computer software is also being developed and tested to allow on-site analysis of field data.

## EXPERIMENTAL METHOD

The basic electrical testing concept where one current electrode is located away from the facility and a current path exists over through a leak penetration in the liner as well as over the buried edge of the liner is shown in Fig. 1. This figure shows that when a leak penetration is present in the liner, current flow between electrodes located inside and outside the facility will follow two paths, namely, through the leak and over the buried edges of the liner.

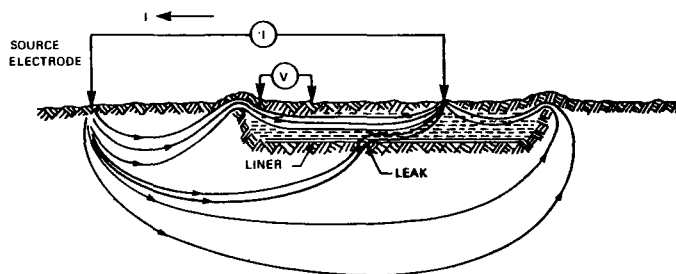


Figure 1.  
Leaking Liner. Arbitrary Search Electrode Position

Since surface potentials are directly related to the current distributions in the vicinity of the search electrode, they can be used to locate the leak.

Fig. 1 represents an idealized case of a non-conducting liner. Actual liner materials have high but finite volume resistivity. The voltage to current ratio at the source electrode can be expressed as a resistance due to the earth in the absence of the liner in series with a total resistance across the liner. If the current density is assumed to be uniform over the entire area of the liner, then this liner resistance may be expressed as:

$$R_L = \frac{\rho_L t}{A} \quad (1)$$

where:

$R_L$  = The total liner resistance

$\rho_L$  = the volume resistivity of the liner material

$t$  = thickness of the liner

$A$  = total surface area of the liner

For a liner 0.030 inches (30 mil) thick and five acres in area, and a material with a volume resistivity of  $2 \times 10^{10}$  ohm-meter, Equation (1) gives a total liner resistance of 750 ohms. Thus, even though the resistivity of the liner material is high, the total series resistance due to the liner can be relatively small for a large facility. While Equation (1) is useful for estimates of liner resistance, it is inaccurate since the current density is very non-uniform over the liner surface in an actual facility.

An accurate analytical solution for potential and current flow is not possible for a realistic facility geometry and numerical methods must be used. An examination of the nature of solutions is, however, very useful in the development of the leak detection technique. The surface potential within the facility can be expressed in terms of the current density across the liner as:

$$V(r) = \frac{I\rho_1}{2\pi t} + \frac{(\rho_1 - \rho_2)}{2\pi} \iint_{S_L} \frac{J_n(r')}{R} da' - \frac{\rho_1 t}{2\pi} \iint_{S_L} J_n(r') \frac{\partial}{\partial n} \left( \frac{1}{R} \right) da \quad (2)$$

where:

$r$  = the distance from the current injection electrode (inside the facility) to the point on the surface at which the potential is measured

$V(r)$  = the potential at point  $r$  on the surface

$I$  = the total injected current

$r$  = the distance from the current injection electrode to the point of integration on the liner

$R$  = the distance between the potential measuring point  $r$  and the integration point  $r'$

$J_n(r')$  = the component of current density perpendicular to the surface of integration, i.e., liner

$S_L$  = the surface defined by the liner

$S_L$  = the surface  $S_L$  with leak areas removed

$\rho_1$  = the volume resistivity of material within the facility, i.e., liquid or solid waste

$\rho_2$  = the volume resistivity of the earth surrounding the facility

$\rho_L$  = the volume resistivity of the liner material

$t$  = the thickness of the liner

$n$  = a unit vector normal to the surface  $S_L$

The current density  $J_n$  which appears in the integrands of Equation (2) is unknown and is dependent upon the geometry of the facility, the resistivities of the materials inside and outside of the liner, and the position of the current injection electrode. Examination of Equation (2) reveals two important features of the electrical method. First, the influence of the liner on the surface potential decreases with distance from the measurement point if the same current density is assumed. Second, the influence of any portion of the liner on the surface potential is proportional to the current density crossing the liner at that point.

The current density crossing the surface  $S_L$  is dependent upon the effective resistance across that portion of  $S_L$ . The effective resistance across the surface, now assumed to be of thickness  $t$ , may be computed from Equation (1) if the area  $A$  is taken sufficiently small for the current density to be essentially constant. Considering two small areas, one containing liner material of resistivity  $\rho_L$ , the other a leak for which the resistivity is  $\rho_1$ , then, from Equation (1), the ratio of resistances is the ratio of the resistivities,  $\rho_L/\rho_1$ . The resistivities of typical liner materials are in the range  $1 \times 10^8$  ohm-meters to  $1 \times 10^{14}$  ohm-meters, while the resistivity of material within a facility will generally be 1 to 10 ohm-meters or less. It may, therefore, be concluded that in the vicinity of a leak, the current density crossing the liner will be many orders of magnitude less than the current density at the leak.

The surface potential at points above a leak will be significantly influenced by the shunting effect of the leak on the current density across the liner (Eq. 2). To obtain more precise information a numerical solution of the problem is required.

The first numerical model study used a general purpose circuit simulation computer program (SPICE). Circuits containing resistors, capacitors, inductors, and voltage and current sources

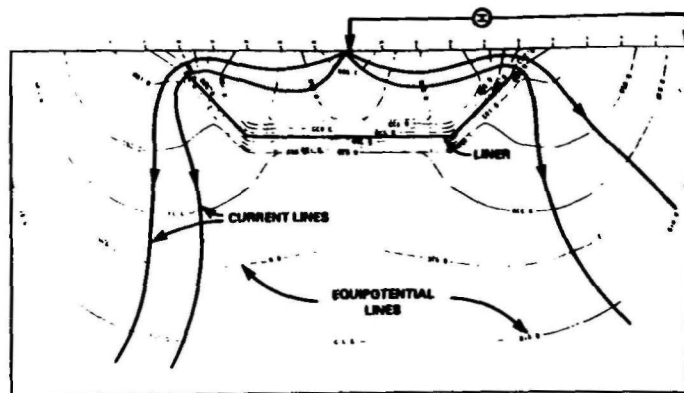


Figure 2.  
Computer-Modelled Vertical Cross Section of  
Waste Liner with No Leaks



Figure 3.  
The Waste Liner Physical Scale Model and  
Instrumentation Van

may be simulated with the program. A two-dimensional resistor network model designed to simulate a membrane liner is modelled using the program. The resistivity of the liner fill and the surrounding earth is modelled using normalized resistance values of one ohm. The insulating effect of the liner is represented in the model by using parallel 10,000-ohm resistors along the path of the liner. A leak (conductive path) in the liner is simulated by replacing one of the 10,000-ohm resistors in the liner with a 1-ohm resistor. The shunting effect of the surrounding soil across the liner edges is simulated by using two-ohm resistors at the surface. Current and voltage sources are used to inject current into the surface of the model.

The output of the model analysis is the voltage at each of the nodes connecting the sensor elements. These values are stored in an array which is then used in a second program which plots the results in the form of equipotential contours. A contour plot showing the two-dimensional potential distribution around a liner without leaks is shown in Fig. 2. The network used to model this cross section is a rectilinear array of 21 by 11 resistors for a total of 494 elements. The current injection point is at the top center of the figure with the other reference electrode connected to a conducting path along the bottom and sides of the cross section. This reference is far enough from the liner to be located at effective infinity. The outline of the liner has been sketched in the figure and is represented by the three-sided trapezoidal figure in the center of the plots. The equipotential lines showing the voltage distribution patterns were computer generated. The current flow paths are at right angles to the equipotential lines and were sketched in by hand. The current flow

over the edges of the liner and into the surrounding earth is illustrated in Fig. 2.

In parallel with the computer analysis work described above, a three-dimensional physical scale model was constructed in an outdoor environment where ground is used as the soil underlying the physical scale model. Fig. 3 is a photograph of the model and the instrumentation van. The 11 ft<sup>2</sup> framework is lined with a 6-mil polyethylene sheet. Shunt resistors on the edges couple the interior of the liner to the surrounding earth. To facilitate voltage measurements, most of the work to date has been done with water in the liner. Current is injected into the liner using a single electrode with the return electrode located approximately 300 ft away from the model. Various liner fill depths could be easily modelled by varying the depth of the water.

Surface voltages were measured with both potential measurement electrodes located in the basin. The potential reference electrode was fixed in position near one corner of the model. The exploration measurement electrode was composed of many electrodes mounted on a fiberglass beam at 2.5 in. spacings. Initially, data were taken on a rectangular grid but it was determined that better quality data could be acquired using a polar grid with the current injection electrode at the center.

Initially, a constant current source was used in the experiments. However, this device did not have the range of current needed for the measurements. Subsequently, a laboratory oscillator was used to supply a 25-Hz signal which was amplified by an audio power amplifier. The output of the amplifier was transformer-coupled to the current injection electrodes. A digital ammeter was used to monitor the 50-ma injection current.

The leaks in the bottom of the liner were generated by driving a 0.5 in. diameter copper-clad steel rod through the liner and into the soil. This rod provided a good conducting path between the water and the soil without loss of water.

In Fig. 4, a close-up of the fiberglass beam with the measurement and current injection electrodes in place is shown. Wave action around the current injection electrodes was found to cause problems in maintaining a stable constant current. For this reason, a PVC still-well was placed around the current injection electrode as seen in the photograph. Monofilament nylon lines were used to accurately locate the current injection electrode.

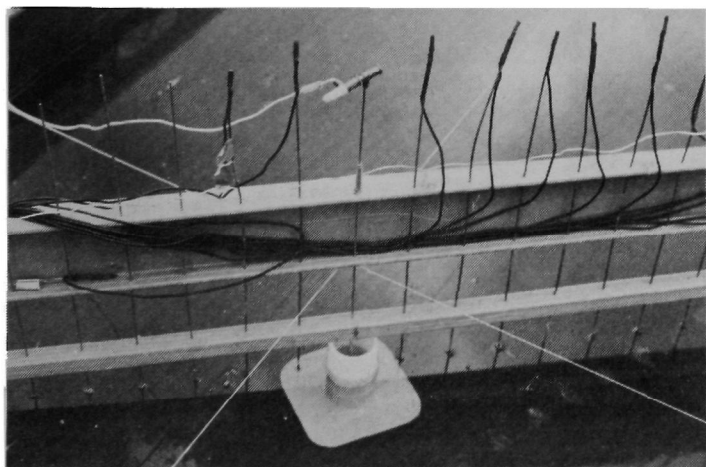


Figure 4.  
Close-up of the Current Injection Electrode and the Still-Well Used to Dampen Wave Effects

For one placement of the beam, data were acquired by making measurements at increasing radial distances away from the current injection electrode. The beam was then rotated by a specified angle about the current electrode position and another series of radial readings taken. Proceeding in this manner, measurements covering the entire model surface were obtained.

## EXPERIMENTAL RESULTS

In developing and employing the technique, it is important to know the electrical properties of the liner materials being used in landfills. Since the electrical parameters of liner materials are not provided by their manufacturers, a laboratory electrical test of samples of liner materials was performed. A sample of the measurements made on the materials is shown in Table 1. The resistivity values were calculated using measured values of resistance.

Table 1.  
Electrical Properties of Landfill Liner Materials\*

Sample Type	Thickness (mils)	Resistance (ohms)	Volume Resistivity (ohm-cm)
High Density Polyethylene (A)	55.0	$4.00 \times 10^{13}$	$2.86 \times 10^{16}$
High Density Polyethylene (B)	121.0	$3.25 \times 10^{13}$	$4.81 \times 10^{15}$
Polyethylene	6.0	$1.80 \times 10^{11}$	$1.18 \times 10^{15}$
Chlorosulfonated Polyethylene (A)	40.0	$3.20 \times 10^4$	$3.14 \times 10^{13}$
Chlorosulfonated Polyethylene (B)	36.0	$3.75 \times 10^{10}$	$4.10 \times 10^{13}$
Chlorosulfonated Polyethylene - nylon reinforced	34.0	$3.60 \times 10^9$	$4.16 \times 10^{12}$
Polyvinyl Chloride	29.0	$1.52 \times 10^4$	$2.06 \times 10^{11}$
Polyvinyl Chloride - oil resistant	30.0	$1.70 \times 10^4$	$2.23 \times 10^{11}$
Chlorinated Polyethylene	32.5	$7.20 \times 10^{10}$	$7.84 \times 10^{12}$
Chlorinated Polyethylene-reinforced	36.0	$6.70 \times 10^4$	$7.32 \times 10^{11}$
Urethane Asphalt	69.0	$2.20 \times 10^{11}$	$1.25 \times 10^{14}$

\*Area of samples = 100 cm<sup>2</sup> except High Density Polyethylene 45.5 cm<sup>2</sup> and Chlorinated Polyethylene (9.0 cm<sup>2</sup>)

The results of one of the computer generated two-dimensional analyses of a liner having a leak in the bottom are given in Fig. 5. The equipotential lines which appear in the figure were generated and plotted automatically by the computer program described earlier.

This result shows that, as predicted, when a leak penetration is present in the liner, current flow between electrodes located inside and outside the liner will follow two paths, namely, through the leak and around the buried edges of the liner. Note the non-symmetry of the equipotential lines terminating on the surface of

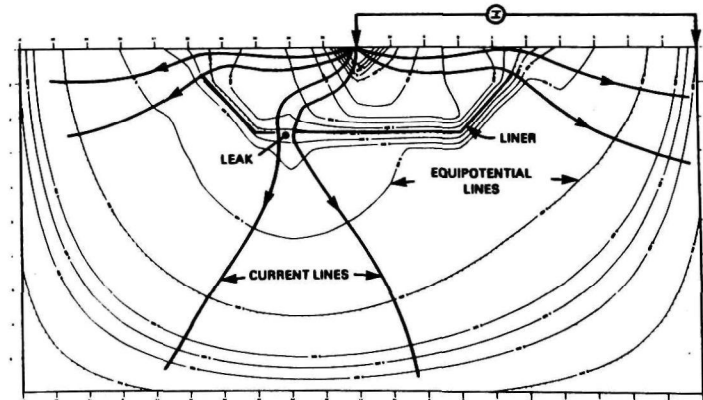


Figure 5.  
Computer Modelled Vertical Cross Section of a Waste Liner with a Leak in the Bottom

the landfill above the liner. The voltage gradient is clearly steeper along the surface on the side of the current injection electrode above the leak. Asymmetries such as this were investigated in subsequent work to develop field measurements which could locate liner leaks.

The relatively inexpensive nature of the two-dimensional computer model and its precise control make it a very productive method of investigating electrical testing concepts related to liner leaks. Even though it is a two-dimensional model that does not accurately simulate the three-dimensional volume of landfill or surface impoundment, the ability to accurately predict the potential distributions in various simulations of liner conditions makes it a valuable tool. The sensitivity of this model to a simulated leak is greater than for a true landfill condition because of the two-dimensional character of the model. Nevertheless, the results obtained are, in general, indicative of the full-scale equipment sensitivity requirements.

Examples of equipotential contours measured using the physical scale model are shown in Figs. 6 and 7. For both cases, a single leak was located at an arbitrary position in the bottom. For all plots, the current injection point is located at the center of the polar coordinate system.

The distortion of the equipotential lines in the neighborhood of the leak which is on the 340° radial is clearly shown in Fig. 6. A steep voltage gradient in the radial direction crossing over the leak distorts the equipotential lines.

A similar plot for a different current injection point is shown in Fig. 7. Again, the current injection point is at the center of the polar coordinate plot. An aluminum block was also placed between the current injection point and the leak. The same pattern of perturbed equipotential lines as observed in Fig. 6 can be seen in Fig. 7 about the leak. No observable distortion was generated by the introduction of the conducting block. Many data acquisition runs

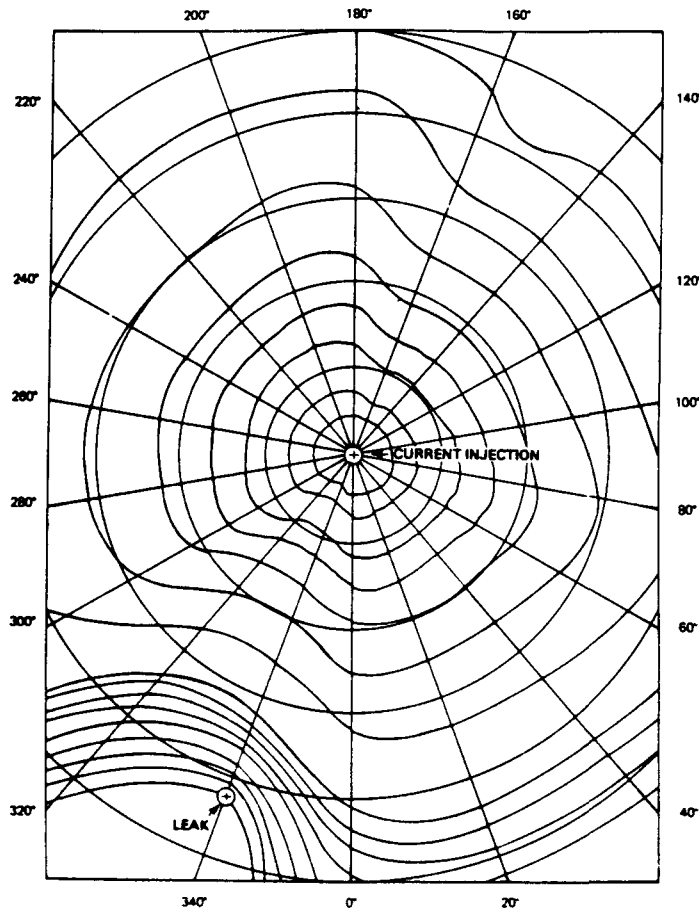


Figure 6.  
Equipotential Lines on the Surface of the Waste Liner Model with a Leak on the 340° Radial

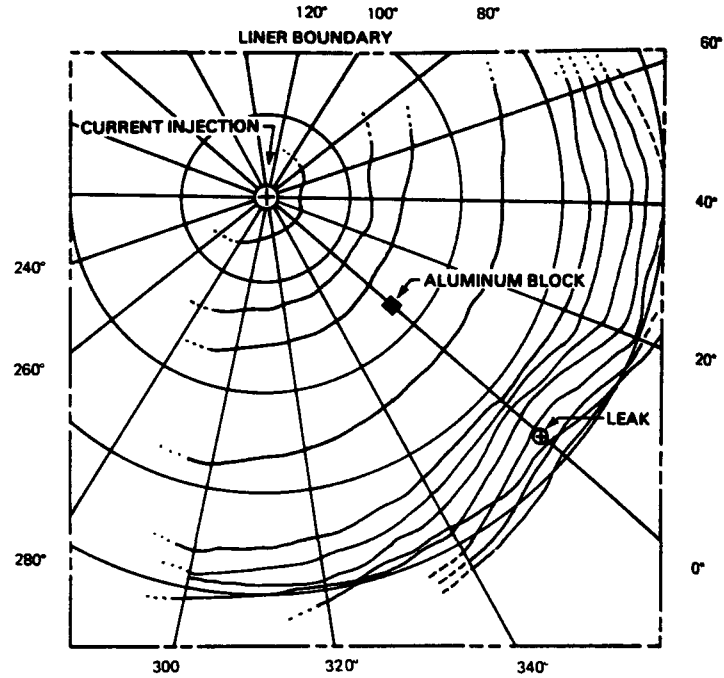


Figure 7.  
Equipotential Lines on the Surface of the Waste Liner Model with a Leak on the 0° Radial and a Conducting Anomaly Beneath the Surface

were conducted using different combinations of water depth, distance between current injection point, leak position, number of leaks, and conductive anomalies in the water. All of the tests resulted in similar types of equipotential plots in which the leak position could be accurately inferred.

Table 2.  
Data from 0° Radial

X(I)	Y(I)	Y(I)	RESIDUALS
10.00	3992.00	4004.88	-12.88
12.50	3581.00	3581.58	-0.58
15.00	3269.00	3235.71	33.29
17.50	2987.00	2943.29	43.71
20.00	2740.00	2669.98	50.02
22.50	2532.00	2466.55	65.45
25.00	2331.00	2266.68	64.32
27.50	2146.00	2085.87	60.13
30.00	1992.00	1920.81	71.19
32.50	1837.00	1768.97	68.03
35.00	1678.00	1628.39	49.61
37.50	1548.00	1497.51	50.49
40.00	1424.00	1375.08	48.92
42.50	1325.00	1260.07	64.93
45.00	1213.00	1151.64	61.36
47.50	1087.00	1049.08	37.92
50.00	985.00	951.77	33.23
52.50	883.00	859.22	23.78
55.00	798.00	770.97	27.03
57.50	702.00	686.64	15.36
60.00	611.00	605.91	5.09
62.50	516.00	528.47	-12.47
65.00	399.00	454.07	-55.07
67.50	283.00	382.47	-99.47
70.00	164.00	313.48	-149.48
72.50	90.00	246.91	-156.91
75.00	74.00	182.60	-108.60
77.50	51.00	120.40	-69.40
80.00	26.00	60.17	-34.17
82.50	14.00	1.80	12.20

A sample of data taken along one radial crossing over a single leak is presented in Table 2. This radial data was taken from the



results illustrated in Fig. 7. The X(I) column is the distance in inches from the current injection point. The corresponding voltage measurements (millivolts) are given in the column labeled Y(I). A logarithmic curve fit was made to these data with the general equation  $Y = a + b \ln(X)$ , resulting in the empirical relationship

$$Y = 8374 - 1897 \ln X. \quad (3)$$

A plot of this curve and the measured data are shown in Fig. 8. The effect of the leak is discernable at a radial distance of 72.5 in.

In the third column of Table 2, labeled Y(I), are the calculated values of voltage based on the fitted curve. The data in the column labeled RESIDUALS are calculated by taking the difference between Y(I) and (YI). At a radial distance of 72.5 in., a very noticeable perturbation caused by the leak occurs in the residuals column where it reaches a minimum value of -156.91. This data reduction technique will be used in the equipment design and data processing to extract the leak generated signatures from the field data.

Using the residual analysis described above on more than one radial line and plotting the analyzed results along the radials gives a contour plot as shown in Fig. 9. Here the physical scale model was configured with two leaks located on radials which were 40° apart. As observed in this figure, the region near the two leaks is clearly discernable from the closed contours which surround the two leak positions. The center of the contour on the left was above one of the leaks and the contour on the right missed the leak by about 5 in. In both cases, the leak targets were in the correct azimuth direction with only small errors in the radial distance. Additional measured values along other radials crossing the first will result in a more precise determination of the leak location.

## FUTURE WORK

The analytical and laboratory model studies of electrical liner testing completed to date have revealed some promising approaches for leak detection. Based on these results, specifications for field instrumentation are being established. Sufficient model testing has been completed to permit full specification of equipment operating characteristics, field requirements, data recording and data processing software.

To supplement the data base obtained to date using the water-filled physical scale model, similar tests are in progress using a soil-filled model. The inhomogeneities associated with this type of fill will better approximate the conditions anticipated at full-scale landfill sites.

At the conclusion of the work in progress, an experimental field system will be assembled for performance demonstration testing and verification of data acquisition precision. The system operating

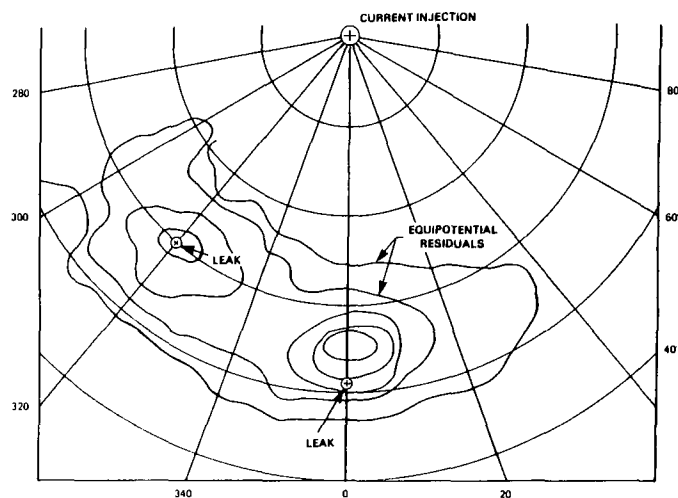


Figure 9.  
Polar Plot of the Residuals Calculated by Taking the Difference Between the Field Data and Logarithmic Fitted Curves. The Leaks Shown Are on Radials Separated by 40°

functions will be implemented using a desktop computer and a digital data recording system. The system will be semi-automatic in that several electrodes will be laid out in advance and automatically scanned and read by the computer. Software written for the computer will be used to process the data in the field to generate plots similar to those obtained in the model studies.

After completion of the system assembly, a field test plan will be developed based upon information describing existing landfill sites and surface impoundments utilizing polymeric membrane liners. Candidate sites will include liners with and without leaks if possible.

## CONCLUSIONS

Computer modelling of electrical techniques of leak detection in liners was successful in proving the fundamental concepts needed to develop a practical system for finding liner leaks in hazardous waste facilities. Two-dimensional analysis provided valuable insights into current flow patterns and equipotential patterns associated with liner geometry and leaks.

The computer work also provided the foundation for the physical scale model studies which were used to generate scaled measurements simulating ideal facility liners with leaks. Equipotential plots of the voltages measured on the surface of the model showed leak-dependent patterns which may be used to locate the leaks. The model studies showed that multiple leaks may also be resolved and that anomalies such as blocks of conductive material buried near the search area do not have a serious effect on the field data. Parametric studies of surface effects versus depth showed that the surface perturbations are reduced for greater fill depths. However, measurable potential patterns in the leak regions still generate useful information which can be used to locate the leaks.

The results of this investigation are very encouraging in regard to the feasibility and usefulness of a practical leak detection and location system. This technique appears to show promise for detecting and locating membrane liner leak paths for new as well as existing landfills and surface impoundments. Future field tests will help verify the system capabilities and the conditions where the most reliable data are produced.

## ACKNOWLEDGEMENTS

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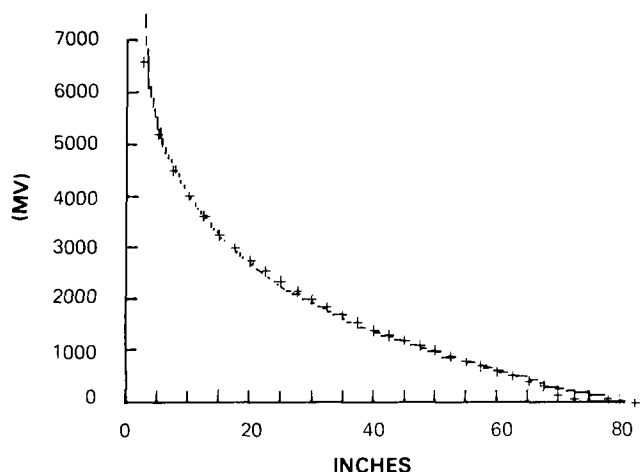


Figure 8.  
Logarithmic Curve Fit for the Data Taken on a Radial Crossing Over the Leak

# EVALUATION AND USE OF A PORTABLE GAS CHROMATOGRAPH FOR MONITORING HAZARDOUS WASTE SITES

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## INTRODUCTION

The imminent threat posed by the continuing discovery of abandoned hazardous waste dumpsites requires the development of rapid and effective on-site chemical analysis techniques to assess the extent of environmental contamination and monitor ensuing clean-up efforts. The USEPA recently evaluated the practicality of using a light weight shoulder-borne gas chromatograph (GC) to monitor potentially hazardous atmospheres at chemical spills and waste chemical dumpsites. The instrument evaluated was the Model 128 Century Organic Vapor Analyzer (OVA) equipped with a flame ionization detector (FID), which is manufactured by the Foxboro Corporation, Burlington, Mass.<sup>1,2,3,4,5</sup> The technical evaluation of this portable unit was a joint venture on the part of USEPA's Environmental Response Team (ERT) and the Oil and Hazardous Materials Spills (OHMS) Branch of the Municipal Environmental Research Laboratory.

In this paper, the authors address several important aspects of their evaluation of the OVA-GC including: instrument operating performance parameters (i.e., detection limits, column efficiency), QA/QC considerations (i.e., accuracy, reproducibility, linear dynamic range), associated operational difficulties and recommended field uses. Analytical methods and specialized techniques developed in the OHMS Branch for the specific use with the OVA-GC were essential to this instrument's evaluation and are contained herein.

The ERT has employed this portable unit during numerous field activations involving hazardous waste storage sites and chemically contaminated lagoons. Successful field applications of the OVA-GC has also involved support to mobile laboratory activations involved with monitoring the effectiveness of waste treatment systems for removing organic contaminants from surface waters, leachates and sediments.<sup>6</sup>

## DESCRIPTION OF UNIT EVALUATED

Several important features of the Model 128 OVA-GC include its ability to: (1) continuously measure the total level of FID detectable organic vapors in ambient air, (2) screen high levels of organic vapor concentrations in environmental samples to protect sensitive analytical instrumentation (i.e., GC/MS) from detector contamination, and (3) generate integrated sample analyses from chromatograms of organic vapors in air mixtures.

The OVA-GC offers both manual and automatic injection capabilities. The manual injection mode requires direct, gas-tight syringe injection through a septum, while automatic injections make use of a positive displacement injection valve incorporated within the instrument. An instrument backflush valve functions to flush from the GC column any high molecular weight organics that may be trapped after a sample run. The column is externally mounted, thus being exposed to ambient temperature conditions during normal use. An accessory for maintaining constant column temperature is available from the manufacturer of the OVA unit.

An instrument output meter serves to indicate, in ppm units, the concentration of total organic vapors in contaminated air mixtures. In the GC mode of operation, a strip chart recorder supplies a chromatogram of the detector output signal.

## INSTRUMENT START-UP

The initial start-up of the OVA-GC requires only 15 min, and this operation includes recharging of the hydrogen supply tank. Hydrogen functions as a fuel for detector combustion and serves as the carrier gas for the GC mode of operation. The instrument is operable in either a portable mode, drawing from a built in battery power source (DC voltage), or in a stationary mode, drawing from a 120V, AC power supply. The instrument is also equipped with a battery charging unit which requires a 24 hr period to fully charge the internal battery pack. A complete battery charge will allow 8 hr of OVA operating time.

Since the detector flame has been ignited, time must be allowed for the output meter attachment and the recorder to stabilize. Usually this can be achieved within one hour, although several days may be required depending on the frequency of use and the degree of instrument and/or detector contamination. A stable baseline in an atmosphere free from organic solvents and combustion processes (i.e., automobile exhaust) will read between 3 and 4 ppm on the meter attachment.

## TEST ATMOSPHERES

Test atmospheres are used to generate data on chromatographic resolution, retention times, linear dynamic ranges, and detection limits of compounds for which the OVA-GC will be used to analyze. There are many techniques by which these test atmospheres can be obtained.<sup>7</sup> Comparisons between a variety of techniques (i.e., dynamic systems vs. static systems) were made in order to judge the most suitable methods for use with the OVA. These comparisons were based on: accuracy and precision, time, cost, complexity, portability, and space requirements.

### Vial Dilution

Test atmospheres can be obtained by using methods of preparation in the field or laboratory. During the course of this instrument's evaluation, the OHMS Branch developed a method whereby known concentrations of materials in the gaseous phase could be accurately prepared. This method is that of vial dilution.

Initially, a gaseous stock vapor solution must be prepared. This is done by dispensing a small volume (i.e., 5-10  $\mu$ l) of an organic liquid contaminant into an empty septum sealed 43 ml glass vial. A small volume of liquid is used to insure that the contaminant will fully vaporize in the vial's air space. Known parameters of saturation coefficients, vial volume, specific gravity of material, volume of dispensed material, temperature and pressure are used to accurately determine the concentration of material in the vial in  $\mu$ g/m<sup>3</sup> or ppm.<sup>8</sup> A dilution sequence may then be prepared by

extracting known volumes of vapor via gas tight syringe from the stock vial's air space. This method is extremely rapid, inexpensive, easy, portable, accurate, and reproducible.

### Premixed Canisters

Test atmospheres can be purchased in commercially available, multi-component canisters at known and accurate concentrations. A vendor will prepare desired mixtures of volatile organic components at prescribed concentrations. Simple mixtures of volatile organics can provide multiple internal standards for field use if the individual components contained in the canister have been previously analyzed to insure concentration accuracy. A syringe adapter can be fitted to the canister to allow withdrawal of contaminants in microliter quantities (via syringe) thus avoiding personnel exposure to hazardous components. This method offers high accuracy and precision, is simple, rapid, and portable but is the most expensive of the three techniques discussed.

### Headspace Analysis

Headspace analysis was a technique introduced to the OHMS Branch by Dr. Thomas Spittler (USEPA Region I).<sup>2</sup> Analytically, head space analysis is used to indirectly determine the level of water contamination due to volatile organics by directly determining the concentration of vapors in the air space above a contaminated water sample.<sup>9</sup>

The headspace technique can be utilized for the preparation of test atmospheres. This is accomplished by first preparing a saturated solution consisting of pure water and one known liquid contaminant at equal volumes. This solution can then be stored in a 40 ml crimp sealed glass bottle. A series of saturated water solutions, each containing a different organic compound, is prepared in the same manner.

A dilution of the saturated water solution(s) is made by withdrawing a known volume of its water phase via microliter syringe and injecting the syringe contents into a second known volume of pure water. The contaminant(s) then imparts(s) a gas phase/liquid distribution coefficient specific to each contaminant diluted into the second vial. The air space of the diluted vial is then analyzed by the OVA-GC. Quantification indirectly related the concentration of the contaminant in air to its concentration in water.

The accuracy of this method is dependent upon: (1) the accuracy of the published saturation coefficients, (2) the ability of each material in a multi-component mixture to exert its own vapor pressure and not effect the other materials present (i.e., Henry's Law), and (3) the human accuracy of dispensing accurate volumes of vapor and liquid via syringe.

The technique of headspace analysis can also be utilized when monitoring soil samples for suspected contamination. However, difficulties in preparing standards of known accuracy and precision in a soil media exist, thus the method results in less than accurate quantitative measures of volatile organics in the soil.

### CALIBRATION

The OVA-GC must be calibrated prior to each field usage to insure the validity and precision of obtained results. Calibration is accomplished by measuring at least three accurately known concentrations of methane in air across the GC attenuation settings (i.e., 1X, 10X, 100X). These concentrations of methane can be obtained in small (i.e., hand held) commercially available, pressurized canisters. A gas sampling bag (i.e., a Mylar or Tedlar bag) is then attached to the OVA sampling probe using an inert flexible tubing. The standard mixture is drawn from the bag and a direct continuous reading (in ppm) is obtained from the output meter. Adjustment of the OVA's potentiometers calibrates the instrument to the desired output meter reading.

Internal standards can be used to identify day to day changes in detection limits and retention times when the OVA-GC is used in the field. Any of the three methods mentioned under the Test Atmospheres heading on page 4 may be used. The most practical method is that of vial dilution.

## INSTRUMENT PERFORMANCE—GC MODE

### Reproducibility

Reproducibility of GC peak heights and retention times was investigated for both the syringe and the automatic injection valve modes of the VOA. Difficulties were encountered when the instrument was operated in the automatic injection valve mode, with non-reproducible peak retention times (i.e., CV\* = 6-12%) resulting.<sup>8</sup> These unacceptable retention time (RT) results were traced to an instrument malfunction. Syringe injection, however, yielded acceptable peak retention time reproducibility (i.e., CV = 1-3%) when using the same "malfunctioning" instrument. Following instrument repair by the manufacturer, both automatic valve and direct syringe injection yielded acceptable reproducibility (i.e., CV = 1-4%). These findings suggest that: 1) the automatic injection valve mode should be used with caution when attempting component identification, and 2) adequate GC peak retention time reproducibility should be established prior to operation in either sampling mode.<sup>1</sup>

Early results in this evaluation revealed that the reproducibility of peak heights is affected by whether the backflush valve is in the up or the down position. Investigation of the significance of the backflush valve position indicated that a backflush valve in the up position correlates with the largest peak height values. Thus, in this evaluation, the backflush valve was fixed in the up position for all sample runs. Verification of GC peak height reproducibility for quantification purposes using both sample injection modes yielded equivalent results (i.e., CV less than 5%).

The stability of relative retention times (RRTs) and absolute retention times (ARTs) when subject to moderate temperature change was also evaluated. A comparison of results revealed that, over a 30° C temperature range, the reproducibility of RRTs for several test compounds was in the range of 5-10% CV, while CV values for ARTs of the same test compounds were in excess of 50%.<sup>1</sup>

### Accuracy

Determinations on the accuracy of the linear dynamic Range (i.e., concentration vs. response) of the OVA detector was performed using benzene and carbon tetrachloride.<sup>10</sup> Benzene gave the largest detector response of the hazardous compounds studied in terms of peak heights per concentration unit. Carbon tetrachloride yielded the smallest peak height per concentration unit (Table 1).

The linear calibration range (0.7 ppm-165 ppm) and the associated calibration errors determined for benzene are shown in Table 2. The highest calibration solution concentration used was 165 ppm which is sufficient for ambient air analyses. The largest calibration error for benzene was found to be 25% at the detection limit and a calibration error of 14% was determined at the highest concentration value. Calibration error values between these limits did not exceed 9%.

**Table 1.**  
**OVA Gas Chromatographic Analysis Parameters for Test Compounds**  
**Benzene and Carbon Tetrachloride.**

Analysis Parameters	Benzene	Carbon Tetrachloride
Ambient Temperature	25°C	28°C
Retention Time	1.77 min	1.53 min
Column	G-24**	G-24**
Injection Mode	Syringe	Syringe
Injection Volume	250 µl	250 µl
Injection Valve	Up	Up
Backflush Valve	Up	Up
Attenuation	0-3 ppm @ 1X 73-166 ppm @ 10X	0-67 ppm @ 1X 100-548 ppm @ 10X
Flow Rate	Factory Set @ 2 (l/min)	Factory Set @ 2 (l/min)

\*The packing material for a G-24" column is 10% SP-2100 on 60/80 mesh supelcoport.

\*ACV (coefficient of variation) of 5% or less is considered acceptable by the OHMS Branch for the purpose of validating reproducible data.

**Table 2.**  
**Linear Calibration Range and Detection**  
**Limit Established for Benzene**

Detection Limit	0.70 ppm				
Linear Calibration Range	0.74 ppm - 164.50 ppm				
Calibration Solution Concentrations (ppm)	0.74	1.47	2.94	73.57	164.5
Mean Peak Height (mm)	3.0	5.0	9.8	22.5	45.8
%C.V.	0.0	0.0	3.3	4.2	0.5
%Calibration Error	25	5	—	9	14

**Table 3.**  
**Linear Calibration Range and Detection Limit**  
**Established for Carbon Tetrachloride**

Detection Limit	8.0 ppm				
Linear Calibration Range	8.0 ppm-547.5 ppm				
Calibration Solution Concentrations (ppm)	8.0	39.72	67.11	273.90	547.80
Mean Peak Height (mm)	5.83	22.83	42.75	166.75	308.13
%C.V.	4.9	2.5	1.8	1.7	1.4
%Calibration Error	19	7	—	3	10

Linear calibration range (8 ppm-547 ppm) and the associated calibration errors for carbon tetrachloride are given in Table 3. An upper concentration limit of 547 ppm is more than sufficient for ambient air analysis. The largest calibration error was 19% at the detection limit and a calibration error of 10% was determined at the highest concentration value. Calibration error values between these limits did not exceed 7%.

#### Detection Limit

The detection limit of the OVA-GC is a function of the test compounds detector response relative to that of the calibrant gas, which in this case is methane. When analyzing for a compound other than methane, the resulting detector response will be either higher or lower than that response generated by an equal concentration of methane.

Detection limits of many hazardous volatile organics have been determined for the OVA, and were found to range from 700 ppb for benzene to 8 ppm for carbon tetrachloride (Tables 1 and 2). Unbranched alkanes were found to yield an even more sensitive detector response than did benzene.

#### Column Efficiency: Ambient Conditions

The types of columns used in the evaluation of the OVA were the G-24" (Table 1), T-12", G-8", and T-8". The shorter columns (i.e., 8 in) were incorporated with a temperature control pack assembly that is available from the manufacturer. The G-24" column had the widest range of application based on the materials studied in this evaluation. Column selection would be based on the desired application of the OVA unit, in terms of compound resolution and retention times (RTs).

The manufacturer of the OVA-GC does not test column performance by using quantifiable techniques, such as theoretical plates and resolution data. Therefore data accumulated on retention times, detection limits, and chromatogram resolution could differ for columns having equivalent parameters, and also from data published by the manufacturer.

When analyzing for a simple mixture of volatile organics in an unknown atmosphere, problems may arise with regard to the resolving ability of the OVA-GC column. For example, compounds with the same or nearly the same RTs could not be resolved from one another, but rather a blending of retention times resulted. Thus compound identification, both qualitatively and quantitatively, become extremely difficult. In addition, when analyzing a mixture with two compounds having nearly the same RTs, the

RT values were found to shift from the expected values (i.e., the RTs became closer to one another). Again, compound identification becomes confounded.

Variation of column length did not significantly improve compound resolution. The maximum column length that can be used with the OVA is 4 ft; use of a column of greater length will result in failure of the detector flame to ignite.

#### Column Efficiency: Thermally Controlled

Constant column temperature can be maintained by using an accessory which consists of a screw-top Nalgene canister, inside of which is an 8 in column encased in an insulating, solidified foam. Column temperature can be controlled by using a metal slug which has been oven heated to a known temperature above ambient conditions. For subambient temperature conditions the manufacturer supplies a screw top plastic cap to be used in place of the metal slug. The cup can be filled with ice, which is then placed into the holding compartment of the Nalgene canister. The ice cup theoretically provides a column temperature of 0 °C.

The disadvantages of the thermal control accessory are: 1) accurate measurements of column temperature over time cannot be performed, 2) teflon line connectors are attached from the insulated column to the column connector fittings outside of the OVA unit. These teflon connectors are easily crimped when field surveys are performed, aside from bench use, 3) due to the short, 8 in. column there are a greater number of compounds that exhibit similar RTs.

#### PERFORMANCE: TOTAL ORGANIC MODE

Interpretation of a total organic vapor concentration from the OVA must be exercised with caution, however it appears possible to use the total organic vapor monitor for the purpose of assuring that airborne organic levels do not exceed prescribed concentrations.<sup>4,9,11</sup>

Concentrations, in ppm, of non-methane compounds in the ambient air are registered on the output meter assembly of the instrument. These concentrations are not direct summations of all individual organic contaminants in the air being sampled; rather, the concentration (in ppm) represents a summation of the percent relative response values characteristic of each individual organic compound in the sample. A reasonable estimate of the total organic vapor concentration in the air can be determined if the qualitative composition of organic vapors in the atmosphere is known, and if the detector weighted response for each compound in an air mixture is known.

#### RECOMMENDED USES FOR THE OVA-GC

The ERT has used the OVA-GC during field activations at many incidents where hazardous wastes were involved. The portable GC has been applied to various situations, ranging from chemically contaminated lagoons, to waste chemical (55 gal) drum storage sites. Based on a variety of field experiences, the ERT recommends the following limited applications for the OVA.

The OVA can be applied as a means of monitoring water and soils for low molecular weight organics by using the method of headspace analysis.<sup>11</sup> Various ERT activities (e.g., Epping, NH) have involved treatment of the contents of chemically contaminated lagoons using a mobile activated carbon treatment trailer and other treatment systems. Here, the headspace method functioned as a means of screening influent and effluent samples prior to their analysis by sensitive bench instruments (i.e., GC/GC/MS), thus helping to prevent laboratory instrument downtime as a result of detector overload. This monitoring method can be rapidly performed, and has proven to be a helpful and inexpensive means of assisting in laboratory analyses.

Monitoring of ambient air at 55 gal drum waste storage dumpsites yielded unexpected results. This application did not record significant levels of volatile organic contaminants unless the OVA

sampling probe was placed within inches of an opened drums bung hole.<sup>9</sup> When monitoring soils contaminated by chemical spills, the same placement of the OVA probe was necessary.

## CONCLUSIONS

Application of the OVA-GC for ambient air monitoring yields best results if the atmosphere being tested is of known volatile organic composition.<sup>11</sup> When the composition of the atmosphere is unknown, both qualitative and quantitative interpretations suffer severely.

To insure proper instrument operation, the reproducibility of RTs must be evaluated through the use of the automatic injector valve. This is accomplished by using any static test atmosphere preparation where dilution of the test atmosphere is not a problem. For example, use of Mylar or Tedlar bags is ideal for this type of instrument check.

An excellent means of preparing internal standards for field application is to generate static test atmospheres using the vial dilution technique. Another way to obtain internal standards is to purchase commercially available multi-component canisters at prescribed concentrations in an air medium. Both methods are accurate, and in addition, the risk of personnel exposure to hazardous compounds is minimized.

Headspace analysis offers an excellent technique for monitoring contaminated waters and soils for low molecular weight organics.<sup>2,3,11</sup> This method functions adequately as a screening device, protecting sensitive analytical instruments from detector overload. Also, headspace analysis can be used as a method to monitor the removal efficiency of low molecular weight organics as applied to the use of carbon treatment systems or other systems designed to remove organics.

It is recommended that, when the OVA-GC is to be applied for qualitative analysis, RRTs be used rather than ARTs. It was found the RRTs yield more precise results in the event of temperature changes and instrument instabilities.<sup>1</sup>

## ACKNOWLEDGEMENTS

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# THE USE OF PORTABLE INSTRUMENTS IN HAZARDOUS WASTE SITE CHARACTERIZATIONS

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## INTRODUCTION

Over the past several years, USEPA, state agency and private contractor personnel involved in hazardous waste site investigations have been employing portable field instruments to assist them in their work. In the New England region, the USEPA and a national EPA contractor, Ecology and Environment, Inc. (E & E), have applied the use of several portable instruments to a wide variety of hazardous waste site situations and activities. This variety of field experience has provided an opportunity to thoroughly evaluate the utility and reliability of the instruments used, and further, has stimulated the development of several innovations which have enhanced the capabilities of the instruments.

The utility of the instruments described herein is primarily based upon their capability for detecting volatile organic compounds, which, because of their wide industrial, commercial and household use, are found to be associated with a large majority of hazardous waste sites. The instruments for which a number of applications will be described include the following: the HNu Systems PI 101 Portable Photoionizer, the Century Systems (Foxboro) Organic Vapor Analyzer (OVA) and the Photovac, Inc. 10A10 Portable Photoionization Gas Chromatograph.

As the focus of work at hazardous waste sites across the country has progressed from the site discovery and investigation phase to the remedial investigation and clean-up phase, the application of portable field instruments has evolved as well. Where the initial uses of portable monitoring instruments were focused upon personnel safety and gross site characterization, the development of some new techniques has enabled the use of portable instruments to become invaluable during remedial investigations and a variety of remedial response activities.

Two areas of remedial activities which are greatly enhanced by portable instrument use are data base acquisition and cost-effectiveness. By employing a variety of field analytical techniques, the amount of data, especially real-time data gathered during remedial activities, can be significant and in some cases, even crucial. Also, cost-effectiveness is achieved since portable instrument use reduces laboratory costs and by providing virtually instantaneous data, can reduce the costs of associated remedial investigation techniques, such as groundwater monitoring well installation. The wide variety of applications to which field instruments have been put by USEPA and E & E investigators in the New England region is summarized in Table 1.

For the majority of applications listed in Table 1, field analysis is where the development of innovative techniques has been most significant. The development of field analytical techniques adapted to instrument design has enabled the list of instrument applications to be greatly expanded. Qualitative and quantitative analytical techniques have been developed and tested under a variety of field conditions and have proven to be reliable, cost-effective and invaluable.

In addition, efforts have been directed at providing a high degree of support and information to other field personnel in order to

Table 1.  
Summary of Portable Field Instrument Applications for Hazardous Waste Site Investigations

Type of Investigative Activity	Applications
Spills/Incident Response	<ul style="list-style-type: none"><li>•Determination of level of personnel/respiratory protection</li><li>•Determination of extent of impact on soil, water and air</li><li>•Evaluation of clean-up/containment effectiveness</li></ul>
Site Discovery/Initial Characterization	<ul style="list-style-type: none"><li>•Determination of level of personnel/respiratory protection</li><li>•Determination of extent of contamination in soil, water and air</li><li>•Identification of potential sampling points and waste container contents</li><li>•Preliminary screening of multi-media samples; provision of rapid documentation of site-related problems</li><li>•Rapid identification of immediate or imminent threats to the public health</li></ul>
Remedial Investigation/Response	<ul style="list-style-type: none"><li>•Determination of level of personnel/respiratory protection during a variety of remedial activities including excavation, transfer, removal, etc.</li><li>•Hydrogeologic investigations—development of depth vs. contaminant concentration profiles, prevention of accidental well contamination</li><li>•Monitoring of performance standard levels for a variety of remedial activities, such as groundwater treatment, e.g., monitoring effluent from carbon filtration, monitoring air quality near air stripping towers, etc.</li></ul>
Ambient Air Monitoring: Real-Time and Time-Integrated	<ul style="list-style-type: none"><li>•Development of real-time data to assist in placement of time-integrated sample stations</li><li>•Development of real-time data during time-integrated sampling to refine interpretation of time-weighted data</li><li>•Generation of data under a variety of meteorological conditions without costly laboratory analysis.</li></ul>

increase the utilization of these field analytical techniques. To this end, a comprehensive field applications manual has been published and several week-long national training courses have been conducted in order to provide the degree of knowledge required to utilize the instruments beyond their "classical", or more obvious applications.

To illustrate the range of applications to which portable field instruments can be put, the authors briefly describe in the next section the field analytical techniques which have been developed. This section will be followed by several site case studies in which

the techniques were applied. The presentation of the techniques prior to the case studies is intended to foster a clearer understanding of the full capabilities of the instruments as applied to the case studies.

### INNOVATIONS FOR PORTABLE INSTRUMENT USE

Several innovations which augment the capabilities of portable field instruments have been developed and field-tested. These innovations include techniques for preparing and using qualitative/quantitative field standards, rapid screening of samples of a variety of media, and the development of a field operator support program which includes an applications manual and a training program. The following sections will summarize these innovations.

#### Field Standards

Two of the portable instruments which have been thoroughly evaluated and field tested are portable gas chromatographs (GCs). In order to identify and quantify compounds detected by the GCs, it is necessary to have standards available. One must also be able to prepare aqueous or vapor standards, depending upon the medium being analyzed.

Quantitative standards for many organic solvents can be prepared quite rapidly from a saturated aqueous solution. The saturated solutions are prepared by placing several milliliters of the pure solvent with an approximately equivalent volume of water into a septum vial. A quantity of mercury may also be placed in the vial to provide a seal for multiple punctures of the septum. The solutions are then allowed to reach equilibrium. Depending upon the density of the solvent, the saturated aqueous layer will occupy the upper or lower portion of the container (Figure 1).

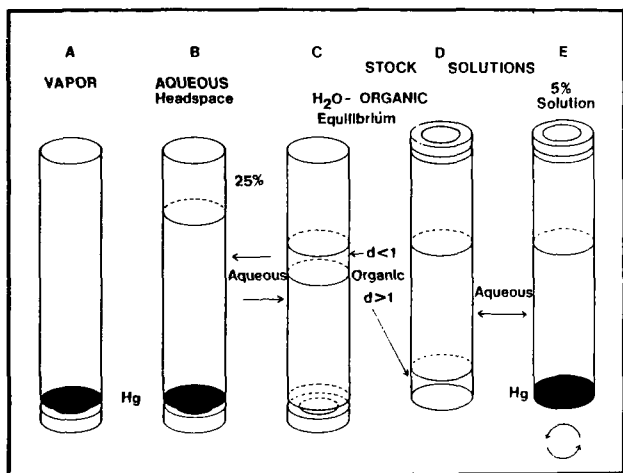


Figure 1.  
GC Standards

"A" (Fig. 1) represents a vapor standard which can be prepared either by placing a small quantity of pure solvent (taken from the pure organic layer of the original standard) in the vial and calculating the vapor concentration for the evaporated solvent, or by removing headspace vapor from a stock bottle of pure solvent and calculating the desired vapor concentration from the equilibrium vapor pressure value. "B" represents an aqueous secondary standard which can be prepared for headspace analysis by diluting aliquots of the saturated aqueous layers taken from stock solutions (standards) "C, D and E." "C and D" represent stock solutions of an organic solvent having a density less than one, and a density greater than one, respectively. "E" represents a stock solution for a solvent which is readily soluble in water, such as methyl ethyl ketone.

By using the solubility value of the solvent in water as the concentration of the aqueous layer, aliquots of the aqueous layer can be used to prepare standards of the desired concentration. Refer-

ences such as the *CRC Handbook of Chemistry and Physics* report that many of the solvents are insoluble in water. A search of other literature reveals that the actual solubilities may range from a few hundred parts per million (ppm) to several thousand ppm.

Since the portable GCs employ columns which are at ambient temperature, only vapor injections may be made. Both the aqueous samples obtained in the field and the standards prepared in the manner described above are analyzed by using the headspace vapor technique. The technique is based upon the fact that an equilibrium is reached between the solvent dissolved in the aqueous phase and the solvent present in the vapor phase (headspace), with the concentrations being directly proportional. Since the quantitative standards are also prepared for headspace vapor analysis, the use of this technique allows easy standard preparation and enables concentrations to be established in the field. The reliability of this standard preparation method has been supported by laboratory trials in which standards prepared in this manner were used to analyze spiked samples by gas chromatograph/mass spectrometer (GC/MS). The concentrations determined were well within acceptable limits. In addition, a large number of samples analyzed under field conditions have been compared to duplicate samples analyzed in the laboratory by GC/MS. Agreement among the data has been excellent.

Qualitative standards for compound identification in the field can also be easily prepared for use in headspace analysis. For example, a mixture of commonly encountered chlorinated solvents can be prepared from the stock saturated aqueous solutions. Prior to going into the field, the retention time order of the compounds in the mixture can be established on several GC columns. Once in the field, a single injection of headspace vapor from this mixture can provide retention times under field conditions for the compounds in the mixture, and the retention times compared to those of compounds which are found in field samples. By using mixtures of other commonly encountered solvents, e.g., a mixture of aromatics, it is possible to very quickly establish tentative identifications of compounds present in the samples. Confirmation is achieved by running the samples and standards on several different columns. A schematic representation of a chromatogram obtained by injecting headspace vapor from a chlorinated solvent mixture is shown in Fig. 2.

#### Sample Screening

It has been the experience of New England region USEPA and E & E personnel that volatile organic solvents are associated with

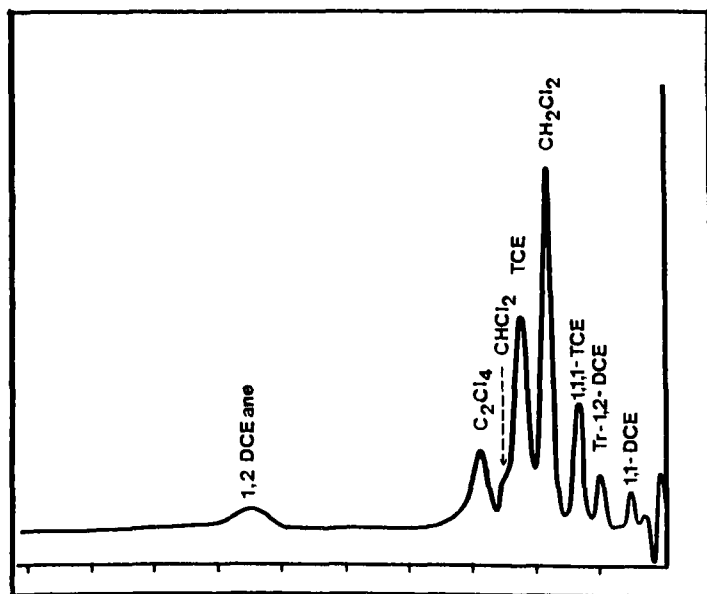


Figure 2.  
CHCl Mix on Col. T-24 50 1x 2v c.s. 2cm/min

the large majority of hazardous waste sites. Even if volatiles are not the predominant waste type at a site, the detection of volatiles may be the first indication that a waste disposal problem exists, since their physical properties cause them to migrate in soil, air and groundwater more rapidly than other types of contaminants.

Obviously, where specific information indicates the presence of non-volatile wastes (e.g., oil, PCBs, creosote, inorganics, etc.) a different approach is indicated. However, the widespread presence of volatile wastes presents an opportunity to use portable instruments capable of detecting these compounds to obtain a large amount of data very quickly and without the costs associated with laboratory analysis.

The two portable instruments which lend themselves exceptionally well to being used for screening samples for volatile organic compounds are the OVA and the Photovac, Inc. portable GC. The OVA is equipped with a valve arrangement which allows a headspace vapor sample to be injected directly to the flame ionization detector (FID). The response of the instrument allows a rapid determination if volatiles are present in the sample. Use of this technique will permit 30-40 samples per hour to be processed. Samples showing the presence of volatiles are then analyzed by changing the valve arrangement so that injections are made onto the GC column. Chromatograms are recorded and the analyses are carried out using the qualitative/quantitative standards described in the previous section. Samples of a variety of media, including air, soil and water, may be screened in this manner.

The Photovac, Inc. portable GC is best applied to screening samples where low  $\mu\text{g/l}$  concentrations of volatile compounds are anticipated. This would include the screening of drinking water samples obtained downgradient from a contamination source where dilution may reduce concentration; or where the leading edge of a contamination plume may be present. Ambient air samples obtained off-site may also typically show contaminants in the low ppb concentration range.

The Photovac GC utilizes a highly-sensitive photoionizer detector (PID) which will respond to a wide variety of organic compounds. This unit may be fitted with two options which permit rapid screening of samples prior to analysis. One option is a back-flush valve which allows carrier gas flow to be reversed. Thus, a sample aliquot may be directed straight to the detector upon injection, so that the response to the presence of total volatiles may be recorded. A second option is a dual column arrangement which permits samples to be initially screened on a short column to determine the general nature of contaminants present, without requiring an inordinate amount of time between injections. Samples thus screened are analyzed further on an appropriate longer column, if the preliminary screening indicates the presence of volatile contaminants.

The HNu portable photoionizer may also be used to a limited degree to screen samples. The probe of the instrument may be inserted into the headspace of a sample jar and the total response noted. Compound identification is not possible and the total response is usually reported as benzene equivalent.

In summary, sample screening with portable instruments can provide a great deal of data in a short period of time and at low cost. The data obtained from this process can be used to select sampling points for detailed laboratory analysis. In addition, the availability of data to field personnel can enable them to narrow or broaden the scope of their efforts as the work progresses. This is especially useful during such work as hydrogeologic investigations—an application which will be illustrated in a case study.

#### Field Chemist Support Program

The portable instruments described herein are widely used throughout the country by USEPA, state and contractor personnel. This is especially true of the HNu photoionizer and the OVA, which had been used for several years in industrial applications prior to adaptation to hazardous waste site work. As part of an effort to disseminate the information about the techniques developed in New England, a week long training program was de-

signed jointly by EPA and E & E. The program provided practical, hands-on instruction in the techniques described in the previous sections. The primary objective was to increase the number of field chemists who are aware of the full range of capabilities of portable instruments. The program was conducted on two occasions and included USEPA, state and contractor personnel.

To provide ongoing additional support, a comprehensive manual describing all aspects of the applications of the HNu and OVA was prepared. In addition to applications information, sections on qualitative/quantitative standard preparation, sample screening and field analysis techniques are included. Additional sections on other instruments such as the Photovac GC and updated information on techniques will be added as the information is developed. It is believed that the effort to provide this type of support has expanded the field investigative capabilities of the personnel who participated and who have continued to be involved in hazardous waste site work.

#### CASE STUDIES

In order to illustrate the application of the techniques described in the previous section, three case studies involving the use of portable instrumentation will be presented. These studies were performed by USEPA and/or E & E personnel during hazardous waste site investigation activities in the northeast. Since litigation is pending for two of the sites, the names of the sites will not be disclosed. Although some of the more "classical" applications of portable instruments are briefly mentioned, the primary focus will be upon the presentation of data obtained through the more innovative applications.

##### Case Study One

This site was an abandoned drum recycling/storage facility where there was evidence that large quantities of waste organic solvents had been discharged onto the ground. A hydrogeologic investigation was conducted in order to determine the extent of groundwater contamination that had occurred in the site vicinity. Locations for the proposed monitoring wells were selected on the basis of the site history, background information on regional hydrogeology and some geophysical studies. During the monitoring well installation, two portable instruments capable of detecting volatile organic compounds were used for several purposes.

First, it was determined through site records that several of the on-site monitoring wells would be installed in areas where highly contaminated soil could be encountered. Therefore, penetration into contaminant-saturated soil and groundwater by drilling equipment could release organic vapors. Personnel working in the direct vicinity of the well-hole would then be subjected to an organic vapor respiratory hazard. The HNu portable photoionizer was used to survey for total organic vapor concentrations in the immediate vicinity of each well-hole.

The HNu instrument is particularly adapted for this type of application since it does not respond to ground methane, which is often encountered during drilling. Responses shown by the instrument are most likely due to the presence of volatile organic contaminants. Also, the instrument can be run continuously without recharging for a normal work day.

At the locations of two on-site monitoring wells, total organic vapor concentrations intermittently approached 1000 ppm, measured at the top of the well-hole. Although concentrations were still in the range of ambient background in the breathing zone of personnel and favorable weather conditions existed (low temperature and strong, steady winds), all personnel working near the well-hole donned Self-Contained Breathing Apparatus (SCBA) to complete well drilling at these two locations. Additionally, SCBA was used during the withdrawal of the drilling auger sections, as highly contaminated soil was brought to the surface during this operation.

Second, an OVA was used as a field GC to analyze several types of samples as the monitoring wells were installed. Fig. 3 is a photograph of the OVA set up in the back of a field equipment van where the analyses were conducted. To the left of the instrument



Figure 3.

OVA with field standards set up in field laboratory

is a portable strip chart recorder used to record chromatograms. Just behind the instrument is a box containing a variety of field analytical standards similar to those described in the section on field analytical techniques. During the drilling of monitoring wells, soil samples were collected using a 2 in O.D. split-spoon sampler. Samples were obtained every 5 ft or change in stratum. In addition to samples for geologic evaluation, a small quantity of soil was placed in a septum vial and screened for the presence of volatile contaminants.

Samples showing the presence of volatile compounds were then analyzed to determine the identity and concentration of contaminants. A variety of volatile organic contaminants were identified, including 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, toluene and ethylbenzene. In this manner, a depth versus contaminant concentration profile was established for each borehole.

The availability of this information enabled field personnel to make a variety of adjustments to the project plan as work progressed. For example, it was ensured that monitoring well placement, as selected from background and geophysical data, was indeed in the pathway of contaminant migration. On the basis of the soil sample screening data, adjustments were made in the placement of subsequent wells.

Further, an evaluation of geologic strata in comparison to contamination present enabled decisions to be made about the appropriate depths for well screen placement and whether multi-level well clusters were warranted at certain locations. For this particular study, it was determined from the field generated data that multi-level well clusters, which had been proposed for several locations, were unnecessary. Thus, some cost savings were realized from this approach.

In addition, the OVA was used to analyze wash water used during the drilling process. Since the only convenient source of wash water was a nearby well thought to be unaffected by contaminants, a sample of each load of water was screened for volatiles prior to its use in the drilling. This ensured that the drilling process was not the source of contamination in a given well-hole.

The analysis of soil samples in the manner described resulted in the detection of a variety of volatile organic contaminants in several of the downgradient boreholes. The use of field standards allowed the identification of the compounds. Field identification agreed with the waste-type records available for the site and subsequent groundwater samples obtained from the wells and analyzed by GC/MS confirmed the presence of the compounds identified in the field. Obviously, the same benefits could not be realized if samples were not analyzed or if samples were sent to a laboratory for analysis, with the latter alternative being totally unacceptable in terms of the time and expense involved.

As a footnote to this case study, one further benefit was obtained from the field analysis technique. When groundwater samples from all of the wells were obtained for laboratory analysis following installation, duplicate samples from each well were obtained for headspace analysis on the OVA. The object was to provide preliminary data for further scope of work development while the laboratory samples were being run. When the laboratory results were reported back and compared to the OVA data, it was found that for several samples, the laboratory failed to report a compound that was found with the OVA. When the laboratory was queried about the discrepancy, it was determined that the laboratory had indeed experienced difficulty with the sample analysis. Subsequently, another round of samples was obtained and the analysis confirmed the original data obtained by field analysis.

### Case Study Two

This site involved an emergency response to the threat that a lagoon containing millions of gallons of liquid waste would overflow into a nearby river at a point upstream from a municipal water supply intake. Samples obtained from the upper aqueous layer of the lagoon contained a variety of volatile organic compounds. It was decided that the appropriate emergency response was to pump off several feet of this top layer, run the pumped material through a portable carbon filtration unit and discharge the filtered effluent into the nearby river. A portable carbon filtration unit was dispatched from the EPA's Environmental Response Team (ERT).

In order to determine when a carbon bed became spent, periodic samples were taken of the bed effluent and analyzed for volatile organic compounds using an OVA which was set up at the site. Qualitative and quantitative analytical standards were used to identify and quantify volatiles in the effluent. This procedure eliminated any guesswork about when it was appropriate to switch to a new filtration bed. It also ensured that the discharged effluent contained no significant concentrations of volatile organic compounds.

Once again, the timeliness which can be achieved through the use of field analytical techniques is illustrated. Since there was minimal delay between sampling and analysis and virtually no cost, which would have been significant if a laboratory had been employed, the entire emergency response procedure took place in a timely and cost-effective manner.

### Case Study Three

This site is a municipal landfill in a large metropolitan area. Records indicate that there was no evidence of chemical waste disposal there. As portions of the site were filled, a number of pipes were installed to provide for venting of vapors and gases and to reduce the lateral migration of ground methane into the basements of some nearby buildings. Preliminary field tests using an OVA confirmed the presence of methane in vent pipe emissions, and further field tests using the OVA, HNu and colorimetric detector tubes indicated that a variety of other substances were present in addition to methane. Of particular concern was the preliminary indication that vinyl chloride was present.

In order to confirm the presence of vinyl chloride in the vent pipe emissions and to further define the extent of air contamination caused by the emissions, an initial characterization was performed using a Photovac, Inc. 10A10 portable photoionization GC. Use of this instrument allows grab samples of air to be injected directly onto a GC column for analysis. The need for pre-concentration of the sample is virtually eliminated because the detector of the instrument is sensitive to a few ppb of many compounds, including vinyl chloride.

Using a gas tight syringe, grab samples were taken directly from the emission stream of several vents. The samples were injected directly into portable GC. In addition, grab samples of ambient air at various locations upwind and downwind of the more active bent pipes were obtained. Several vinyl chloride standards were used to establish retention time matches and to determine concen-

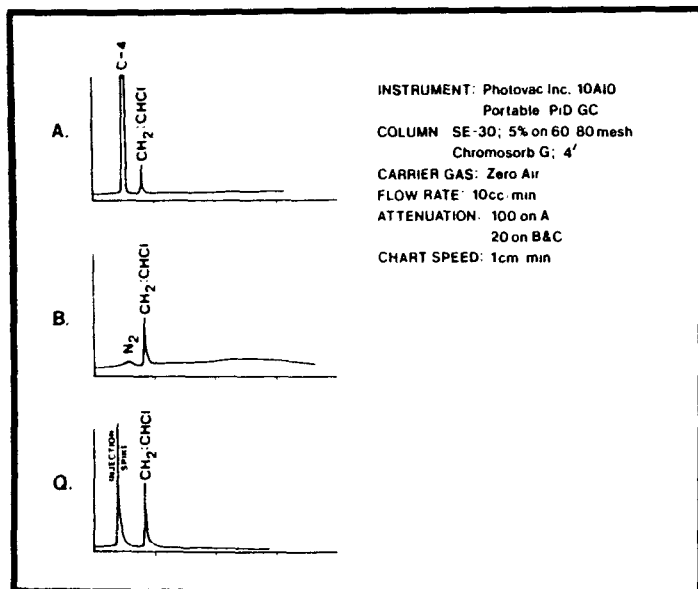


Figure 4.  
Schematic Representations of Vinyl Chloride Chromatograms

trations of vinyl chloride in the samples. Reproductions of several chromatograms recorded during the study are shown in Fig. 4. "A" is a 10 microliter (ul) injection of a sample obtained directly from one of the vents. The first large off-scale peak was identified as a C-4 hydrocarbon and the smaller, sharp peak is vinyl chloride. The retention time of the vinyl chloride under the operating conditions was about 40 sec. "B" is a 10 ul injection of a 11.0 ppm vinyl chloride standard (balance as nitrogen). The first, small peak is actually the nitrogen. (There are several theories for the reason the instrument will respond to the nitrogen in a standard, but not the nitrogen in air). "C" is a 1 Cm<sup>3</sup> injection of an ambient air grab sample obtained approximately 30 ft downwind from an active vent. Here, the sensitivity of the instrument was increased five-fold and the injection size was much larger than those of samples taken directly from the vents.

Concentrations of vinyl chloride in the vent emissions, as determined by field analysis, ranged from 10-50 ppm. Subsequently, samples of the vent emissions were obtained for laboratory analysis. Laboratory results agreed well with the field generated data. Concentrations of vinyl chloride in the ambient air in the vicinity of the vents varied. Obviously, wind direction with respect to the vents and the sampling locations was a major factor. Another factor was the air temperature, which approached 90 °F on one day during the study, but was 70-75 °F during another phase of the study. The concentrations of vinyl chloride in the ambient air ranged from a few ppb up to 100 ppb.

In addition, the field analysis identified the presence of several other compounds in the vent pipe emissions including trichloroethylene and toluene. These were present at generally lower concentrations than the vinyl chloride. The presence of these compounds was also confirmed by laboratory analysis. Through the use of a backflush valve and using the technique described earlier, it was possible to determine if heavier molecular weight substances were present. None were detected.

The first phase of this study took place over two days, during which approximately 35 air samples were obtained and analyzed. On the basis of the field analytical data generated during this time, several time-integrated samples were obtained by drawing ambient air through activated charcoal tubes. The tubes were solvent desorbed in a laboratory and subsequently analyzed. No vinyl chloride was detected; however, the detection limit for this method

is generally 1 ppm. This illustrates that the use of direct injections into a portable GC can provide a more sensitive method than current laboratory procedures for detecting vinyl chloride in ambient air.

During the next phase of the study, the same approach was used to obtain some data for determining the nature of the dilution of vinyl chloride as it is emitted from a vent into the ambient air. In addition, several time-integrated sampling stations were set up with activated charcoal tubes to be thermally, rather than solvent, desorbed. Several instantaneous grab samples were obtained by gas-tight syringe at a point 30 ft directly downwind from a vent and at the location of a time-integrated sampling station. The maximum vinyl chloride concentration was 20 ppb. Analysis of the time-integrated sample showed a time-weighted vinyl chloride concentration of <1 ppb.

Using a variety of factors, which had been determined for this particular vent, some calculations were performed using simple Gaussian dispersion equations. The calculations predicted the maximum vinyl chloride concentration at the sampling point to be 2.8 ppb. This result agrees quite well with the field data, although several assumptions were made for purposes of the calculations. Additional work is needed to answer several questions which have been raised about the vent pipe emissions.

A number of 1 Cm<sup>3</sup> grab samples of ambient air were also obtained off-site. These were injected directly into the Photovac 10A10 and analyzed for vinyl chloride. No vinyl chloride was detected under the conditions present during this limited study. Counting the samples analyzed from on-site, a total of almost 50 air samples were obtained and analyzed over a three-day period.

## CONCLUSIONS

The use of portable instruments and field analytical techniques have been applied to a variety of hazardous waste site investigative activities. USEPA and E & E personnel in the New England region have found that the use of these instruments greatly increases the amount of data which are available for evaluating the extent and degree of volatile organic compound contamination at sites. Where several of these instruments have previously seen most of their use in helping to determine levels of personnel protection and to perform initial site characterization, the new and relatively simple techniques which have been developed have expanded instrument potential.

The primary advantages which can be realized by using these techniques are time and cost savings. The use of field analytical techniques provides data more rapidly and allows the data to be factored into field investigations while the work is actually taking place. The data also enable investigators to develop additional plans for field activities while awaiting laboratory confirmation. This contributes to the more rapid completion of projects.

In situations where public health might be threatened, the ability to acquire reliable data rapidly is also an obvious advantage. By using the sample screening techniques described in the first section and a portable GC, a USEPA chemist was able to analyze 30 private drinking water samples for volatile organic contamination within 24 hours. This enabled authorities to reassure residents until laboratory results confirmed the initial screening conclusions.

Cost savings are realized because expensive laboratory time is not wasted on unnecessary samples. Investigators are afforded a luxury in that the number of field analyses need not be limited. Once the results of field analyses with portable instruments have been evaluated, a much smaller, select number of samples can be obtained and analyzed in the laboratory for further confirmation. This obviously reduces laboratory costs.

Finally, as illustrated in case study three, the improved technology that some portable instruments offer provides greater sensitivity than currently accepted laboratory methods.



# **ANALYTICAL AND QUALITY CONTROL PROCEDURES FOR THE UNCONTROLLED HAZARDOUS WASTE SITES CONTRACT PROGRAM**

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## **LEGISLATIVE BASIS**

USEPA has begun a major effort to identify and clean up uncontrolled and abandoned waste disposal sites that are hazardous to the environment. This effort includes the investigation and monitoring of several thousand potentially hazardous uncontrolled sites throughout the nation. Recent legislation entitled "Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)", commonly referred to as Superfund,<sup>1</sup> has given increased emphasis to this part of the Agency's activities.

## **SCOPE OF THE HAZARDOUS WASTE PROBLEM**

Implementation of the Superfund legislation requires reliable analytical tools and methodology. Of special concern are the requirements for identification and delineation of waste sites, characterization of waste composition and waste sites, and detection of environmental contamination due to hazardous waste operations. These areas present a range of multimedia problems that are not easily addressed with current technology. For example, the waste itself can include complex mixtures of hazardous substances at concentrations ranging from nearly pure material to dilute solutions. The waste may occur as a solid, semi-solid, or liquid material. It may be stored in enclosures or simply dumped in landfills, pits, open fields, ponds, or lagoons.

## **THE NATIONAL CONTRACTS LABORATORY ANALYTICAL PROGRAM (NCLAP)**

In order to accomplish the difficult task of characterizing these uncontrolled waste sites the USEPA has found it necessary to supplement its in-house analytical resources with contractor-operated analytical laboratories. This need has resulted in the National Contracts Laboratory Analytical Program (NCLAP) which provides the Agency with a variety of capabilities for the analysis of low, medium and high concentration waste site samples for toxic organic and inorganic compounds. Sample matrices to be analyzed may include soils, sediments, sludges and aqueous or non-aqueous media. The NCLAP offers a variety of other analytical services to Agency clients but in this paper the authors will only discuss the analysis for organics at low and medium levels in mixed media.

Analytical services are obtained by first advertising the Agency's requirements in Commerce and Business Daily. Interested parties are advised that the complete Invitation for Bid (IFB) is available from the USEPA Procurement and Contracts Division. Sealed bids are then submitted to that office. Responsive offerors submitting the lowest bids are notified of their potential eligibility and that a performance evaluation (PE) sample is being sent to them for analysis. The analytical results submitted by the laboratories are then evaluated by the Environmental Monitoring Systems Laboratory at Las Vegas (EMSL-LV) using criteria which are included in the IFB package and therefore known to the offerors. An example of the PE evaluation criteria is provided in Table 1.

Those laboratories judged to have acceptably analyzed the PE samples are subsequently visited by USEPA personnel. The purpose of these on-site visits is to evaluate the bidders' personnel, facilities, equipment, and written procedures. Since these are the requisite tools for successful completion of the contractual requirements, a contract will not be awarded unless these requirements are in place and of sufficiently high quality to meet the Agency's standards.

## **SELECTION OF ANALYTICAL METHODOLOGY**

The analytical methodology utilized for monitoring hazardous waste sites must be facile, yet capable of identifying and quantifying a diversity of organic and inorganic chemicals in multimedia wastes. Current estimates of the number of chemicals manufactured in the United States range from 50,000 to 75,000 compounds,<sup>2</sup> while the number of chemicals registered with Chemical Abstracts is reported as five million.<sup>3</sup> The difficult analytical task of identifying large numbers of chemical compounds in wastes is aggravated by the fact that waste site concentration levels may range from parts-per-billion (ppb) levels to neat chemicals. Notwithstanding these difficult requirements, the analytical methods of the NCLAP must produce data of demonstrable quality which is sufficient for enforcement actions.

To aid in the selection of the analytical methods to be used for environmental monitoring, the EMSL-LV is compiling manuals of the best available sampling and the best available methods.<sup>4</sup> As a minimum requirement any analysis procedure used in the NCLAP has been evaluated, in at least one laboratory, for accuracy, precision and sensitivity. Ideally every NCLAP method should have undergone an interlaboratory comparison test utilizing the

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.



**Table 1.**  
**Performance Evaluation Sample Data Scoring**

Laboratory _____		Date _____	
<b>Analytical Procedure Scoring</b> (Maximum = 100 points per sample set)			
Sample Set B: _____		Sample Set C: _____	
I. Hazardous Substances List (HSL) Compound Results	B	C	
A. Identifications (Maximum of 20 points)			
1. All HSL compounds correctly identified.	20		
2. One HSL compound not correctly identified.	18		
3. Two to four HSL compounds not correctly identified.	15		
4. More than four HSL compounds not correctly identified.	0		
B. Quantitation (Maximum of 20 points)			
1. All HSL compounds within performance control window set by USEPA.	20		
2. One to two HSL compounds not within performance control window.	18		
3. Three to five HSL compounds not within performance control window.	15		
4. More than five HSL compounds not within performance control window.	0		
C. Matrix Spike and Duplicate			
1. Matrix Spike Recoveries (Maximum of 10 points)			
a. All within performance control window.	10		
b. One outside performance control window.	8		
c. Two outside performance control window.	5		
d. More than two outside performance control window.	0		
2. Precision of Duplicate Results (Maximum of 10 points)			
a. All HSL compounds within performance control window.	10		
b. One to two HSL compounds outside performance control window.	8		
c. Three to five HSL compounds outside performance control window.	5		
d. More than five HSL compounds outside performance control window.	0		
D. Quality Assurance Data	B	C	
1. Surrogate Spikes (Maximum of 5 points)			
a. All within performance control window.	5		
b. One outside performance control window.	4		
c. Two outside performance control window.	2		
d. More than two outside performance control window.	0		
2. Reagent Blank HSL Compounds (Maximum of 5 points)			
a. None reported.	5		
b. None reported at greater than 50% of detection limits.	4		
c. One to four reported at greater than 50% of detection limits.	2		
d. More than four reported at greater than 50% of detection limits.	0		
II. Non-HSL Compound Detection Results			
A. Identifications (Maximum of 20 points)			
1. All detected.	20		
2. One not detected.	18		
3. Two to four not detected.	15		
4. More than four not detected.	0		
B. Non-HSL Compounds in Reagent Blank (Maximum of 10 points)			
1. None reported.	10		
2. None reported at greater than 25% of internal standard area.	8		
3. One to two reported at greater than 25% of internal standard area.	5		
4. Three or more reported at greater than 25% of internal standard area.	0		
TOTAL ANALYSIS SCORES _____			
(Maximum of 100 points per sample set)			
<b>Screening Procedure Scoring</b> (Maximum = 60 points)			
Sample Set A: _____		Points	Set A
I. Sample A.1—Aqueous Screening Sample:			
A. Volatile fraction evaluated correctly.	10	_____	
B. B/A/N fraction evaluated correctly.	10	_____	
C. Pesticide fraction evaluated correctly.	10	_____	

II. Sample A.2—Soil/Sediment Screening Sample:

- |  |    |       |
|--|----|-------|
| A. Volatile fraction evaluated correctly.  | 10 | _____ |
| B. B/A/N fraction evaluated correctly.     | 10 | _____ |
| C. Pesticide fraction evaluated correctly. | 10 | _____ |

TOTAL SCREENING SCORE \_\_\_\_\_  
(Maximum of 60 points)

TOTAL COMBINED SCORE \_\_\_\_\_  
(Sample Sets A, B and C)  
(Maximum of 260 points)

guidelines established by either the ASTM<sup>3</sup> or the AOAC.<sup>6</sup> A few environmental analytical methods have undergone interlaboratory comparison tests,<sup>7,8</sup> but since these intercomparison tests are both costly and time-consuming, most NCALP procedures have undergone only single-laboratory evaluations.

The EMSL-LV is currently directing an intercomparison study of the IFB procedures for determining volatile and semivolatile organics in solid wastes.<sup>9, 10</sup> In addition, the Environmental Monitoring Support Laboratory in Cincinnati (EMSL-CI) is subjecting the IFB procedure for dioxin in water (Method 613) to an interlaboratory comparison evaluation.<sup>11</sup>

**ANALYTICAL METHODS SPECIFIED IN THE IFB FOR THE DETERMINATION OF MEDIUM LEVEL/LOW LEVEL ORGANICS IN MIXED MEDIA**

As an example of the types of analytical services offered by the Agency, via the NCALP to its clients, the analytical and quality control requirements specified in the IFB for the determination of medium level/low level organics in mixed media will be described in some detail.

The tasks specified for the contractor in this IFB are:

- To receive and prepare hazardous waste site samples under strict chain-of-custody and sample preparation procedures which are defined in the IFB
- To screen sample extracts for IFB target compounds using gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS). The purpose of this GC screen is to provide an estimate of analyte concentrations so that extract volumes may be suitably adjusted to protect the GC/MS detector
- To identify the target compounds by comparison of the mass spectra and GC relative retention times of unknowns in the extract with the corresponding data derived from standards
- To quantify the identified target compounds
- To identify the non-target compounds of greatest apparent concentration (up to 10 unknowns in the volatile fraction and up to 20 unknowns in the semivolatile fraction)

The analytical methods specified by the IFB to accomplish these tasks are:

- Water Methods:
  - Method 608 (pesticides)
  - Method 613 (dioxin)
  - Method 624 (volatile compounds boiling up to 150°C)
  - Method 625 (semivolatile compounds)
- Medium Level Solid Waste Methods:
  - EMSL-LV #1 (volatiles)
  - EMSL-LV #2 (semivolatiles)
- Low Level Solid Waste Methods:
  - Modified EMSL-CI procedures for volatiles and semivolatiles
- GC Screen for Organics in Water:
  - NEIC #1 procedure for volatiles and semivolatiles in water

The "600 series" water methods have been developed by the EMSL-CI and have been published.<sup>12-15</sup> The procedures for volatile and semivolatile organics at medium levels (10 ppm to 15%) in solid wastes have been prepared and evaluated by the Battelle Columbus Laboratories under contract to the EMSL-LV.<sup>9</sup> The low-level procedures (less than 10 ppm) for volatile and semivolatile organics in solid wastes have been developed by the EMSL-CI, subsequently modified, and have been used by the USEPA in its Love Canal effort,<sup>16,17</sup> and elsewhere. The GC screening procedure for organics

in water is a modified form of a method developed by USEPA's National Center for Enforcement and Investigation (NEIC) and has seen widespread usage in USEPA Regional laboratories.

The IFB analytical schemes for volatiles, semivolatiles and pesticides in mixed media are illustrated in Figs. 1, 2 and 3. Each sample is assumed to contain medium levels of organics which must undergo a GC screen. The results of the GC screen dictate whether the sample must undergo a medium- or low-level workup procedure. The screen result is also used to determine any adjustments in extract volume required to optimize the subsequent GC/MS analysis. It is particularly important to keep the concentrations of individual extract components sufficiently low to prevent saturation of the mass spectral detector. Detector saturation which may result in a contaminated mass spectrometer source is not unusual with hazardous waste samples and can be a major cause of instrumental down time.

#### QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

To ensure the reliability of all analytical data derived from the NCALP, the IFB requires adherence to stringent quality assurance/quality control (QA/QC) requirements by all contractors. These QA/QC requirements fall into the twin categories of contractor in-house QA/QC and USEPA external QA/QC.

#### Scheme VOA GC Screen and GC/MS Analysis

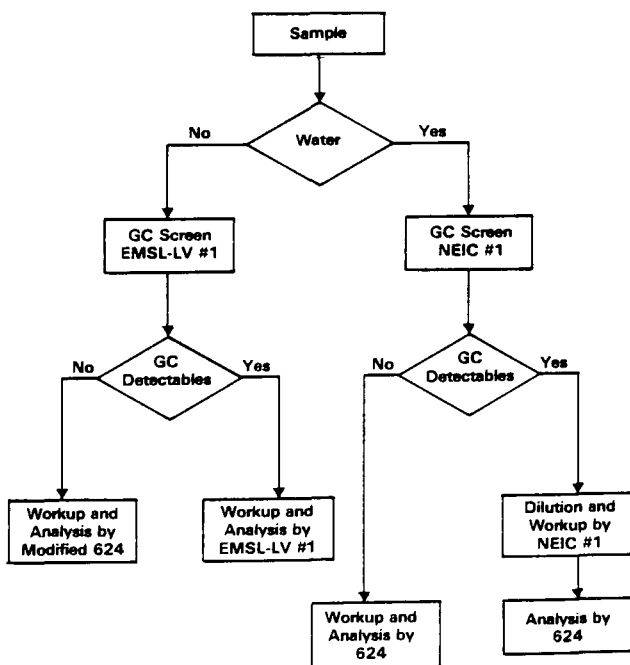


Figure 1.

VOA GC Screen and GC/MS Analysis

Included in contractor in-house QA/QC are daily calibration and maintenance of instruments, maintenance of instrument logs and adherence to standard operating procedures (SOPs), adherence to chain-of-custody procedures, and preparation of control charts to monitor the sample workup efficiency and the reproducibility of GC/MS response factors (used for analyte quantitation). In addition, the contractor must analyze a minimum of one matrix spike, one duplicate sample and one blank for each case of 20 samples.

QA/QC externally imposed by the USEPA on its contractors includes pre-award and quarterly on-site inspections, analysis of pre-award and quarterly performance evaluation samples and blind check samples, and the checking of contractor-reported data (deliverables) which consist of data forms and magnetic tapes. The data package required from all IFB laboratories is summarized in

#### Scheme Semivolatile (Base/Acid/Neutral) GC Screen and GC/MS Analysis

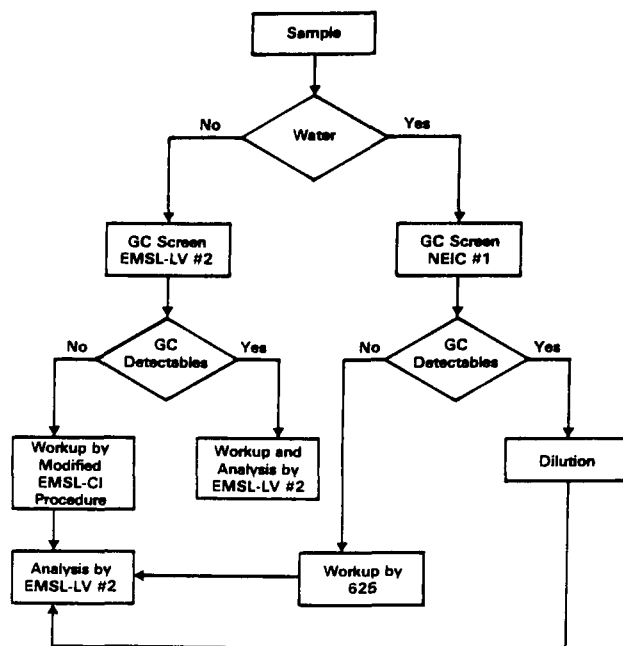


Figure 2.

Semivolatile (Base/Acid/Neutral) GC Screen and GC/MS Analysis

#### Scheme Pesticide GC Screen and GC/MS Analysis

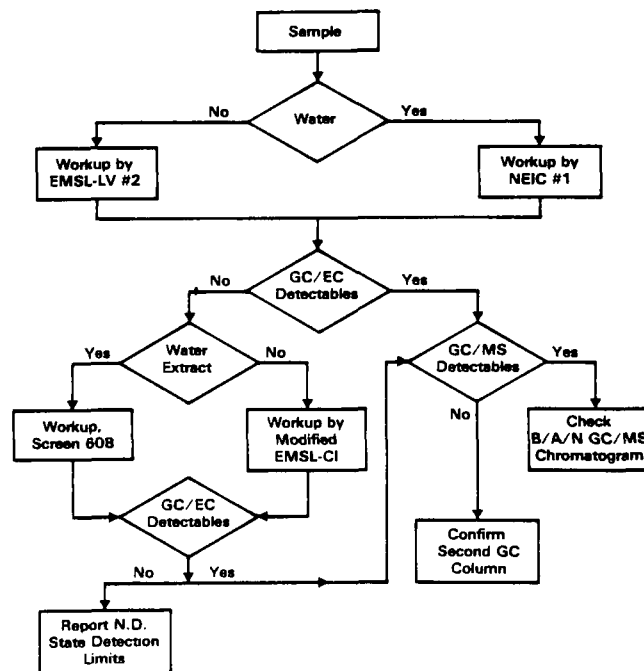


Figure 3.

Pesticide GC Screen and GC/MS Analysis

Table 2. The monitoring of matrix spikes, surrogate spikes, duplicates, and PE samples provides the USEPA with an ongoing check of the method efficiency. If a check of contractor data suggests poor performance, sample deliveries to that contractor are halted or reduced until the problem is corrected to the satisfaction of the USEPA.

## SURROGATE RECOVERY RESULTS

Surrogates are chemical compounds which are added to samples or extracts to monitor the method's efficiency. The IFB defines acceptable surrogate recovery windows; recovery values outside these windows may provide the first indication that a method is out of control. The lower limit of the formal performance control window for surrogate spike recoveries are 50% for acidic semivolatiles, 70% for base/neutral semivolatiles and 80% for volatiles. The mean values of the surrogate recoveries from a randomly selected set of 26 samples are shown in Table 3. All samples were submitted to contractors for low-level analysis; the 26 samples consisted of 17 aqueous and 9 soil matrices. The data in this table illustrate the recoveries that are expected and an overview of what was actually achieved by the laboratories. Results averaging less than the minimum performance criteria, or greater than 100%, may not necessarily indicate poor quality data but may reflect the intervention of other factors such as matrix effects or chromatographic interferences.

Table 2.  
Data Package

### QA/QC DATA

For Each Sample	For Each Set of Samples (20)
<b>Calibration Data</b>	<b>Method Blank Analysis</b>
•DFTPP, Spectrum and Tabulation	•Data Summaries
•BFB, Spectrum and Tabulation	•RIC and Spectra
	•Quantitation Report
<b>Standards Reference Data</b>	<b>Matrix Spike Analysis</b>
•Acid/Base/Neutral RIC and Spectra	•Matrix Spike Result Summaries
•Volatiles RIC and Spectra	•QC Spike Results
•Pesticides and PCBs GC-ECD Chromatograms, RIC and Spectra	•RIC and Spectra
	•Quantitation Report
<b>Sensitivity Tests and Tailing Factors</b>	<b>Duplicate Analysis</b>
•Acids/Base/Neutrals	•Data Summaries
•Volatiles	•Duplicate Analysis Results
•Pesticides and PCBs	•Relative Percent Difference Calculations

Table 3.  
Surrogate Recoveries  
Laboratory Performance, %

Compound	Lower End of Performance Window	Mean*	Standard Deviation	Min.	Max.
Volatiles	80%	111	9	96	132
Base/Neutral Semivolatiles	75%	69	16	35	103
Acid/Semi-volatiles	50%	57	17	2	79

\*Based on 26 sample analyses.

The average recoveries of volatile surrogates from both water and soil/sediment samples are excellent (Table 4). Average recoveries of base/neutral surrogates from water samples are also excellent, however, their average recovery from soil/sediment samples is not as high. The average recoveries of acidic surrogates are low regardless of the sample matrix type. There are at least three factors which may explain these variations between volatile and base/neutral surrogate recoveries: (1) the greater efficiency of a purging extraction technique over solvent extraction, (2) the greater polarity of the semivolatile with respect to the volatile surrogate standards, and (3) the possibility of irreversible adsorption or decomposition of surrogate standards on soil or sediment samples. However, these conclusions are tentative as this data base of 26 samples is too small. More definitive conclusions regarding surrogate recoveries will be available as sample data accumulate in the EMSL-LV data bank.

Table 4.  
Recoveries of Volatile and Semivolatile Surrogate Compounds  
from Water, Soil and Sediment Samples

Low Level Water Samples						
Compound	Surrogate Level (ug/L)	Recovery (%)				
Bromochloromethane	4	123	105	121	103	98
1,4-Dichlorobutane	4	101	104	110	94	97
D <sub>6</sub> -Benzene	4	89	99	111	97	89
D <sub>8</sub> -Toluene	4	98	100	100	117	98
D <sub>5</sub> -Nitrobenzene	101	92	119	113	105	72
2-Fluorobiphenyl	101	96	92	109	106	87
D <sub>8</sub> -Naphthalene	101	99	100	116	110	87
2-Fluorophenol	11	27	36	43	36	54
D <sub>5</sub> -Phenol	72	10	18	11	17	21
Low and Medium Level Soil/Sediment Samples						
D <sub>6</sub> -Benzene	50 <sup>b</sup>	100	96	116	138	112
D <sub>8</sub> -Toluene	50	102	98	116	126	108
D <sub>5</sub> -Nitrobenzene	25	14	69	68	74	62
2-Fluorobiphenyl	25	36	74	50	47	43

<sup>a</sup> Surrogate level 50-100 ug/L.

<sup>b</sup> Micrograms per gram.

The individual surrogate recoveries from eight of the 26 samples are shown in Table 5. For comparison purposes the recovery results from an organics-free method blank are included. An idea of the recovery precision may be gained from the results of triplicate analyses for some of the surrogates listed in this table. With the exception of d<sub>5</sub>-phenol the absolute recovery and recovery duplication is quite good.

Table 5.  
Surrogate Recovery from a Low Level Aqueous Sample Matrix

Compound	Surrogate Level (ug/L)	Sample Number										Method Blank
		1	2	3	4	5 <sup>a</sup>		6 <sup>b</sup>		7	8	
D <sub>6</sub> -Benzene	50	82	96	110	100	104		100	98	100	98	96
1-Chloro-2-bromo-propane	50	96		104	102	98		96	94	96	92	90
D <sub>8</sub> -Toluene	50	82	102	114	104	98		100	102	106	100	98
2-Fluoro-phenol	103	57	79	72	86	75	81	64	60		60	59
D <sub>5</sub> -Phenol	104	47	86	76	82	42	35	35	35		33	26
D <sub>5</sub> -Nitrobenzene	101	88	79	71	99	83	62	60	57		63	77
2-Fluoro-biphenyl	101	95	81	88	90	91	70	73	65		77	89
D <sub>8</sub> -Naphthalene	101	95	73	85	93	94	67	66	60		69	88

<sup>a</sup> Sample not analyzed for volatile surrogates.

<sup>b</sup> Sample not analyzed for semivolatile surrogates.

## PERFORMANCE EVALUATION (PE) SAMPLE RESULTS

An indication of the relative performance of analytical laboratories can be obtained by inspecting the results obtained from a blind check analysis or performance evaluation (PE) sample (PE samples must be analyzed on a quarterly basis by all NCALP contractors). A recently distributed PE aqueous sample (Table 6) contained 20 target compounds spiked at levels ranging from 80 to 500 µg/l. The spike compounds selected for the PE sample were target compounds which must be analyzed for, by all NCALP laboratories, under the IFB terms. A complete list of IFB target compounds is provided in Table 7 (non-target compounds must also be identified if they fulfill the IFB criteria). This PE sample was analyzed by 16 laboratories for the volatile and base/neutral

**Table 6.**  
**Composition of Performance Evaluation Sample**

Fraction	Compound	Concentration ( $\mu\text{g/L}$ )
Volatiles	Chlorobenzene	80
	1,1,2,2-Tetrachloroethane	100
	Methylene chloride	160
	1,1,2-Trichloroethane	150
	Chloroform	120
Base/Neutrals	1,4-Dichlorobenzene	260
	Naphthalene	200
	Acenaphthylene	95
	Hexachlorocyclopentadiene	500
	Dibenz(a,h)anthracene	175
	N-Nitrosodiphenylamine	500
	2-Chloronaphthalene	150
	Benzidine	400
Acids	4-Nitrophenol	400
	Pentachlorophenol	350
	Phenol	200
Pesticides	$\beta$ -BHC	150
	p,p'-DDD	200
	Endosulfan II	175
	Endrin	250

**Table 7.**  
**Hazardous Substances List**

1. acenaphthene	44. chrysene	88. hexachloroethane
2. acenaphthylene	45. 4,4'-DDD	89. 2-hexanone
3. acetone	46. 4,4'-DDE	90. indeno(1,2,3-cd)pyrene
4. acrolein	47. 4,4'-DDT	91. isophorone
5. acrylonitrile	48. delta-BHC	92. methylene chloride
6. aldrin	49. dibenzo(ah)anthracene	93. 2-methylnaphthalene
7. alpha-BHC	50. dibenzofuran	94. 4-methyl-2-pentanone
8. aniline	51. 1,2-dichlorobenzene	95. 2-methylphenol
9. anthracene	52. 1,3-dichlorobenzene	96. 4-methylphenol
10. benzene	53. 1,4-dichlorobenzene	97. naphthalene
11. benzidine	54. 3,3'-dichlorobenzidine	98. 2-nitroaniline
12. benzo(a)anthracene	55. 1,1-dichloroethane	99. 3-nitroaniline
13. benzo(a)pyrene	56. 1,2-dichloroethane	100. 4-nitroaniline
14. benzo(b)fluoranthene	57. 1,1-dichloroethene	101. nitrobenzene
15. benzo(ghi)perylene	58. trans-1,2-dichloroethene	102. 2-nitrophenol
16. benzoic acid	59. 2,4-dichlorophenol	103. 4-nitrophenol
17. benzo(k)fluoranthene	60. 1,2-dichloropropane	104. N-nitrosodiphenylamine
18. benzyl alcohol	61. cis-1,3-dichloropropene	105. N-nitrosodipropylamine
19. benzyl butyl phthalate	62. trans-1,3-dichloropropene	106. o-xylene
20. beta-BHC	63. dieldrin	107. PCB-1016
21. bis(2-chloroethyl)ether	64. diethyl phthalate	108. PCB-1221
22. bis(2-chloroisopropyl)-ether	65. 2,4-dimethylphenol	109. PCB-1232
23. bis(2-ethylhexyl)-phthalate	66. dimethyl phthalate	110. PCB-1242
24. bis(2-chloroethoxy)-methane	67. di-n-butyl phthalate	111. PCB-1248
25. bromodichloromethane	68. 4,6-dinitro-2-methylphenol	112. PCB-1254
26. bromomethane	69. 2,4-dinitrophenol	113. PCB-1260
27. bromoform	70. 2,4-dinitrotoluene	114. phenanthrene
28. 4-bromophenyl phenyl ether	71. 2,6-dinitrotoluene	115. phenol
29. 2-butanone	72. di-n-octyl phthalate	116. pentachlorophenol
30. carbon disulfide	73. 1,2-diphenylhydrazine	117. pyrene
31. carbon tetrachloride	74. endosulfan I	118. styrene
32. chlordane	75. endosulfan II	119. 2,3,7,8-tetrachlorodibenzo-p-dioxin
33. 4-chloroaniline	76. endosulfan sulfate	120. tetrachloroethene
34. chlorobenzene	77. endrin	121. 1,1,2,2-tetrachloroethane
35. chlorodibromomethane	78. endrin aldehyde	122. toluene
36. chloroethane	79. ethylbenzene	123. toxaphene
37. 2-chloroethyl vinyl ether	80. fluoranthene	124. 1,2,4-trichlorobenzene
38. chloroform	81. fluorene	125. 1,1,1-trichloroethane
39. chloromethane	82. gamma-BHC (lindane)	126. 1,1,2-trichloroethane
40. 4-chloro-3-methyl phenol (para-chloro-meta-cresol)	83. heptachlor	127. trichloroethene
41. 2-chloronaphthalene	84. heptachlor epoxide	128. 2,4,5-trichlorophenol
43. 4-chlorophenyl phenyl ether	85. hexachlorobenzene	129. 2,4,6-trichlorophenol
	86. hexachlorobutadiene	130. vinyl acetate
	87. hexachlorocyclopentadiene	131. vinyl chloride

compounds and by 17 laboratories for the pesticides. Twelve of these laboratories were contractor laboratories and five were USEPA Regional Laboratories. The PE results for this sample are summarized in Table 8.

Some trends are immediately apparent in Table 8. Nine of twelve contractor laboratories were unable to detect benzidine. Benzidine is known to be toxic and it is also known to pose many analytical problems.<sup>18</sup> Endosulfan II, a cyclic sulfite ester of a chlorinated bicyclic pesticide, went undetected by 5 of 12 contractor laboratories. This compound may be undergoing a slow hydrolysis

under the pH conditions of the analysis. Beta-BHC, a chlorinated cyclohexane, was not detected by three laboratories. This compound may undergo a slow pH-catalyzed dechlorination.<sup>19</sup> Because of the problems encountered, benzidine has been excluded from subsequent PE samples, however, a solution to the pesticides degradation problem is difficult since many pesticides are known to undergo decomposition during analytical workup or chromatographic analysis.<sup>20</sup>

In particular, Table 8 reveals a very poor performance by Laboratory No. 9. This laboratory failed to detect 5 of 20 compounds, and some of its quantitation results appear to be an order of magnitude too high. After inspecting its PE results, the sample shipments to this laboratory were terminated. This is an example of the IFB QA/QC checks detecting a potential problem with the contractor laboratories. The EMSL-LV is currently compiling all PE data in a computer bank. The data are undergoing statistical treatment for the purpose of establishing precision and accuracy guidelines for this analytical methodology.

The true spike values with the recoveries obtained by four of the contractor laboratories are compared in Table 9. These laboratories were selected to compare the performance of laboratories operating in control to that of Laboratory No. 9, and to compare their individual performances with those of the statistically treated data from all 16 laboratories. The mean and the standard deviation of the recoveries for 16 laboratories (the data from Laboratory 9 are excluded) are tabulated and, for the purpose of this study, performance windows were defined as 0.5-3 times the true spike levels (T). Data within the performance windows are not necessarily viewed as acceptable by the Agency, however, data outside the windows are viewed as unacceptable and will trigger an appropriate QA/QC response such as termination of sample shipments or an on-site audit and action to correct potential problems. An additional function of these windows is to indicate to the contractor laboratory the efficiency and the possible necessity for improvements of their in-house QA/QC program.

The EMSL-LV is currently compiling PE data for soil, sediment and water samples in a computer data base with the ultimate purpose of refining the performance windows for each matrix type. It is hoped that analytical difficulties resulting from the uniqueness of individual sample matrices will not preclude the narrowing of performance windows for general matrix types.

#### IMPROVING ANALYTICAL CHEMICAL DATA DERIVED FROM THE NCALP

In a recent article<sup>21</sup> the American Chemical Society's Ad Hoc Committee Dealing with the Scientific Aspects of Regulatory Measurements has suggested some potential problems with the collection and use of analytical data by regulatory agencies. This article concludes (in part), "Assuring the validity of quantitative interlaboratory measurements at the parts-per-million level and below is an extremely difficult technical problem. Additional demands must be met when the data are to be used for regulatory purposes." The USEPA is ensuring the reliability of its environmental analytical data by the following measures:

- The imposition and implementation of strict QA/QC procedures
- The usage of analytical protocols which have been subjected to at least a single-laboratory evaluation
- The subjection of those analytical protocols in widest usage to interlaboratory comparison tests
- The refinement of analytical protocols by input from EPA scientists, EPA contractors and from external sources
- The development of confirmatory techniques to supplement existing analytical methods. The potential of gas chromatography/Fourier transform infrared spectroscopy (GC/FT-IR)<sup>22,23</sup> for organics confirmation and inductively coupled plasma emission spectroscopy (ICP) for inorganics confirmation are currently under active investigation. ICP has recently been employed by the EMSL-LV as a screening tool for metals.<sup>24,25</sup>
- Utilization of external and internal peer review procedures in those instances where time permits
- Development of, and increased reliance on additional standard reference materials<sup>26,27,28</sup>

Table 8.  
Performance Evaluation Sample Results

Compound	Contractor Laboratories												EPA Laboratories					True Value
	1	2	3	4	5	6	7	8	9	10	11	12	A	B	C	D	E	
Chlorobenzene	46	95	57	32	41	51	60	64	39	29	38	42	40	39	37	<sup>a</sup>	42	80
1,1,2,2-Tetrachloroethane	ND <sup>b</sup>	59	110	63	10	94	107	18	ND	76	63	90	68	73	99	<sup>a</sup>	90	100
Methylene chloride	20	99	31	ND	65	54	58	88	35	16	69	55	68	64	17	<sup>a</sup>	11	160
1,1,2-Trichloroethane	10	150	160	100	121	130	152	148	148	120	100	112	85	115	94	<sup>a</sup>	103	150
Chloroform	14	69	42	37	43	36	31	61	303	39	37	40	50	51	40	<sup>a</sup>	40	120
1,4-Dichlorobenzene	160	ND	100	140	ND	160	116	214	ND	140	96	285	130	121	120	186	152	260
Napthalene	100	41	200	140	133	170	98	223	2710	130	131	285	150	129	130	180	168	200
Acenaphthalene	40	60	100	70	ND	96	86	109	1220	75	70	169	84	83	100	143	106	95
Isophorone	100	3200	590	660	ND	370	ND	ND	ND	290	222	ND	280	280	200	328	220	300
Hexachlorocyclopentadiene	380	280	710	200	1105	ND	747	1818	4600	530	ND	ND	380	441	440	461	190	500
Benzidine	ND	ND	42	160	ND	10	ND	ND	ND	ND	ND	ND	20	ND	33	5	8	400
Dibenz(a,h)anthracene	180	ND	120	80	29	62	10	ND	120	160	95	ND	50	76	190	237	345	175
N-Nitroso-diphenylamine	350	1300	830	580	926	520	1016	894	13400	610	493	1118	510	396	10	722	780	600
2-Chloronapthalene	50	220	170	100	130	130	132	175	1800	100	113	220	120	103	130	123	157	150
4-Nitrophenol	375	160	279	360	246	ND	443	150	2050	285	168	754	180	344	190	144	262	400
Pentachlorophenol	210	220	190	230	429	520	285	304	1840	280	238	1080	360	454	360	462	326	350
Phenol	170	98	82	110	80	69	248	113	1330	130	6	160	120	104	75	87	82	200
$\beta$ -BHC	ND	130	120	100	148	130	ND	61	512	ND	140	99	160	113	130	5	117	150
p,p'-DDD	140	213	150	150	ND	150	218	136	167	200	130	197	240	119	290	231	174	200
Endosulfan II	ND	ND	300	170	224	50	ND	150	ND	ND	160	197	20	190	ND	5	23	175
Endrin	ND	180	220	300	0.06	180	222	159	212	ND	160	217	240	189	220	345	340	250

<sup>a</sup> Laboratory "D" did not analyze the sample for volatile organics.

<sup>b</sup> ND = Not detected.

Table 9.  
Analysis of Performance Evaluation Sample Data

No.	Compound	Laboratory No.				True Value	Mean <sup>a</sup>	Standard Deviation (S.D.)	Performance Window 0.5T - 3T	Performance Window Mean $\pm$ 2 S.D.
		1	3	6	9					
1	Chlorobenzene	46	57	51	39.5	80	49.5	17.4	40 - 240	14.7 - 84.3
2	1,1,2,2-Tetrachloroethane	ND	110	94	ND	100	75	29.6	50 - 300	15.8 - 134.0
3	Methylene chloride	20	31	54	35.1	160	54.2	26.3	80 - 480	1.6 - 107.0
4	1,1,2-Trichloroethane	10	160	130	148	150	116.0	42	75 - 450	32.3 - 200.0
5	Chloroform	41	42	36	30.3	120	44.3	10.7	60 - 360	22.9 - 66.7
6	1,4-Dichlorobenzene	160	180	160	ND	260	165	53.4	130 - 780	58.4 - 272.0
7	Napthalene	100	200	170	2710	200	160	69.5	100 - 600	20.2 - 300.0
8	Acenaphthalene	40	110	58	1220	95	96	35.8	47.5 - 285	26.4 - 170.0
9	Hexachlorocyclopentadiene	380	710	ND	4600	500	617	450	250 - 1500	0 - 1517
10	Benzidine	ND	42	10	ND	400	78.3	70.9	200 - 1200	0 - 220
11	Dibenzanthracene	180	120	62	120	175	109	74.4	87.5 - 525	0 - 258
12	N-Nitroso-diphenylamine	350	830	520	13400	600	851	309.0	300 - 1800	249 - 1468
13	2-Chloronapthalene	50	170	130	1800	150	143	48	75 - 450	47 - 239
14	4-Nitrophenol	375	270	ND	2050	400	294	169	200 - 1200	0 - 632
15	Pentachlorophenol	210	190	520	1840	360	368	237	175 - 1050	0 - 842
16	Phenol	170	82	69	1330	200	122	48	100 - 600	26 - 218
17	$\beta$ -BHC	ND	120	130	512	150	132	33	75 - 450	46 - 178
18	p,p'-DDD	140	150	150	167	200	186	50	100 - 600	86 - 286
19	Endosulfan II	ND	300	50	ND	175	179	84	87.5 - 525	11 - 247
20	Endrin	ND	200	180	212	250	219	87	125 - 750	45 - 393

<sup>a</sup> The listed mean values for compounds No. 1 to 5 are based on 16 laboratories. The mean values for compounds No. 6 to 13 are based on 16 laboratories and do not include values reported by laboratory No. 9. Mean values for compounds No. 14 to 20 are based on 17 laboratories and do not include values reported by laboratory No. 9.

## DEFINITIONS

- CERCLA**—Comprehensive Environmental Response, Compensation and Liability Act of 1980  
**NCALP**—National Contracts Laboratory Analytical Program  
**GC/MS**—Gas Chromatography/Mass Spectrometry  
**IFB**—Invitation for Bids  
**PE**—Performance Evaluation  
**GC**—Gas Chromatography  
**VOA**—Volatile Organics Analysis  
**SOP**—Standard Operating Procedure  
**DFPPP**—Decafluorotriphenylphosphine  
**BFB**—p-Bromo-fluoro-benzene  
**RIC**—Reconstructed Ion Chromatogram  
**PCB**—Polychlorobiphenyl  
**BHC**—Benzene hexachloride  
**HSL**—Hazardous Substance List  
**ASTM**—American Society for Testing and Materials  
**AOAC**—Association of Official Analytical Chemists

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# BIOLOGICAL SAMPLING AT ABANDONED HAZARDOUS WASTE SITES

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## INTRODUCTION

The Field Investigation Team (FIT) for the USEPA Region II has investigated over 200 uncontrolled hazardous waste sites. Activities at these sites included extensive sampling programs to determine the extent of contamination. Standard approaches to characterizing a site included the sampling of soil/sediment, surface waters, groundwater, leachate, drums, oil, and gas vents, the drilling of monitor wells, and the monitoring of ambient air. At sites where extensive surface water contamination was suspected, biological sampling was part of an integrated approach to site investigation.

Many studies of water pollution have concentrated on chemical or physical parameters, however, the principal effect of water pollution is on biological organisms.<sup>1</sup> Most aquatic organisms have very narrow tolerance limits for any environmental changes. Changes in pH as a result of acid rain, minimal increases in metal concentrations, or organochlorine insecticides have affected aquatic organisms at all trophic levels.<sup>2,3,4</sup> Aquatic organisms can act as natural monitors and even during short-term exposure to water pollution will exhibit changes in their community structure. Traditionally, biologists will sample an area of an impacted community and an area of a control or unaffected community.

Organisms are identified to a species level and compared numerically using a diversity index. A healthy community, generally, is characterized by having a large number of different kinds of organisms—high diversity index—rather than a large number of a few species. Unfortunately, this method is time-consuming and expensive. Alternate diversity indices such as the Sequential Comparison Index (SCI)<sup>5</sup> which do not require any taxonomic expertise since specimens are compared one-to-one, are still time consuming.

While diversity indices will reveal whether the aquatic community has been exposed to pollutants, it does not identify specific pollutants or in what concentrations they are present. Since abandoned hazardous waste site investigations are directed toward specifically characterizing possible impacts tissue analyses of aquatic organisms are necessary. Programs initiated by the states<sup>6,7</sup> and federal government<sup>8</sup> have monitored priority pollutants present in the species of aquatic organisms human beings consume for several years. Very few studies exist, however, which investigate the effects of specific hazardous waste sites on aquatic organisms.

Biologists routinely conduct aquatic bioassays to test the toxicity of various pollutants. However, it is difficult to predict in a natural environment that a given concentration of chemical will cause a given amount of stress. The interaction of favorable and unfavorable stresses may result in the organisms concentrating pollutants at levels which are toxic to human beings<sup>9</sup> but not to the animals. If a particular site is contributing to an aquatic environment's contamination, tissue analyses will be required to determine what chemicals are being accumulated by the organisms and in what concentrations.

In this paper, the authors discuss the design and execution of biological sampling programs and present a detailed case study.

The names, specific locations, and identifying characteristics of sites mentioned in this paper have been changed.

## DESIGN AND EXECUTION OF BIOLOGICAL SAMPLING PROGRAMS

During 1981 and 1982, the Field Investigation Team concluded extensive biological sampling efforts on five sites, one in New Jersey (site A), one in New York (site B) and three in Puerto Rico (sites C, D, and E) to determine the effect of priority pollutants on aquatic fauna. The criteria for the selection of these five sites, the design of the sampling programs, sampling equipment, and sample handling procedures for each are discussed below.

### Criteria For Site Selection

Three criteria were considered to determine if the potential existed for aquatic ecosystem impact. The first criterion was location. All five sites were located sufficiently close to water bodies to permit direct surface and/or subsurface discharge of contaminants. Direct discharge to surface water was either observed or the potential for subsurface discharge was substantiated by staff hydrogeologists.

The second criterion was a history of uncontrolled disposal of hazardous materials at the site. The existence of compounds readily accumulated by aquatic organisms, such as polychlorinated biphenyls (PCBs) and mercury, were either documented through previous testing or disposal records or were alleged by knowledgeable individuals within local environmental agencies.

The final criterion was the regular utilization of the adjacent water bodies by sport and/or sustenance fishermen. The three water bodies in Puerto Rico were extensively utilized by local residents as a major source of food.

In addition, consideration was given to the usefulness of the resulting data in the development of an enforcement case. This was a major factor at the New Jersey and New York sites. Additional information demonstrating the detrimental impact of the sites was beneficial to the appropriate environmental agency's case against the site operators.

### Sampling Program Design

The biological sampling programs were designed to be site specific. Each program considered accessibility, expected aquatic fauna, sampling equipment and potential health hazards to sampling personnel.

Sampling stations were tentatively identified after preliminary investigations. The initial selection of the sampling stations was designed to permit statistical comparisons between aquatic fauna from contaminated and uncontaminated areas. In the cases of sites A, B, and C, sampling stations were located upstream, adjacent to, and downstream of the points of known or suspected discharge, permitting classical upstream-downstream comparisons. Site A is described in greater detail in the case study section. Site D was located near the head of the potentially impacted stream thus permitting only downstream observations. Site E had potentially

impacted two large lagoons and a stream. A model of ideal locations for sampling stations is presented in Fig. 1. Station locations were occasionally modified during sampling operations due to unforeseen accessibility problems and also to utilize local sampling equipment.

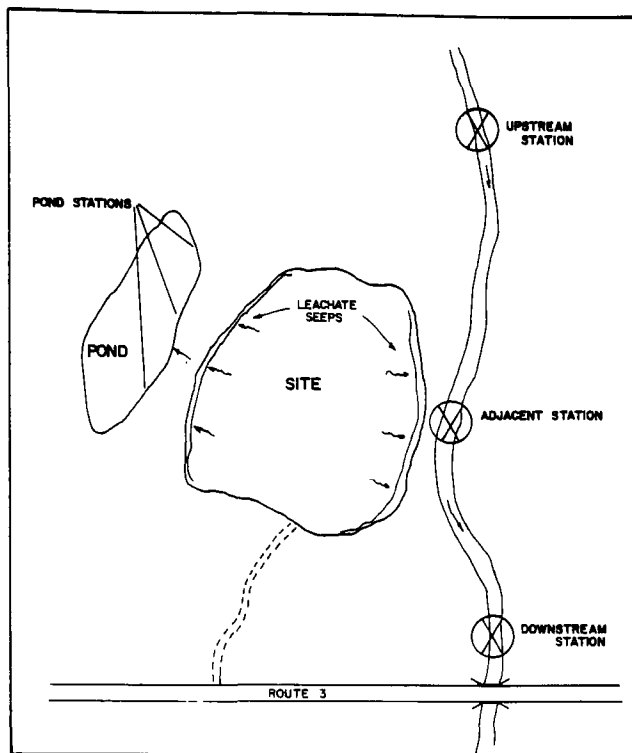


Figure 1.

Model of Ideal Locations for Biological Sampling Stations

An attempt was made to collect a variety of aquatic organisms from the water bodies near each site. Species selection included such considerations as organisms most apt to concentrate contaminants, organisms with limited mobility and thus greater potential for exposure, organisms sought by local fishermen and organisms within the various trophic levels to determine where pollutants were accumulating in the ecosystem. Organisms most likely to accumulate pollutants included predacious fish and organisms with high body lipid or fat concentrations such as eels and carp. Less mobile species included small fish and sediment dwelling invertebrates. Species sought by anglers were determined by observation and discussion with government fishery biologists and local residents. Additional modifications to the sampling programs were then made during implementation because all desired species were either not caught or were not caught in sufficient numbers for laboratory analysis.

### Sampling Equipment

The selection of sampling equipment was determined by characteristics of each site such as water depths, stream versus pond, water conductivity, stream bed consistency and expected organisms. A brief description of equipment used at each site, including methodologies, is presented below. Examples of equipment utilized are presented in Fig. 2.

**Site A**—The water bodies were narrow, steep-banked, soft-bottomed, tidal creeks which precluded the use of large nets. The creeks were slightly brackish so electrofishing units could not be used. Minnow traps were selected because residential small fish were known to inhabit the creeks. Traps were baited and set for approximately 24 hr. The stream banks were inhabited by burrowing crabs. Shovels were used to dig these organisms out of burrows. Site A is discussed in further detail in the case study.

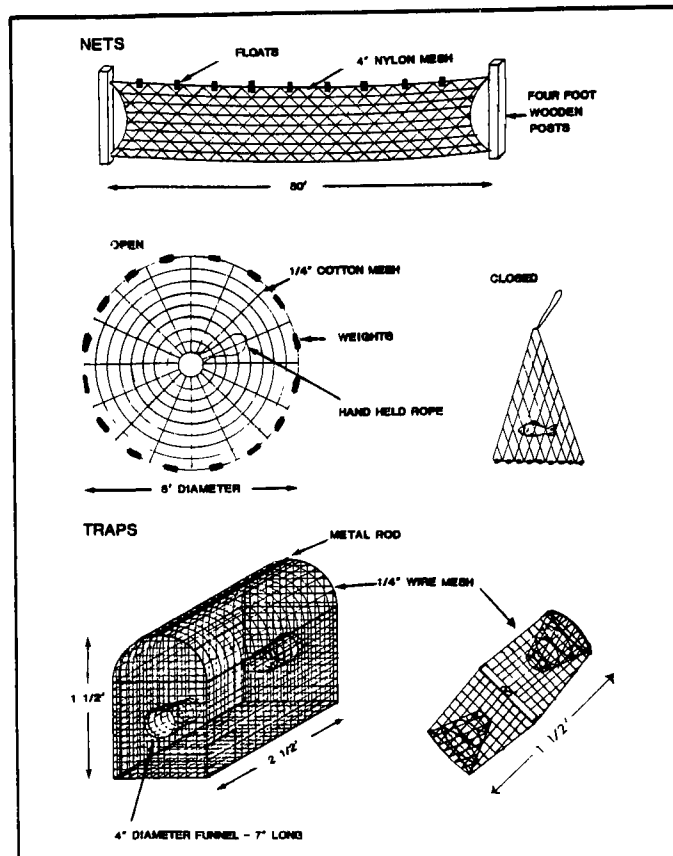


Figure 2.

Examples of Equipment Used to Catch Aquatic Organisms

**Site B**—The stream adjacent to this site had a firm bottom and was shallow enough to be waded. A portable back pack type electrofishing unit was used since it permitted efficient sampling of pooling areas adjacent to stumps and undercut banks. Sweeps of approximately 200 ft stream sections were made at the three sampling stations. Stunned fish were collected using dip nets.

**Site C**—The stream adjacent to this site also permitted the use of a portable electrofishing unit and was sampled similarly to site B. Large freshwater shrimp which also inhabited the stream were collected using the electrofishing unit. Galvanized steel minnow traps and local fish traps were baited and set.

**Site D**—A variety of sampling equipment was utilized at this site because of the different types of aquatic habitats. A small seine was used along the banks of the lagoons. Local fishermen also assisted with setting circular throw nets and setting and hauling an 80 ft gill net by boat. Hooks-and-lines were also utilized because of a recommendation from local fishery biologists.

**Site E**—Biological sampling at this site was not originally scheduled during the trip to sample Sites C and D. However, conversations with local environmental officials revealed potential mercury contamination. Oysters were then observed in the area of the suspected discharge. These organisms were chipped from the sides of a concrete dike using a hammer and screwdriver. To determine if contaminants were reaching a nearby bay, fresh fish caught within the bay were purchased from local fishermen.

Consideration also had to be given to the protection of personnel from exposure to chemical and biological hazards. Several of the sampling stations at Site A were in an area that required respiratory and skin protection. Cartridge respirators, waders and protective gloves were worn during the sampling operations. Two sites in Puerto Rico, Site C and D, were located in freshwater areas of the island where the parasitic trematode, *Schistosoma masoni*, occurs. This parasite is transmitted to humans, its final host, via contact with water. Contact with the surface water at Sites C and

D was minimized. Waders were worn at all times as well as elbow-length water proof gloves. Rain gear and hard hats with face shields were occasionally worn. When contact did occur, the areas of the body were flushed with rubbing alcohol and abraded with rough cloths. Aquatic organisms collected at these sites were frozen before processing to kill any remaining parasites.

### Sampling Handling

An important aspect of the biological sampling programs was handling and processing samples for tissue analysis. Care was taken to prevent tissue decomposition which could result in the breakdown of organic contaminants. Cross-contamination of samples from different species and stations was also avoided. Procedures followed were generally consistent with those prescribed by USEPA, NY Department of Environmental Conservation and NJ Department of Environmental Protection.<sup>10,11,12</sup>

Tissue decomposition was minimized by icing the organisms until they could be processed or frozen for processing at a later date. Dry ice was utilized for quick freezing when available. The samples taken in Puerto Rico presented unique problems because of high temperatures, difficulties in procuring ice and dry ice in remote areas, and parasite contamination. The collected organisms were packed in ice in coolers and shipped overnight to a laboratory facility where they were frozen.

The preparation of tissue samples for laboratory analyses was conducted under both field and laboratory conditions. All equipment coming in contact with the samples was detergent washed and solvent rinsed with methylene chloride. This cleaning procedure was repeated between samples from each station and between samples of each species.

The size of the fish collected determined the processing technique. Larger fishes were filleted while smaller fishes were scaled, deheaded, detailed and eviscerated. The shells of the oysters were removed while whole body samples of crabs and shrimp were used. The prepared tissue from each sample was either minced or homogenized in a blender and placed in detergent washed, solvent rinsed glass jars with Teflon lined lids. The prepared samples were frozen, packed in ice or dry ice in coolers and shipped overnight to contract laboratories for analysis.

Field processing of samples presents logistical problems and should only be attempted when a large number of samples is not planned. Field processing requires establishing a temporary work area with equipment such as scales, measuring boards, glass trays, and knives. The work area must provide a clean environment to prevent contamination of samples during processing. When conducted out of doors consideration must be given to possible adverse weather conditions such as extremely high or low temperatures, precipitation and winds which may carry contaminants. Provisions for cleaning equipment between samples, discarding used solvent, and disposing of unused portions of the organisms must also be made.

### CASE STUDY

Site A landfill is located adjacent to a tidal wetlands near a heavily populated area. During the 1970s several thousand drums were buried at the site. A lagoon formed east of the landfill and was observed to be flowing into a tidal creek, Creek A, at a point north of the landfill (Fig. 3). The USEPA initiated action and to intercept, store and remove the leachate for proper disposal on an interim basis. The total quantities of leachate which drained into Creek A are unknown. Samples collected from 1978 to 1980 by the USEPA from leachate seeps surrounding the landfill identified numerous hazardous organics and levels of PCBs ranging from 1 to 200 mg/l.

In 1981, Fred C. Hart Associates, Inc., acting as the Field Investigation Team (FIT), was directed by the USEPA to conduct a biological sampling program to determine if an impact of the lagoon discharge on aquatic organisms could be demonstrated. A reconnaissance of the area was conducted in late fall to determine the accessibility of the creeks.

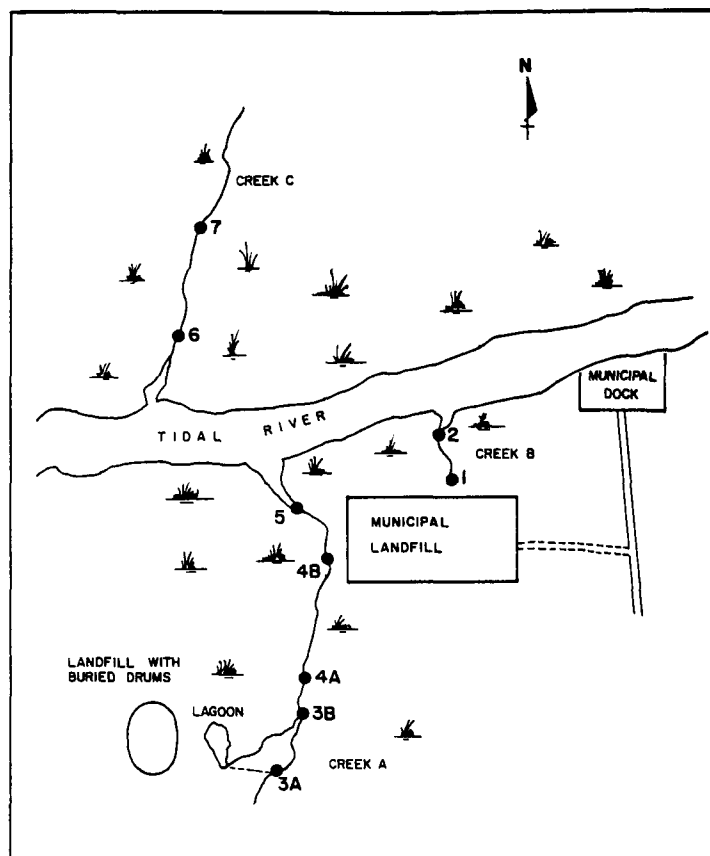


Figure 3.  
Site Map and Sampling Station Locations

Seven sampling stations were initially selected (Fig. 3). Stations 1 and 2 were located at the head and near the mouth of Creek B, respectively. Three stations were initially established on Creek A: 3A, 4A, 5. Station 3A was thought to be located at the discharge point of the lagoon. During the actual sampling, station 3A was determined to be a minor discharge point. The primary point of entry of lagoon leachate was at station 3B. Station 4B was added during the invertebrate sampling program to provide a point approximately midway between the leachate discharge and the mouth of Creek A. Stations 6 and 7 were located on control Creek C, near the mouth and upstream, respectively.

The study design was based on "after-impact" data and analyses of the lagoon's impact were complicated by the location of the town-operated municipal sanitary landfill. Creek B was selected to assess separately any effect of the municipal landfill on aquatic organisms.

Tissue samples were collected from minnows, eels, fiddler crabs, shrimps, mud crabs, and amphipods. Sediment samples were collected from the channel bottom and marsh soils on the creek banks adjacent to the sampling stations. Water samples were also collected.

Two 12 ft aluminium boats with small outboard motors each manned by two FIT members were used to approach the sampling stations since the channels were surrounded by a tidal marsh and steep, soft creek banks made it very difficult to conduct land operations. FIT members wore cartridge respirators in Creek A, and waders and neoprene gloves in all creeks. Each boat had one walkie-talkie to maintain contact with a land-based observer on top of the municipal landfill. Line-of-sight observation was not possible for the land-based observer when the boats were in Creek C. The boats, however, maintained sight contact with each other at all times.

Sampling in Creek A was complicated by the presence of three oil booms, contaminated sediments and the proximity to the lagoon. FIT personnel occasionally became stuck in the mud during

sample collection. Strenuous physical exertion was necessary to remove the waders and FIT member from the mud. Cartridge respirators, although necessary because of the close proximity to the lagoon, were difficult to use while breathing heavily.

Galvanized steel minnow traps were selected for fish collection based on the species captured during short seine hauls taken during the preliminary reconnaissance. The traps were baited with bread and raw chicken, tied to bricks and floats, and placed in the deepest area of the channel at stations 1, 2, 3A, 4A, 5, 6, and 7.

The traps were retrieved after approximately 24 hr. All fish collected were the common mummichog *Fundulus heteroclitus*. The fish from each trap were placed in prepared 16 oz. wide-mouth jars. The jars were capped with Teflon-lined lids and iced in a cooler. Excess fish from the traps were returned to the water. Two eels were captured, one from station 3A and one from station 7. They were placed in separate sample jars and iced. The iced fish were transported to the laboratory and frozen.

Fiddler crabs, *Uca Minax*, were dug from the creek banks where they were hibernating, at stations 1, 2, 3B, 4B, 5, 6, and 7. Dip nets were used to capture shrimps, *Palaemonetes sp.*, wherever sufficient weights for analysis of crabs were not collected. A few mud crabs, *Rhithropanopeus harrisi* and amphipods, *Gammarus sp.*, were also included in many of the invertebrate samples. The fiddler crabs accounted for at least 90% of the sample weight at all stations except 6 and 7, where the crabs accounted for approximately 50%. The crabs and other invertebrates were thoroughly rinsed with creek water at each station to remove adhering sediments. Rinsed invertebrates were placed in plastic bags and iced. The samples were transported to the laboratory and frozen.

Trap retrieval and invertebrate sampling were done simultaneously with sediments and water sampling. Problems during trap retrieval included difficulties in maintaining a stationary boat position due to swift currents, and motor failure due to extremely cold weather. Maneuvering the booms in Creek A also proved difficult due to the strong current.

Fish samples were prepared for laboratory analysis by the following procedure. The fish from each station were partially thawed and then placed in a glass tray. After it was measured and weighed, each fish was beheaded, detailed and eviscerated. The fish bodies were then minced with a stainless steel knife. Appropriate modifications of the protocols developed by the New Jersey Department of Environmental Protection<sup>12</sup> for cleaning equipment and preparation of fish flesh for tissue analyses were used to prevent cross-contamination between stations. Composites for the fish from each station were placed in two prepared sample jars, one for organics analysis and one for metals analysis. The jars were capped with Teflon-lined tops and refrozen. The two eels were similarly prepared, but only for organics analysis. Whole body composites of the invertebrates were prepared similarly. During evisceration of the fish, the incidence of internal parasitization was also recorded.

**Table 1.**  
PCB Concentrations (ppm) in Vertebrates,  
Invertebrates, and Channel Sediments

Location	Vertebrates	Invertebrates	Channel Sediments
Station 1	0.94	0.27	ND*
Station 2	2.0	0.36	1.42
Station 3A	5.5 1.8 (eel)		0.08
Station 3B		6.30	67.80
Station 4A	6.0		9.78
Station 4B		2.92	
Station 5	8.6	2.25	2.08
Station 6	0.64	0.24	ND
Station 7	0.71 1.6 (eel)	0.61	ND

\*Detection limit was 0.1 ppb

## Results

The results of the organics analyses are shown in Table 1. Vertebrates, unless otherwise specified, are the common mummichog, *Fundulus heteroclitus*, and were collected at all stations sampled. More eels were not collected since large adults move downstream in autumn. It is clear that animals collected at stations 3 through 5, Creek A, had levels of PCBs significantly above the values found in Creeks B and C. Elevated levels of PCBs were also present in the channel sediment of Creek A. Metal analyses of the tissue samples revealed elevated levels of aluminum in both fish and invertebrates in Creek C. Cadmium was detected at higher levels in the invertebrates tissue samples from stations 4B and 5 (Creek A) and was detected in a water sample at station 3A.

Before the fish were prepared for tissue analysis, each fish was measured for total length, weighed and examined for gross deformities, abnormalities = , and parasites. The mean total lengths, condition indices, and percent of fish parasitized in the three weeks are shown in Table 2. The condition index, a measure of the robustness (relative health)<sup>13</sup> for total length  $K_{tl}$  was calculated for each specimen. An analysis of variance (ANOVA) was used to compare the total lengths in the three creeks. Statistically significant differences were noted in the length of Creek A mummichogs compared to the other two creeks; mummichogs in Creek A were significantly smaller. Examination of the correlation coefficients suggested that PCB concentration may be responsible for the difference in total lengths. The condition factor also exhibited the pattern of less healthy fish in Creek A.

**Table 2.**  
Comparison of Mean Total Length (TL), Condition Index  
( $K_{tl}$ ), and Percent of Fish Parasitized

Location	TL (cm)	$K_{tl}$	%Parasitized	N
Station 1	7.19	1.55	5	58
Station 2	8.25	1.38	0	46
Station 3	6.83	1.08	50	62
Station 4	7.53	1.30	33	72
Station 5	7.60	1.41	3	59
Station 6	8.55	1.38	0	44
Station 7	8.17	1.47	0	45

Note:

TL = total length (cm)

$K_{tl} = (W \times 10^3)/TL^3$ , where W = fish weight(g)

N = number of fish

Parasites were found during evisceration within the abdominal cavity of the fish and appeared to be a single species, probably a monogenetic trematode, commonly found in mummichogs. No external parasitizations, fin-rot, or other fungal diseases were recorded. The incidence of parasitization did not correspond to previously established baselines on seasonal parasite burden (which for winter should be zero) or the relative size of the mummichogs.<sup>14</sup> Gross deformities were recorded, however, on the eel collected from Creek A. The eel had ulcerations and tumors on its skin as well as internal parasites. In contrast, the eel collected from Creek C had no parasites or deformities.

The concentration of PCBs found in the tissue analyses did not appear to be acutely toxic to the mummichog. However, the striking incidence of parasitization in the fish and statistically significant lower total lengths and  $K_{tl}$ s of the organisms in Creek A suggest sublethal effects that may be related to the leachate discharging from the lagoon. Sublethal reproductive, physiological, and morphological effects of low concentrations of PCBs (1 to 5 ppb) have been documented for fish and fish which were not adversely affected at the time of initial exposure later succumbed to fungal disease.<sup>15</sup> Additionally, negative interactive and synergistic effects of salinity, temperature, and PCB concentration on survival and developmental rate of chronically exposed fish are documented.<sup>16</sup>

The high levels of PCBs found in the aquatic organisms led to questions by the USEPA on the local population's fishing habits, since the mummichog is a forage fish often consumed by piscivor-

FISH INVESTIGATION FORM  
Catch & Effort Form

DATE: \_\_\_\_\_

LOCATION: \_\_\_\_\_

Trip Type: Pier, dock \_\_\_\_\_  
 Jetty, breakwater \_\_\_\_\_  
 Bridge, causeway \_\_\_\_\_  
 Other man-made \_\_\_\_\_  
 Beach/Bank \_\_\_\_\_  
 Party boat \_\_\_\_\_  
 Charter boat \_\_\_\_\_  
 Private or rental boat \_\_\_\_\_

Effort: Departure time \_\_\_\_\_  
 Return \_\_\_\_\_  
 Hours fished \_\_\_\_\_  
 No. of Anglers \_\_\_\_\_  
 Residence: State \_\_\_\_\_  
 County \_\_\_\_\_

Catch data:	Species	No. Caught

Are you going to sell any of your catch? \_\_\_\_\_

Boat type: \_\_\_\_\_ Length: \_\_\_\_\_ Trailer \_\_\_\_\_

Total # of trips/season \_\_\_\_\_

Type of Fishing Equipment: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Observed Level of Fishermen Activity:

	No. of Fishermen
High	_____
Average	_____
Low	_____
None	_____
Unknown	_____

Figure 4  
Catch-and-Effort Form

ous species. The FIT was then directed to find out what and where people were catching fish in the tidal river. The FIT developed a catch-and-effort form (Fig. 4) and then conducted a half-day car survey of both banks of the tidal river within 10 miles of Creek A to determine where local fishermen had access to the river. The municipal dock next to the municipal landfill was one of two within the car survey radius that provided easy and convenient access for local fishermen. Fishermen crabbed, and caught, and ate several species of fish directly off the boat municipal dock. A large part of the information gathered in interviewing the fishermen was anecdotal or historical in nature. The FIT limited data to reports of fish caught on the survey data or within the previous week.

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# **CORRELATION BETWEEN FIELD GC MEASUREMENT OF VOLATILE ORGANICS AND LABORATORY CONFIRMATION OF COLLECTED FIELD SAMPLES USING THE GC/MS**

## **EXTENDED ABSTRACT**

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### **INTRODUCTION**

A procedure has been developed involving a two phase monitoring program to monitor low levels of volatile organics in ambient air. The first phase involves field measurements using a sensitive portable gas chromatograph with a photoionization detector capable of determining most common organic solvents in the range of 0.1 to 20 ppb.

Variations in sensitivity depend on the electronic nature of the molecule. Sensitivities vary in the general order of chlorinated ethylenes > aromatics > oxygenated solvents > chlorinated alkanes > saturated hydrocarbons. Field measurements are typically performed over a 1 to 2 day period using syringe-collected air samples directly injected into the GC. Sample size can range up to 10 cm<sup>3</sup> and down to 1 µl.

In order to determine the overall concentration range of volatiles, two other field instruments are employed: (1) a non-selective organic vapor detector (with sensitivity of around 0.5 ppm) and, (2) a portable FID GC with sensitivity in the 0.2 ppm range for some volatiles. Differentiation between ambient hydrocarbons (Methanes and automotive exhaust) and solvents is easily achieved on either GC.

Once the areas of concern are defined, a few laboratory samples are collected over 4 to 8 hr periods for laboratory GC and GC/MS analysis. Samples are collected on pre-cleaned activated charcoal and/or Tenax packed in stainless steel tubes. Typical volumes for integrated samples are 5-30 liters.

The laboratory analysis is performed using a Programmed Thermal Desorber which desorbs the contents of the field sampler into a 300 cm<sup>3</sup> teflon lined piston from which aliquots can be withdrawn for GC analysis or GC/MS confirmation.

### **DETAILED STUDY PLAN**

Based on the results of this first phase, a detailed field study plan is formulated. At this point, the field and laboratory data from phase 1 have delineated the volatile organics of concern and the general areas of significant impact around the site.

Field collection of the second phase samples is again done on pre-cleaned charcoal and/or Tenax tubes. Laboratory standards are prepared for any of the solvents detected in phase 1 and collection-desorption efficiency studies are inaugurated for any compounds encountered in phase 1 for which the laboratory has no prior data.

Field sample tubes are carefully preserved against contamination after pre-cleaning by storage in individually sealed containers and field blanks are included with each study. Samples are transported in metal cannisters containing charcoal and are refrigerated after collection and in the laboratory until analysis.

In the laboratory, analysis is performed using the Programmed Thermal Desorber, GC-PID and GC/MS. Appropriate standards are prepared fresh for all volatiles found in phase 1 and both the GC and GC/MS are calibrated using these standards.

For GC/MS analysis of aliquots from the PID, a large syringe is used to enable up to 60 cm<sup>3</sup> of vapor from the 300 cm<sup>3</sup> piston to be injected into the GC/MS. A dry purge and trap technique was developed and each sample is spiked with 1 to 3 internal standards that were not found in the phase 1 study. The internal standard is introduced into the syringe used to withdraw samples from the PTD just prior to injection into the dry P&T setup.

### **RESULTS**

To date, the correlation between initial phase 1 field data and final GC/MS confirmation quantitation and qualitative identification has been excellent. Often the entire problem is outlined in the first day of field work and tentative identifications are made using a set of field standards.

The overall technique described here is relatively simple to employ, produces answers in a rapid turnaround time and has been taught in two courses to Field Investigation Teams (FIT) throughout the ten USEPA regions. Several New England states are also getting ready to use the technique in their investigations of hazardous waste sites and chemical industry odor complaints.

The procedures described and the equipment used, especially the sensitive PID GC, will require a chemist with experience in gas chromatography. This instrument is sensitive to picogram quantities of volatile organics and hence requires careful work and scrupulous technique to prevent errors due to low level contamination.

Equipment\* described is supplied by the following: PID (Photoionization GC); Photovac, Inc. FID and PTD (Flame ionization GC and programmed thermal desorber); Foxboro Analytical.

\*Mention of trade names or commercial products does not constitute endorsement or recommendation for use by USEPA.



# A GENERALIZED SCREENING AND ANALYSIS PROCEDURE FOR ORGANIC EMISSIONS FROM HAZARDOUS WASTE DISPOSAL SITES

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## INTRODUCTION

Emissions of organic compounds from hazardous waste disposal sites (HWDS) can take place by a variety of routes, including gaseous emissions, liquid runoff, and solid emissions such as dust and other respirable particles. Analyses of each of these emissions are required to determine the environmental and health related impacts of HWDS. Also, analyses of solid and liquid materials at HWDS are important for assessing potential emissions and impacts of site disturbances. Normally, a wide variety of techniques is used to analyze solid, liquid, and gaseous environmental samples. When assessing emissions in all these phases from one site, the use of different types of analytical techniques can result in ambiguities when interpreting data, as well as increasing costs.

The purpose of this paper is to describe a versatile analytical technique capable of analyzing samples of air, water, or soil matrices. This technique is primarily for the determination of emissions of volatile compounds with a boiling point range of  $-100^{\circ}\text{C}$  to over  $200^{\circ}\text{C}$  covered during a single analysis. In addition, the technique responds well to a wide variety of compounds, including halogenated organics, sulfur-containing organics, aromatics, aldehydes, alkenes and alkanes. A variety of detectors have been used with this technique to provide generalized screening data, specific data on certain classes of compounds, or confirmatory data.

This technique basically consists of the following steps:

- Separation of volatile organics from the sample matrix
- Cryogenic concentration and focusing of organics
- Gas chromatographic separation using fused silica capillary columns
- Detection and screening using FID, PID, and HECD, in single or dual detector mode
- Sample component confirmation by mass spectrometry

The fact that the same technique can be used to analyze air, water and soil samples greatly simplifies the task of data interpretation. Application of this technique to prediction of volatile organic emissions from chemical wastewaters and soils will be demonstrated. In addition, good versatility accomplished through the use of multiple chromatographic detectors with respect to screening and/or confirmatory information for a variety of organic compounds was obtained. Applications of several combinations of detectors will be demonstrated.

## EXPERIMENTAL

A block diagram of the technique is presented in Fig. 1. The system was designed to accept air samples either directly from pressurized canisters, or from solid sorbents via thermal desorption. The system was also designed to transfer volatile organics in water samples to the gas phase via a liquid purge, and in soils samples via heated or ambient temperature solid purges.

After volatile organics from any of the waste site matrices were transferred to the gas phase, the purge gas (and organic constituents) was passed through a single tube Perma Pure<sup>®</sup> drier to remove moisture. Typical sample flow rates through the drier were 100 ml/min and purge rates were maintained at 1000 ml/min. The drier was heated to  $60^{\circ}$  and purged for 10-15 min between analyses. All organics were then concentrated and focused on a 15 cm. by 0.3 cm. o.d. nickel trap packed with 80/100 mesh glass beads and cooled in liquid oxygen ( $-183^{\circ}\text{C}$ ).

The design of the valving associated with the traps, and the efficiency of hydrocarbon collection have previously been described.<sup>1</sup> One modification of the design for this work was replacing the high precision pressure gauge with a high precision vacuum gauge (Wallace and Tiernan Model 61C-1A-0015) and evacuating the gas reservoir. The volume of gas passed through the cryogenic trap was calculated by monitoring the pressure differential of the evacuated gas reservoir.

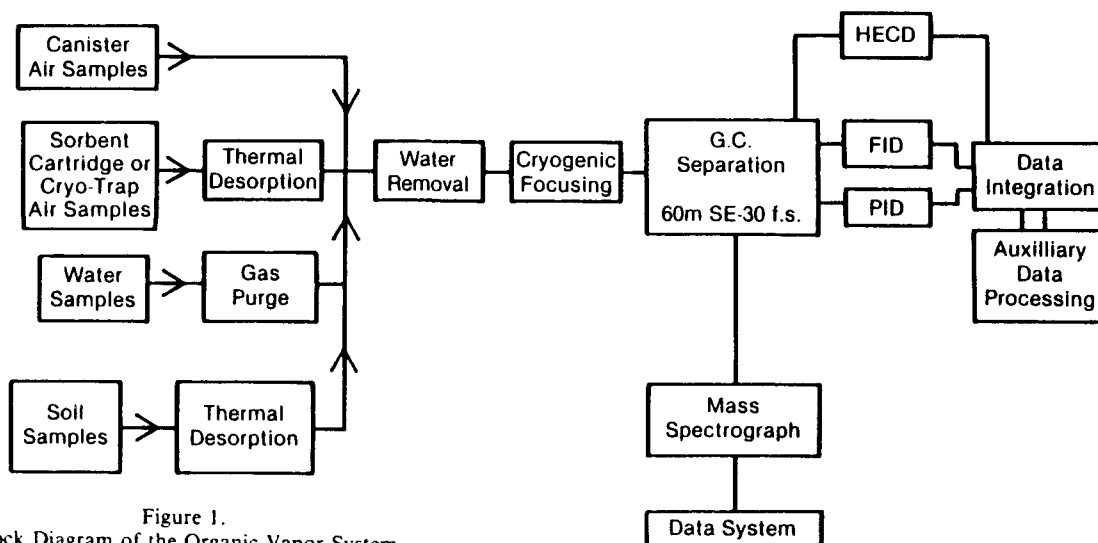


Figure 1.  
Block Diagram of the Organic Vapor System

Samples containing ppm level organic content were analyzed by direct injection to the cryogenic trap using a 5 ml gas tight syringe. Trap loading and injection flows were controlled using a two-position eight-port valve (Valco #V-8-HTa). The valve and associated stainless steel connecting tubing were heated to 60°C to avoid sample condensation.

Organic species were rapidly desorbed by immersing the trap in boiling water until the temperature of the trap reached 90°C. At that time (approximately 20 secs), the water bath was removed and the trap was heated to 180°C with a 750 watt heating cartridge (Watlow #J4A198). Trap temperatures were controlled with an Omega Model 4201 RTD Temperature Controller. Desorbed compounds were swept from the trap to the chromatographic column by the carrier gas. The transfer lines to the column were heat traced (60°C) 0.16 cm. o.d. stainless steel tubing.

For gas chromatographic analyses, separation of organic species was achieved on a 60 m SE-30 wide bore, thin film fused silica capillary column (J & W Scientific). The column was operated at an initial temperature of -50°C for 2 min, then temperature programmed to +100°C at a rate of 6°/min. The carrier gas was UHP grade helium at a rate of approximately 2 ml/min and a column head pressure of approximately 130KPa.

The output of the capillary column was split to two detectors simultaneously using a capillary splitter (Scientific Glass Engineering) which has been described. The instrument used was a Varian 3700 gas chromatograph with subambient temperature programming capabilities, dual flame ionization detectors (FID), a photoionization detector (PID), and a Hall electrolytic conductivity detector (HECD). For gas chromatographic/mass spectrometric analyses, separations were obtained on a 50 m DB-5 banded phase fused silica capillary column (J & W Scientific). This column was operated at an initial temperature of -20°C for 2 min, then temperature programmed to 60°C at 30°/min, and to 250°C at 4°/min. The instrument used was a Finnigan Model 4023 GC/MS. The spectrometer interface was direct source coupled, the scan range was 35-300 amu, and the ionization voltage was 70 eV.

Chromatographic data were processed using a Varian 401 Chromatography Data System. This served primarily as an integrator and transferred integrated data to an Apple II Plus Microcomputer which was used for quantitative and qualitative peak identification and calculation of relative response ratios for the various detector combinations. GC/MS data were processed by an INCOS computer utilizing searchable NBS libraries and manual spectral interpretation.

## RESULTS AND DISCUSSION

### System Performance

The unique aspects of these techniques are the ability to analyze air, water and soil samples using the same analytical system, and the wide range of compounds which can be determined through the various detector combinations. These aspects provide very cost effective techniques, as well as greatly simplifying data interpretation for predicting volatile organic emissions from various matrices. Analyses of air, water, and soil samples on the same analytical system were accomplished by transferring volatile organics to the vapor phase, removal of moisture, and cryogenic concentration and focusing. The transfer of volatile organics from solid sorbents was accomplished via thermal desorption. For water samples, the transfer was affected using a low-volume (5-10 ml) Bellar and Lichtenbergh apparatus. For soil samples, small quantities of soil (50-100 mg) were placed in an all glass sparging chamber and purged with UHP N<sub>2</sub> at ambient or elevated temperatures.

Analysis of soil and water in this manner provided an indication of organic vapor emissions which could occur during treatment or disturbances of the site. Analysis of air samples by the same technique provides a ready confirmation of emissions during treatment procedures or site disturbances.

The problem of moisture in the sample gas stream has mandated the use of a variety of different analytical techniques for air, water and soil analyses in the past. The use of capillary columns and

subambient temperatures have been hampered by moisture, which causes freezing at the head of the column. The single-tube Perma Pure® drier used for this work functioned very well for the removal of moisture and in the throughput of organic vapors. Recoveries of a variety of organic classes through Perma Pure® driers are presented in Table 1.

In general, good recoveries were obtained for low and medium molecular weight aliphatic and aromatic hydrocarbons, chlorinated hydrocarbons, aldehydes, and sulfur containing hydrocarbons. Low recoveries of alcohols and variable recoveries of ketones were obtained with Perma Pure® driers.

Fused silica capillary columns and subambient temperature programming were used to cover a wide range of organic compound volatilities and functionalities. With the SE-30 column, compounds with boiling points ranging from -100°C to +200°C could be determined in a single analysis. With the DB-5 column used for GC/MS, compounds with boiling points ranging from 36°C to 220°C were normally determined in a single analysis. Organic compound elution orders on both columns were essentially based on boiling points, which aided in chromatographic data interpretation, and in comparisons of GC and GC/MS data.

**Table 1.**  
Summary of Organic Vapor Recoveries Using Perma Pure® Driers

Class	Carbon No. Range	Concentra. Range (ppb-C)	No. Species Tested	Percent Recovery (%)
Alkanes	2-10	16- 280	19	95-106
Alkenes	2- 5	141- 204	8	100-101
Aromatics	6-10	167- 505	12	90- 99
Chlorinated Hydrocarbons	1-6	66- 206	6	99-104
Aldehydes	2-5	140-1400	6	84- 95
Ketones	3-5	28- 66	4	0-70*
Alcohols	1-5	25-1500	5	0

\*Change in drier permeability observed

### Correlation of Emissions

Correlation of organic vapor emissions from liquid and solid phases at HWDS can be difficult when different techniques are used to analyze various sample phases. Leachate from a HWDS was collected and tested using laboratory scale biotreatment chambers to determine if the leachate could be disposed of in this manner. Normally, these tests are performed by only monitoring influent and effluent concentrations of pollutants in the aqueous phase. In this case, the system aeration was carefully controlled to simulate large scale treatment facilities, and air purging through the system was collected and analyzed.

An analysis of the water influent to the treatment system (1/20 dilution of leachate with artificial sewage) using the purge technique which was described, and an analysis of air passed through the treatment system is shown in Fig. 2. Volatile chlorinated hydrocarbons as well as aromatics were observed in the air.

Even with the nonselective detector which was used in this case (FID), the correlation of organic components in air with those in the water is apparent. Species identifications in the water were confirmed by GC/MS. It is apparent from this study that during biotreatment of chemical wastes, air emissions as well as water effluent emissions should be monitored to properly determine environmental impact of the treatment.

### Multiple Detector Applications

The use of multiple gas chromatographic detectors with this technique provides generalized screening information as well as confirmatory data, depending on the application. Examples of various detector combinations on the analysis of different types of waste samples will be presented.

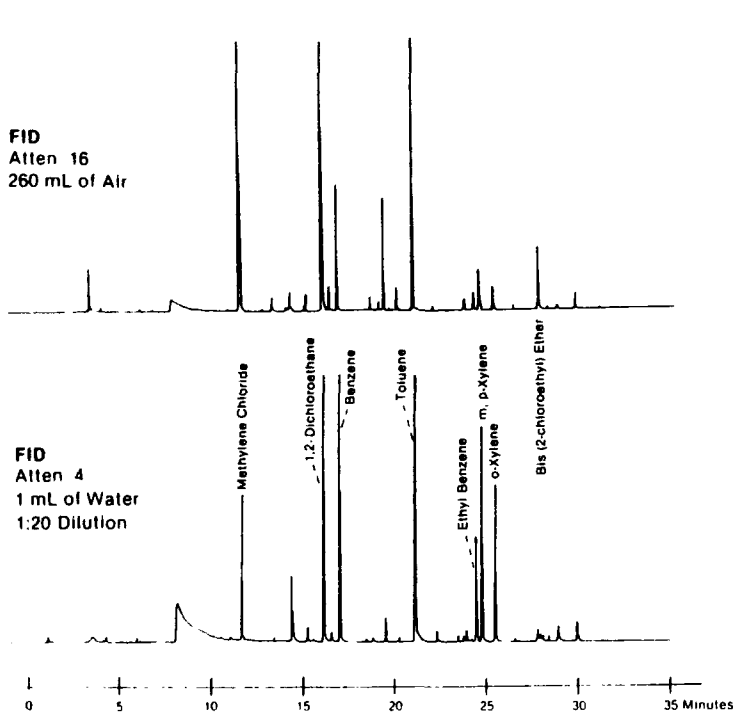


Figure 2.

Analysis of the Aqueous Influent and Treatment Air from a Bench Scale Biological Treatment Study of a Hazardous Waste Site Leachate

The combination of flame ionization and photoionization detectors provides a good generalized screening technique for organics present in ambient air. The flame ionization detector in general responds to compounds on the basis of carbon content; hence, it serves as a universal detector for hydrocarbons and is good for quantitative purposes. The photoionization detector responds to compounds based on their ionization potentials, which in turn is dependent on the degree of unsaturation in the molecule among other factors. By calculating a ratio of the response between the two detectors, it was possible to estimate the degree of unsaturation (and chemical class) for a compound producing a given chromatographic peak.

The chemical class information provided by the dual detector technique proved to be a valuable tool when used in conjunction with GC retention time data for species identifications. Normalized response data for a variety of volatile organic compounds on the two detectors have been developed.<sup>2</sup> Average PID/FID responses normalized to that of toluene (TNR) are presented in Table 2 for a variety of organic classes. These data were separated for those compounds eluting before and after 17 min (the time at which aromatics begin to elute).

This detector combination provides identification information for a wide variety of compounds, including alkanes, alkenes, aldehydes, ketones, aromatics, saturated and unsaturated halogenated compounds, and sulfur containing hydrocarbons. The versatility of this detector combination in combination with high resolution chromatography makes it ideal for screening air, water and soil samples from HWDS. An example of the analysis of air collected at a HWDS by this technique is presented in Fig. 3. The identification of a number of aldehydes, aromatics, and chlorinated aromatics is illustrated.

The Hall electrolytic conductivity detector (HECD) can be used in modes selective for halogenated, nitrogen, or sulfur containing compounds. When used in conjunction with the PID, the two detectors provide a range of unique types of information. Application of the HECD-halogen detector in conjunction with the photoionization detector for analysis of a mixture of halogenated and aromatic compounds is illustrated in Fig. 4. This figure demonstrates that with this technique, all of the US EPA 601 and

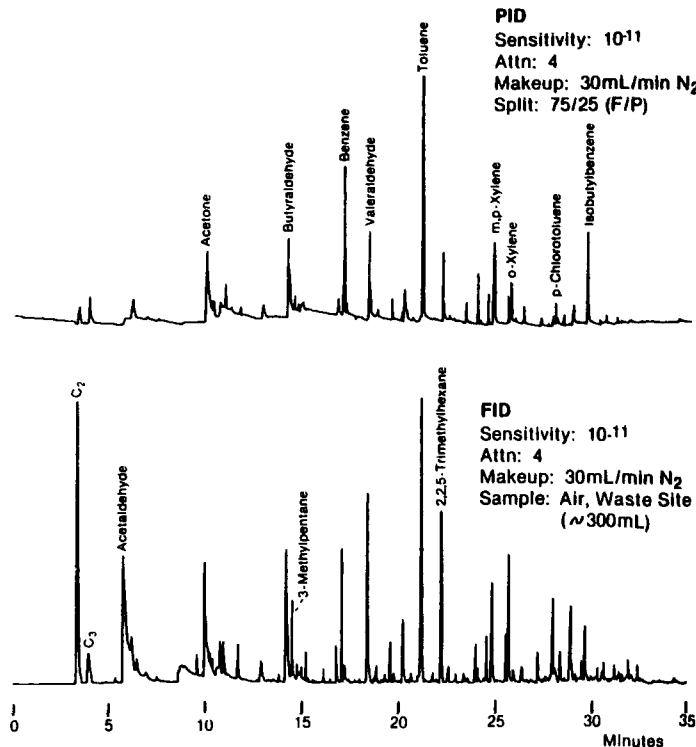


Figure 3.

Analysis of Air Collected Over a Hazardous Waste Disposal Site by Simultaneous PID/FID Detection

602 purgeable compounds<sup>3</sup> can be determined in a single analysis. All of the halogenated compounds were detected by the HECD, whereas nonhalogenated aromatics were detected only by the PID. In addition, the PID provides discriminatory information for halogenated compounds, since this detector only responds to the unsaturated halogenated organics.

Application of this technique to a chemical wastewater sample is shown in Fig. 5. Low concentrations of aromatics and higher levels of oxygenated compounds were detected by the PID. A number of different halogenated compounds were detected by the HECD. No response for the halogenated compounds on the PID confirmed that these species were saturated.

Table 2.  
Hydrocarbon Class PID/FID Normalized Responses (Ref. 2)

Class	Retention Times <17 min		Retention Times >17 min	
	Species Tested	TNR (Mean ± SD)	Species Tested	TNR (Mean ± SD)
Halogenated alkanes	9	0 ± 0	6	1 ± 1
Simple alkanes	13	3 ± 3	10	12 ± 4
Cyloalkanes + Trimethyl-alkanes	2	3 ± 1	5	27 ± 8
Alkynes	3	3 ± 3	0	---
Alkenes	23	70* ± 11	20	55 ± 10
Aldehydes	4	69† ± 10	1	56 ±
Ketones	2	157 ± 5	2	123 ± 25
Aromatics	0	---	21	---
Chlorinated Aromatics	0	---	7	141 ± 12
Chlorinated Alkenes	3	218 ± 180	4	211 ± 97
Sulfur Hydrocarbons	2	500 ± 210	2	129 ± 37

\*Does not include ethylene

†Does not include acetaldehyde

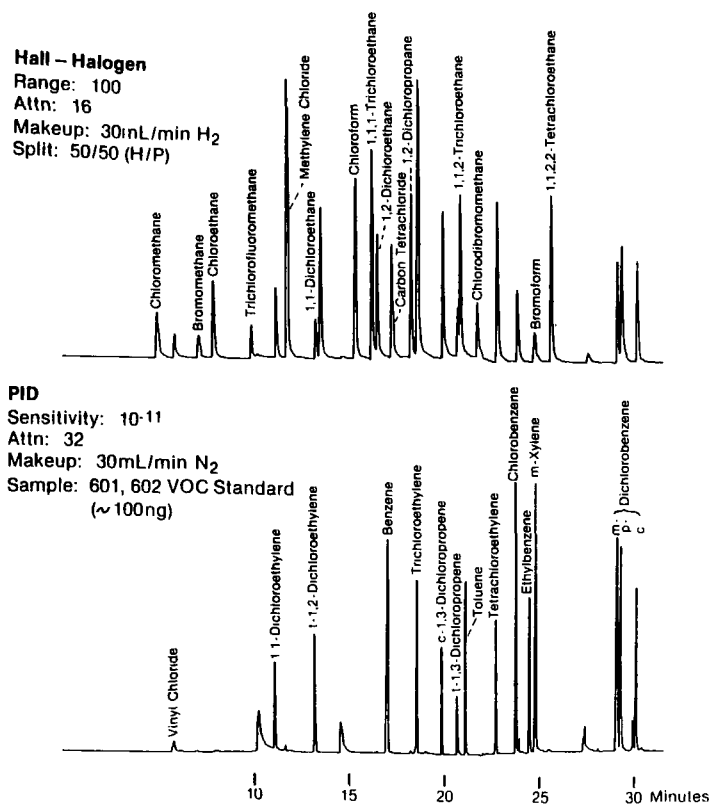


Figure 4.

Analysis of 601, 602 Purgeable Standards by Simultaneous HECD-Halogen and PID Detectors

The HECD can also be used in a mode selective for sulfur containing compounds. In addition, the PID gives a very strong response for sulfur containing compounds. The two detectors in conjunction provide confirmatory information for a variety of sulfur containing compounds. The PID does not respond to hydrogen sulfide or carbonyl sulfide, but gives very good responses for the mercaptans, organic sulfides, and thiophenes. The analysis of air collected during trenching operations at a HWDS by this technique is presented in Fig. 6. A large amount of sulfur dioxide was detected by the HECD, along with small quantities of several mercaptans and dimethyl thiophene. The PID did not give a response to SO<sub>2</sub>, but did give responses for the other sulfur containing compounds and a number of aromatics.

When samples from HWDS become too complex, or when a high degree of confirmation is required, GC/MS techniques must be used. The similarities in chromatography of the SE-30 column used for GC analyses and the DB-5 column used for GC/MS analyses simplify interpretation of data between these techniques.

## CONCLUSIONS

The techniques described in this paper provide a wide range of information concerning volatile organic emissions from hazardous waste disposal sites.

- The use of the same technique for analyzing air, water and soil samples simplifies the tracking of volatile emissions from soil or liquid wastes, as well as providing data necessary for prediction of emissions from HWDS.
- The use of multiple chromatographic detectors provides unique screening and class selective data, as well as cost effective analyses.
- Determinations of a variety of different compounds and organic classes from samples collected at HWDS were demonstrated.
- When complex samples or a high degree of confirmation is re-

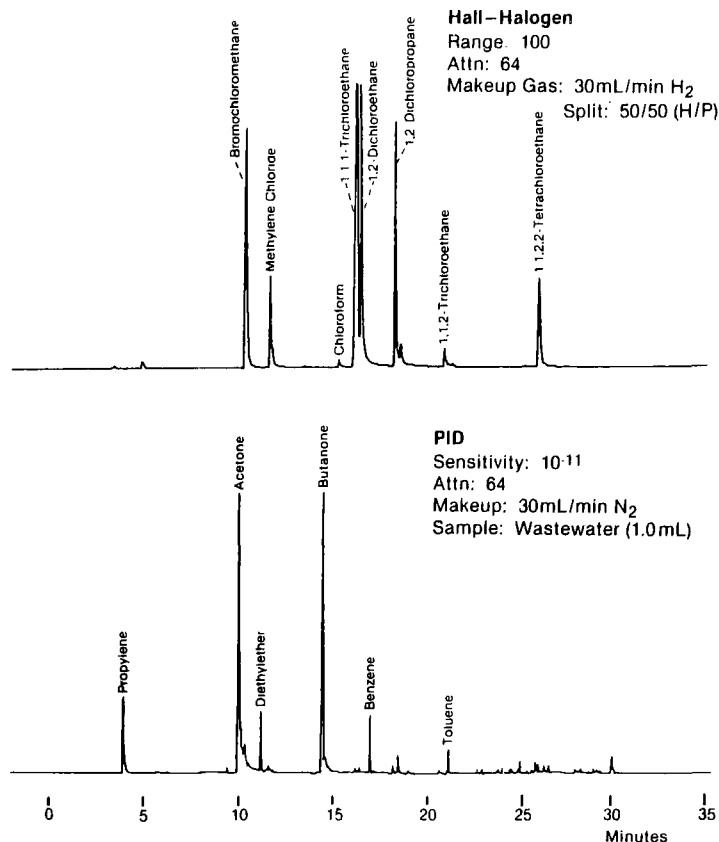


Figure 5.

Analysis of a Chemical Wastewater Sample by Simultaneous HECD-Halogen and PID Detection

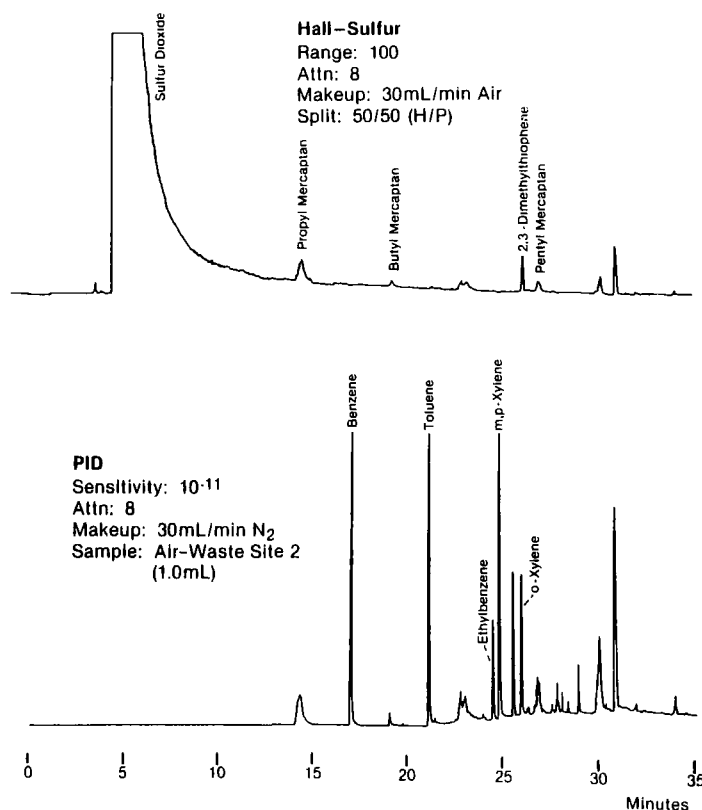


Figure 6.

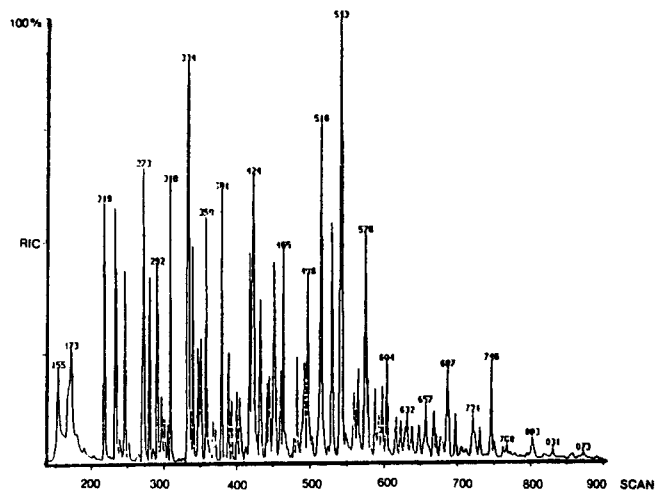
Analysis of Air Collected During Trenching Operations at a HWDF by Simultaneous HECD-Sulfur and PID Detectors

quired, GC/MS techniques were used.

- Comparisons of GC and GC/MS data were simplified by using similar columns and the same sample component separation and injection techniques.

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2. Cox, R.D. and Earp, R.F., "Determination of Trace Level Organics in Ambient Air by High Resolution Gas Chromatography with Simultaneous Photoionization and Flame Ionization Detection," *Anal. Chem.*, in press, Nov., 1982.
3. USEPA, "Guidelines Establishing Test Procedures for the Analysis of Pollutants," *Federal Register*, 44 (233):69468-69476 (1979).



### Compound Identification

Compound Identification	Scan No.
1. Butane	171
2. Trichlorofluoromethane	239
3. Pentane	247
4. Benzene	359
5. Toluene	442
6. Tetrahydrothiophene	487
7. Methyltetrahydrothiophene‡	539
8. Ethyl benzene	555
9. Xylene‡	567
10. Xylene‡	602
11. Dimethyltetrahydrothiophene‡	626
12. Dimethyltetrahydrothiophene‡	632
13. Dimethyltetrahydrothiophene‡	759
14. Ethyl tetrahydrothiophene	698
15. Trimethyl benzene‡	831

‡One of two or more structural isomers reported in this sample.

Figure 7.  
Reconstructed Ion Chromatogram of 100 mg Soil Sample  
Analyzed by GC/MS on 50 m SE-54 fsc.

# THE AIR QUALITY IMPACT RISK ASSESSMENT ASPECTS OF REMEDIAL ACTION PLANNING

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## INTRODUCTION

As part of the current federal activities aimed at cleaning up hazardous waste sites under Superfund, Roy F. Weston, Inc. (WESTON) has had remedial action planning responsibility for USEPA Regions III and V. To date, WESTON has had experience with a significant number of sites including both Superfund and municipally funded landfill problems. These sites have all had diversified air exposure risks associated with them, and have required differing levels of analysis. Some recent sites analyzed include:

- Chem-Dyne, Hamilton, Ohio—surface storage of drum and bulk waste, possible surface and subsurface disposal problems.
- Sylvester Landfill, Nashua, New Hampshire—contaminated groundwater migration to surface stream.
- Lehigh Electric, Old Forge, Pennsylvania—PCB contaminated soil, including coal fines, from leakage of stored transformers and capacitors.

At each of these sites, the total array of potential air exposure risks were not recognized because of the primary focus on hydrogeological concerns. Historically, the only air pollution emphasis involved: (1) the safety protocols set to protect on-site workers and (2) emergency planning to protect the surrounding community in case of an accidental release of hazardous chemicals. The benchmarks being used for such assessments were limited to Threshold Limit Values (TLVs) and Permissible Exposure Limit (PELs). Little or no consideration has been given to the off-site migration of low levels of potentially carcinogenic compounds during disturbed or undisturbed site conditions.

There are three steps in remedial action planning in which air exposure risks must be considered, both from a health impact and a liability point of view. The purpose of the authors in writing this paper is to identify and explain the necessary elements of such assessments as well as present several case studies where the air risk became a remedial action design criteria.

## SCOPE OF REQUIRED RISK ANALYSIS

There are many factors that must be considered when one is evaluating the air quality risk considerations of a hazardous waste site. The potential long-term carcinogenic risks associated with low pollutant concentrations emphasize the need for a careful analysis.

As mentioned above, there are three logical divisions in this type of evaluation. The first is an assessment of the present off-site risk before any type of action is considered since air risk considerations may be a remedial action design factor. This assessment would include an analysis of any existing air quality impact data. In each of the three sites noted in the introduction, there was no information concerning off-site pollutant migration simply because this pathway was seldom considered.

Oftentimes, the only air data available from hazardous sites consists of total organic concentrations given in the parts per million range, which is approximately the concentration that causes subacute health effects. Because of this data scarcity, the monitor-

ing requirements of the particular site must be assessed. In areas where the contents of the landfill or storage area are known, limitations may be placed on the number of toxics that may be sampled for and analyzed. This must be determined on a case-by-case basis.

The second major task is associated with the potential air quality impacts of remedial action alternatives. An air risk assessment of the candidate alternatives must be undertaken to predict the ramifications of whichever cleanup alternative is chosen. Technical alternatives which have potential air risks may include:

- Physical removal operations
- Air or steam stripping operations
- Chemical stabilization
- On-site combustion

Most remedial action alternatives are likely to increase the exposure risk in the short-term, so this increase must be monitored and controlled by instituting operational practices to minimize off-site exposures. For example, at the Lehigh site, dust suppression may be required to limit off-site transport of PCB-contaminated coal fines.

Regardless of the mitigating measures taken, the authors believe that a credible monitoring program should be conducted during the remedial activity to fully document any off-site exposures in order to preclude future liability. This monitoring program should be designed to quantify exposures at the most critical receptor areas. Body burden calculations can be made to estimate the potential impact of these exposures from a long-term, carcinogenic, point of view. The compressed short-term nature of this exposure must be taken into consideration when assessing the body burden.<sup>1</sup>

In addition to the low level body burden considerations of remedial action, the subacute off-site emergency type exposure potential must also be considered. This would include steps to be taken in the event of any significant release due to drum rupture, explosion, etc. Dispersion modelling should be employed to determine what on-site concentrations might cause potential problems off-site. Evacuation/notification plans should be developed accordingly.

The final phase of a complete air quality risk assessment deals with post-closure considerations. This would primarily consist of continued area monitoring over a short period of time where air risks were clearly identified as a remedial action problem. The purpose of this monitoring is to document the fact that air risks have been reduced to acceptable levels. This is an additional liability prevention step.

## HEALTH EFFECTS CRITERIA

In all segments of this assessment, certain criteria must be used to determine when a risk level is, or is not present. There is a good deal of uncertainty as to which effects criteria should be used especially when it relates to cancer risk. This controversy is one of the major hurdles which must be quickly overcome if the prevention of hazardous pollutant exposure is going to develop in a



uniform and rational fashion. WESTON has been using the following criteria to evaluate the range of risk levels of interest:

#### •Cancer Assessment Group Values (CAGs)<sup>2</sup>

These are recommended lifetime exposure limits to known carcinogens which have been developed by the USEPA for a limited number of toxic compounds. The CAG number represents maximum allowable concentrations that may result in incremental risk of human health over the short-term or long-term at an assumed risk. This assumed risk is the expected number of increased incidences of cancer in the effected population when the concentration over a lifetime equals the specified value.

The CAG values are listed in the "Land Disposal Toxic Air Emissions Evaluation Guideline" published by the USEPA in Dec. 1980. They represent a further refinement of carcinogenic assessment beyond the MEG values because of the compound specific nature of the toxicological evaluation involved with CAG documentation. Therefore, Cancer Assessment Group values should be used in all cases of conflict between MEGs and CAGs.

#### •Multimedia Environmental Goals (MEGs)<sup>3</sup>

The MEGs were developed in recent years by the Research Triangle Institute for the USEPA to meet the need for a workable system of evaluating and ranking pollutants for the purpose of multimedia environmental impact assessment. Consideration in arriving at these ambient level goals was given to existing Federal standards or criteria, established or estimated human threshold levels, and acceptable risk levels for lifetime human exposure to suspected carcinogens or teratogens, among others.

#### •Threshold Limit Value (TLV)<sup>4</sup>

TLVs are established by the American Conference of Governmental Industrial Hygienists as guidelines for prevention of adverse occupational exposures and are based on both animal studies and epidemiological findings and inferences. They refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed for eight hours a day, five days a week, without adverse effects. Many TLVs also protect against short-term aggravations such as eye irritation, odor impacts, headache, etc. However, TLVs do not represent the hypersusceptible minority of individuals. Additionally, by definition, they assume a daily period (non-working hours) of non-exposure time.

Many states have developed or are currently developing ambient air hazardous waste guidelines and regulations based on these TLVs. A common practice is to adjust the TLV for a 24 hr exposure and then divide by some large uncertainty factor. Common limits are TLV/300 - TLV/420.<sup>5,6,7</sup>

## CASE STUDIES

### Chem-Dyne: Hamilton, Ohio

The Chem-Dyne site consisted of approximately 40,000 waste-containing drums and 15 to 20 bulk storage tanks containing an unknown array of chemical substances. The site borders a residential neighborhood with a large adjacent recreational area complete with several ballfields and a swimming pool. Although not quantified, there was a concern that on-site contaminants were migrating off-site and impacting on the surrounding residents.

Prior to any remedial action undertaken by WESTON, state officials arranged for a large quantity of drummed wastes to be removed by the generators, leaving approximately 10,000 drums and the remaining bulk wastes.

The first step from an ambient air assessment point of view was to determine what the existing concentrations were before any on-site remedial activity began. This determination would help quantify existing levels and serve as a baseline. A comparison of baseline values with concentrations determined during operational phases would document increases due to on-site activity and also demonstrate ambient air quality improvement after the remedial activity is concluded and the site closed.

The background sampling program consisted of a two-day, five sample per day perimeter monitoring operation using USEPA recommended methodology.<sup>8</sup> One sampler was placed upwind and four spanned the appropriate downwind areas. During the actual sampling process, two samples per day were collected at downwind locations. This sampling protocol was limited by project budgetary considerations.

The monitoring identified 17 different contaminants leaving the site both prior to, and during the on-site remedial activities. Three of the most significant contaminants and the peak levels identified during the entire five-day operation are shown in Table 1.

Table 1.  
Selected Air Contaminants found at Chem-Dyne

Air Contaminant	Peak Concentration (ppb)	CAG Level (ppb)	Ratio Concentration/CAG
Benzene	19.2	0.065	295
Trichloroethene	1.8	0.44	4.1
Tetrachloroethene	0.62	0.194	3.2

Benzene presents the most danger to the surrounding population. Exposure concentrations of the magnitude determined, for even a short period of time (months to years), may cause an exceedance of the body burden calculations on which the CAG value is based, therefore, theoretically increasing the cancer risk in the area. The ambient air exposure route in the case of the Chem-Dyne site should be a determining factor in deciding upon various remedial action alternatives.

Furthermore, these documented levels will allow a comparison between pre- and post-closure site conditions. When all the wastes have been removed, a significant improvement in air quality should result. If, in fact, this does not occur the other emission sources such as contaminated soil must be analyzed to insure the health of the surrounding population.

### Nashua, New Hampshire

The problem at Nashua resulted from illicit dumping of approximately three million gallons of hazardous waste onto an illegally operated disposal site. Groundwater contamination was extensive and the groundwater plume was migrating toward a small nearby stream.

The air quality concerns involved the eventual interception of the groundwater plume with the stream and the subsequent volatilization of the organics. The air quality assessment dealt with the alternative of a no-action scenario, in other words, allowing the contaminated groundwater to meet the stream without any type of remedial action. The assessment of the potential ambient air impact associated with this site necessitated a completely different analytical protocol (Fig. 1).

Using various emission estimates<sup>9,10</sup> in conjunction with known contamination levels in the groundwater, a rate and period of volatilization was predicted above the stream. The expected atmospheric concentrations in a nearby trailer park were modeled<sup>11</sup> based on these emission rates. The predicted exposures for the most critical contaminants based on health effects considerations are shown in Table 2. The table shows the comparison of the permissible body burden exposures to the predicted exposures. Chloroform was the most critical contaminant, being 85 times above the criteria.

Table 2.  
Predicted Concentrations Downwind from the Lyle Reed Brook

Criteria	Contaminant	CAG or MEG (ppb)	Off-Site Concentration (ppb)	Long-Term Body Burden Exposure*	Ratio BB/CAG or MEG
CAG	Chloroform	0.033	10.0	2.8	85.0
CAG	Trichloroethylene	0.440	1.54	.44	1.0
MEG	Dimethyl Sulfide	20	3.7	1.04	.05
MEG	Methylene Chloride	200	95.0	27.0	.14

**Critical Parameters**

- estimate volume of contaminants
- range of measured concentrations of each contaminant in the groundwater
- varying groundwater flow rate
- contaminant flushing time
- varying concentrations in groundwater over time
- contaminant evaporation rates, i.e. hourly, daily, annual due to temperature, wind speed, etc.
- dilution rate of contaminant
- wind direction
- spacial distribution of exposed population downwind from the brook
- health impact criteria

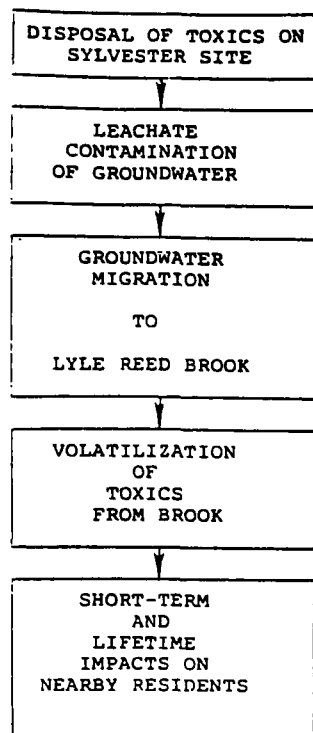


Figure 1.

A schematic of the basic processes which may cause short- and long-term ambient air impacts on residents living near the Sylvester Site.

The Nashua case is unique. No actual monitoring was feasible due to the nature of the problem, or rather the predicted problem, so no definitive information was available to determine ambient air concentrations. However, the emission estimation and the predicted off-site concentrations became a controlling factor in the particular remedial action alternative chosen, i.e., pump and treatment of the contaminated groundwater.

#### Lehigh Electric, Wilkes-Barre, Pennsylvania

This case represents another situation where the relevant ambient air pathway was initially ignored, but where subsequent modelling analysis showed potential off-site impacts.

The Lehigh Electric site had been an electrical equipment service and storage facility since the mid-1960s. In 1980, it was found that some of the site's 3,000 transformers, capacitors, and other electric apparatus had been leaking polychlorinated biphenyl (PCB) contaminated fluids. Subsequent on-site soil sampling and analysis revealed concentrations of up to 65,000 ppm.

The surface soil at the Lehigh site is dominated by coal fines with some ash and shale to the one-foot depth. The predominance of carbon in the fines is ideal for significant PCB adsorption. The PCB contamination as a fraction of coal particle size is shown in Table 3. There was not a sufficient sample fraction in the less than 45  $\mu$  size range to determine PCB contamination, but one would expect to find similar or higher PCB concentrations because of the higher surface area to mass ratio in the smaller particulate size range.

Table 3.

#### PCB Concentration on Coal Fines at Lehigh Electric

Particle Size ( $\mu$ )	PCB Concentration (ppm)
> 105	2500
45 to 105	3700
< 45	Insufficient sample

In the absence of appropriate low level particulate monitoring, an analysis of the ambient air PCB levels was determined through the use of a USEPA-approved model.<sup>12</sup> This model predicted par-

ticulate concentrations in the air from wind erosion, which corresponded to no on-site activity, and from on-site truck traffic, which would necessarily result from some remedial activity. This predicted particulate level was translated into a PCB concentration conservatively based on the 3,700 ppm PCB-contamination of coal fines in the mid-range.

The results of this modelling analysis indicated that simple on-site wind erosion would not yield significant concentrations of PCB's off-site. This assessment was based on the USEPA CAG value of 0.0075  $\mu\text{g}/\text{m}^3$  of PCB. When dilution and wind direction were taken into consideration, it was predicted that no off-site residential exposure would exceed the applicable CAG value.

However, when on-site activity which would include a moderate number of trucks and other equipment was considered, the model indicated that a potentially significant off-site concentration of PCBs might result. This assessment again was based on the CAG value, and in this case, further modified to account for the short time frame of the on-site activity compared to a lifetime exposure.

This analysis developed two recommendations for safeguarding the public health and eliminating future liability. First, an appropriate low level monitoring program should be implemented to confirm the model's predicted impacts from both a status quo and a remedial action scenario. Second, any on-site remedial activity should be accompanied by a comprehensive dust suppression program to reduce the possibility of off-site, PCB-laden, particulate transfer.

#### CONCLUSIONS

It is evident from the evaluation of these three hazardous waste sites that a wide range of potential problems may occur in properly evaluating the off-site risk to the nearby population. These problems must be dealt with on a case-by-case basis.

Certain common elements, however, should be included in all ambient air risk assessments. Initially, an evaluation of the status quo situation should be made. This is best accomplished through the use of a well-designed monitoring program. The use of modelling analyses can be used to assist, but should not be relied upon totally, in most cases. The Lehigh site is an example of a case where modelling was relied on totally because appropriate background monitoring was not conducted. The Nashua site is an example where modelling was the most appropriate analytical path to follow because of the particular circumstances of the site, i.e., groundwater contamination with latent surface elution.

The second component of an ambient air risk assessment of a hazardous site involves the monitoring of the concentrations of toxic pollutants during on-site activity. This accomplishes two main objectives. First, it will determine whether any significant concentrations are being released during the remedial action from a short-term health protection point of view. High readings would direct management personnel to take measures to prevent or reduce this exposure. Additionally, any ambient air contamination will be documented, thereby preventing unwarranted liability from future claims of health impairment.

The final step should include post-remedial action monitoring. This step will document the actual improvement in air quality due to the remedial action or, conversely, emphasize the need for further investigation and cleanup if levels have not been reduced. Again, this step is important from both a health and liability point of view.

All hazardous waste site ambient air evaluations must follow this basic assessment methodology, although the emphasis will vary as is evidenced by the three examples presented in this paper. A failure to follow the system in a thorough fashion may result in:

- Poorly designed site safety considerations
- Excessive population exposures to carcinogens from a long-term, chronic perspective
- Possible liability cases against the contractor, consultant, USEPA/state/local agencies

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# AIR MONITORING OF HAZARDOUS WASTE SITES

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## INTRODUCTION

Air monitoring of hazardous waste sites is done for numerous reasons: to identify and quantify specific hazardous contaminants present in the environment, to determine how waste site workers are exposed, to investigate community complaints, to determine if the compliance with various health standards is being followed, and to evaluate the effectiveness of disposal and storage methods.

The purpose of the sampling will dictate the type of sampling strategy that will be used. If the waste site is a large dump that covers many acres of an area then a grid type pattern may be conducted to determine what is present in different areas. This same strategy can be used if a contaminant was spilled or dispersed over a large area. A grid pattern is also effective to evaluate the effectiveness of clean-up operations and containment of spills. In this method of area sampling, the area is marked with tape or by physical landmarks such as streets or city block areas. These areas are then systematically numbered, sampled and the results recorded in the field notebook. Record keeping is an extremely important step in a successful contaminant sampling program. Once an area is set up for sampling careful identification of potentially hazardous substances may be initiated. An understanding of general contaminant classification will aid the identification process. Airborne contaminants can be divided into two major categories: (1) particulates and aerosols, (2) and gasses and vapors. Particulates and aerosols are particles of matter small enough to be dispersed in the air, either in a solid or liquid (droplet) form. They can be divided into subcategories.

Dusts are solid particles which become airborne as the result of grinding or crushing of solid materials, or through the disturbance of bulk masses of powders. Examples of this would be asbestos that has been disposed in a waste site and cyanide dusts.

Other particulates are fumes, smokes and mists. Smokes may be found at burning landfills or dump sites. Fumes are not normally present at dump sites since they are dispersions of solid particles formed by condensation of a vapor. The vapor is formed by heating a material which is normally a solid at room temperature. These are most commonly found in welding. Mists are droplets of liquid substances and could be found in containers that are under pressure, which are leaking.

Of major concern at a waste site is whether or not particulates are respirable or non-respirable. Particulates are classified as non-respirable if they are either too large (75 microns) or too small (less than 0.1 micron in diameter). These particles would not normally be retained in the lungs if they are inhaled.

Gases are substances which are gaseous at normal room temperature and air pressure. Vapors are substances which are liquid (or solid) at normal room temperature and air pressure, but which volatilize under extreme environmental conditions (as through evaporation). There are currently numerous sources of information which provided detailed information concerning dangerous contaminant levels:

1. Industry booklets—such as “*The Hazardous Materials Guide*” by Sun Oil Company.
2. “*Handbook of Organic Industrial Solvents*” by the Alliance of American Insurers.
3. “*Handbook of Hazardous Materials*” by the American Mutual Insurance Alliance.
4. “*Job Health Series*” by OSHA.
5. “*NIOSH Health & Safety Guides*.”
6. “*NIOSH Criteria Documents*.”
7. “*NIOSH Recommended Standards*.”
8. “*AGGIH—TLV Booklet*.”
9. “*AIHA—Hygienic Guide Series*.”

## PRELIMINARY SURVEY

At a hazardous waste site, it will usually be necessary to conduct a preliminary survey. An experienced environmental specialist or professional industrial hygienist can, in many cases, evaluate quite accurately, the magnitude of chemical hazards associated with a waste site without the benefit of any instrumentation. The first step is to make a careful examination of the site. It may be possible to screen the area for empty containers which still have labels on them. This does not guarantee that the containers actually contain these materials. Are any bulk powders or dusts present, are drums of materials intact, or are they leaking due to deterioration of containers? Are there any underground fires from pockets of materials that are producing smoke?

A preliminary inventory should be made. The list should include the suspected contaminants, their composition and any by-products which may be associated with them.

This means that the investigator should obtain complete information on the composition of the various commercial products. This information may be obtained from the Material Safety Data Sheets of their manufacturers. Manufacturers of chemical agents often sell the same substance under several different trade names, each with slightly different formulas; this can make it difficult to identify all the chemical components of trademarked substances. Material Safety Data Sheets (MSDS's) help solve this problem.

The Material Safety Data Sheet (Form OSHA-20) is divided into nine (9) sections containing detailed technical information about a substance, including hazardous ingredients, physical data, fire and explosion hazard data, health hazard data, reactivity data, spill or leak procedures, special protection information, special precautions, and manufacturing info (name and address). 29 CFR 1915, 1916, and 1917, Public Law 85-742 and Public Law 92-596 are the applicable regulations.

During a preliminary walk-through investigation, many potentially hazardous areas can be visually detected. Are large amounts of dusts present? The senses of sight, smell, are used in this preliminary investigation. The entire effort in this case is to add to information about a waste site. In some cases, the workers at a dump site may be able to provide some information if they have

kept any type of records, or if they have noticed any unusual odors. For many substances the odor threshold concentration is greater than the permissible safe exposure level. However, many substances such as hydrogen sulfide produce olfactory fatigue. Ask workers whether they have experienced any symptoms such as eye or skin irritation, dizziness, nausea, etc., when working in specific areas. Try to be as specific as possible, exact symptom identification can provide important clues about the identity of an unknown contaminant.

Certain contaminants have distinctive odors which can aid in their identification. For example, it is possible to distinguish between the hay-like odor of phosgene and the fish-like odor of trimethylamine. Many contaminants are odorless, however, and some may actually act as olfactory anaesthetics as has been previously mentioned. Hydrogen sulfide, for example, smells distinctly like eggs, but prolonged exposure to it can dull a worker's sense of smell so severely that he may not notice heavy concentrations of other contaminants. The odor threshold of  $H_2S$  is 0.00047 ppm; the TLV is 10 ppm. A list such as this is prepared by the American Industrial Hygiene Association Journal and it is useful in the education of workers and industrial hygiene students.

### AREA THAT SHOULD BE SAMPLED

There are at least three general locations in which air samples may be collected: (1) at a specific container within the waste site, (2) ambient air, or (3) in a worker's breathing zone. The choice of the location is dictated by the type of information needed, and often the use of all three methods will be necessary to provide detailed information.

Most frequently, the sampling is performed to determine the level of contamination present in a specific container. In this instance a grab sample or instantaneous concentration is all that is needed. A portable instrument or detector tube may be used. If a worker's exposure is needed, it may be necessary to collect samples in the worker's breathing zone. If area samples are needed, then they should be collected using area monitors.

### SAMPLING DURATION

The sampling time is usually the minimum sampling time necessary to obtain an amount of material sufficient for accurate analysis. The duration of the sampling period is therefore based on the following considerations: the sensitivity of the analytical procedure, the permissible exposure limit or TLV of the particular substance and the anticipated concentration of the contaminant in the air being sampled. The sampling period should represent some period of time if relative to worker exposure; i.e., the amount of time that the worker spends at the waste site or particular grid area for one day. It is desirable in this case to sample the worker's breathing zone for his full work shift at the waste site. This is important if sampling is being conducted to determine compliance status relative to OSHA standards.

Evaluation of a worker's daily-time weighted average exposure is best accomplished by personal sampling. For personal sampling, the sampling train consisting of a pump, drawing air through a collection medium, which separates and collects contaminants for later laboratory analysis. For personal sampling, the sampling train assembly is attached to the individual exposed, with its collection medium positioned so that the air sampled is collected from the worker's breathing zone. For area sampling, the sampling train assembly is placed at a fixed point.

The ceiling exposure and time-weighted average must both be considered when planning a sampling program. The ceiling exposure is determined by taking a 16 minute sample at the place of heaviest anticipated contaminant concentration.

The choice of a particular sampling instrument depends on a number of factors which include portability and ease of usage, efficiency of the instrument or sampling method, reliability, availability of the instrument, and whether instantaneous readings are desired, and cost. Presently there is no one universal sampling instrument or method in use today.

One of the most useful type of instruments for evaluating hazardous spills and unknown contaminants at hazardous waste sites is the use of direct reading colorimetric detector tubes.

### DETECTOR TUBES

The advantages of having direct reading detector tubes are rather obvious. On-site evaluations of atmospheric concentrations of hazardous substances may be made immediately. The size of a detector tube system is very light and highly portable, typical systems may weigh under 36 ounces. Direct reading tubes are available for over 200 different substances, and many of the tubes may be used to screen for groups of materials such as the use of an amines detector tube which will detect any one of 30 different amines.

The use of detector tubes permits rapid estimation of the concentration of a contaminant, permitting on site evaluations and implementation of immediate corrective measures. The use of these tubes may save time and expense of laboratory analyses and may be used as evidence in court proceedings. The cost of detector tubes is not high considering comparable methods. Because they are so lightweight it is easy to carry a shoulder bag with 40 or 50 boxes of detector tubes to screen for a variety of substances. If the investigator wants to make his own field kit 4 or 5 tubes for 100 different substances can be carried.

Detector tubes are glass tubes that are packed with a chemically treated substance (usually silica gel, or alumina) which gives an immediate, direct reading of a contaminant level. In colorimetric tubes, the degree of concentration of the contaminant causes the hue of the tubes chemically treated substance to take on varying intensities. The exposed tube must be compared to a color standard or chart.

In length of stain tubes, the substance develops a stain the length of which is proportional to the contaminant level.

One should always read the complete instructions found in each box of detector tubes. Some tubes require humidity, altitude, and temperature compensation factors for accurate readings. These special requirements will be described in the instructions.

Detector tubes should be stored in a refrigerator to prolong their shelf life, but must always be allowed to reach room temperature before being used. These tubes are marked with an expiration date which should always be noted.

Table 1.  
Gas Detector Tube Unit Certification Compounds 11/20/81

Gas	Certified Range (ppm)
Acetone	500 to 5000
Ammonia	25 to 250
Benzene	5 to 50
Carbon Dioxide	2500 to 25000
Carbon Disulfide	10 to 100
Carbon Monoxide (Range A)	25 to 250
Carbon Monoxide (Range B)	250 to 2500
Carbon Tetrachloride	5 to 50
Chlorine	0.5 to 50
Ethyl Benzene	50 to 500
Ethylene Dichloride	25 to 250
Formaldehyde	1 to 10
Hexane	250 to 2500
Hydrogen Chloride	2.5 to 25
Hydrogen Cyanide	5 to 50
Hydrogen Sulfide (Range A)	5 to 50
Hydrogen Sulfide (Range B)	50 to 500
Methyl Bromide	7.5 to 75
Methylene Chloride	250 to 2500
Nitric Oxide	12.5 to 125
Nitrogen Dioxide	2.5 to 25
Perchloroethylene	50 to 500
Styrene	50 to 500
Sulfur Dioxide	2.5 to 25
Toluene	50 to 500
Trichloroethylene	50 to 500

While it is true that the operating procedures for colorimetric indicator tubes are simple, rapid and convenient, there are distinct limitations and potential errors inherent in this method of assessing concentrations of toxic gases and vapors.

They may lead to dangerously misleading results unless they are used by an adequately trained person who: (1) enforces periodic testing and calibration of individual batches of each specific type of tube for its response against known concentrations of contaminants as well as refrigeration of the tubes, (2) understands the physical and chemical interferences associated with their use, (3) uses other independent sampling and analytical procedures to back up results. The American Industrial Hygiene Association publishes an excellent manual entitled "*Direct Reading Colorimetric Indicator Tubes Manual*." This manual described in detail a recommended practice for the use of colorimetric indicator tubes, and their limitations.

#### Procedures for Use

To use a detector tube, its tips are broken off, the tube placed in the manufacturer's pump and the recommended volume of air is drawn through the tube. Each air moving pump or device must be calibrated frequently.

The pump can be calibrated using a standard bubble buret and by performing a soap bubble test. This test uses a soap film which is drawn by the air moving device. The distance the soap bubble travels may be measured in cc's marked on the buret. An acceptable pump should be correct to within  $\pm 5\%$  by volume. The pump should also be checked for valve leakage and inlet plugging frequently. A calibration sticker should be placed on the pump.

An accessory which may be used with detector tubes includes extension hoses where the detector tube is placed at the end of a length of hose. This permits sampling in holes, tunnels, or in areas where contaminants may have entered such as a manhole or underground tunnel. If hot gases are to be checked such as those com-

ing from underground landfill fires, a hot probe may be used to cool the sampled air, prior to its entry into the detector tube.

Examples of detector tubes utilization have been numerous throughout the past 20 years. Some of these uses were in Florida to check empty drums of chemicals found dumped beside the highway. These drums were suspected of containing hydrogen cyanide and acetic acid. Detector tubes were used to verify what the labels on the container listed. This method was rapid and allowed for immediate protective clothing to be worn when handling the drums containing the cyanide. The area was also checked for spillage. Soil samples would, in this instance, also be submitted to a laboratory for analysis. Detector tubes may also be used to check burning materials at dump sites which in many cases contain hazardous substances. Detector tubes are available for over 200 substances. Table 1 contains a list of those tubes which are certified by the National Institute for Occupational Safety and Health.

There are numerous analytical methods for monitoring hazardous waste sites. Each should be used, depending upon the local situation. The primary purpose of this paper has been to make investigators of hazardous waste sites aware that detector tubes do offer a quick and reliable method for screening. While they are far from perfect they do provide a useful method to assist in the evaluation of uncontrolled hazardous waste sites.

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# AIR EMISSION MONITORING OF HAZARDOUS WASTE SITES

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## INTRODUCTION

Volatile chemicals in surface impoundments can readily escape into the air and result in an area-source of emissions. Surface impoundments serve as aqueous waste storage basins, pretreatment basins and treatment basins. In all cases the natural water surface area plus any mechanically generated interfacial area is in contact with the atmosphere, thus providing a direct pathway for dissolved chemical species vaporization.

Means of assessing the air emissions from such wastewater sources are needed. The assessment methods should have a two-fold approach: 1) field techniques for monitoring the air emissions from measurements taken at or near the site and, 2) verified mathematical models with a predictive capability that allow accurate estimation of the emissions based upon the chemicals present in the impoundment. The latter approach is needed by permit writers while the proposed impoundment is in the planning and design stages.

The work presented here is primarily concerned with chemical emissions from two surface impoundments of a hazardous waste disposal facility. The identity of the volatile chemicals involved, the concentrations in air and water, and measurements of the flux rate of emission are reported. Emission calculations based on the mathematical model are also presented. Comparison of the measured and model predicted emission rates are presented and discussed.

## CONCENTRATION PROFILE TECHNIQUE

A field method of measuring volatile chemical emission rates from area sources has been developed.<sup>1</sup> The method, the so-called concentration profile (CP) technique, employs profiles of chemical concentrations, temperature and wind speed to quantify the chemical emission rate. One significant feature of the method is that it does not disturb the natural transport processes in effect on the water surface. The method is limited with respect as to sample time, wind speed, fetch-to-height ratio of upwind disturbances, etc. These limitations, along with the theory of operation, are contained in the above referenced document. Only the final working algorithm of the CP technique will be presented here.

Only field measurements of the concentration of the chemical in air,  $\rho_{A1}$  (g/L); wind speed,  $v_x$  (cm/s), and temperature  $T_1$ , ( $^{\circ}$ K), within the turbulent boundary layer (no more than two to three meters above the water surface) are made. Six observations of each parameter, distributed in a logarithmic fashion from the water surface and taken well downwind of any wind velocity disturbances, should be made. Based on these measurements, the following equation is used to determine the vertical flux of the chemical species (i.e., species B) from the water surface:

$$n_B = -(D_{B1}/D_{A1})^{2/3} S_v S_{\rho} k^2 / \phi_m^2 Sc_{A1}^{(1)} \quad (1)$$

where  $n_B$  is the chemical flux rate ( $\text{ng}/\text{cm}^2 \cdot \text{s}$ ),  $S_{\rho}$  is the slope of a line from a graphical plot (or linear regression) of  $\rho_{A1}$  vs.  $\ln y$ , where  $y$  is the sample height above the water surface in cm.

If  $S_{\rho}$  is negative then chemical emission is occurring from the source whereas if  $S_{\rho}$  is positive, then the water surface is absorbing the chemical species.  $S_v$  is the slope of a line from a similar relation between  $v_x$  vs.  $\ln y$ . This slope should always be positive and have units of cm/s. The combination of the units of  $S_{\rho}$  in g/l and  $S_v$  in cm/s is the units of flux in  $\text{ng}/\text{cm}^2 \cdot \text{s}$ .  $k = 0.4$  is the von Karman constant. Since the air sampling is done close to the water surface, only the vertical flux is needed to assess the emission rate. Note that  $S_v$  is related to the friction velocity at the surface,  $V^*$ , by  $S_v = V^*/k$ .

The chemical concentration and velocity vs.  $\ln$ -height profiles should be linear over the full range of the six observation heights only if the air boundary layer is neutral (i.e., essentially isothermal). The profiles will likely be non-linear under stable and unstable micrometeorological conditions and thus display some curvature. In such a case, the slopes of tangent lines drawn to the profiles in the boundary layer region nearest the water surface are used for  $S_{\rho}$  and  $S_v$ .

The stability-turbulent Schmidt number correction factor (i.e.,  $\phi_m^2 Sc_{A1}^{(1)}$ ) in Equation 1 is obtained from the following empirical equations developed for water (i.e., species A) vapor:

$$\phi_m^2 Sc_{A1} = (1 + 50 Ri)^{-1/2} \quad (2a)$$

for stable conditions and  $|Ri| \leq 1.0$

$$\phi_m^2 Sc_{A1} = (1 - 50 Ri)^{1/2} \quad (2b)$$

for unstable conditions and  $|Ri| \leq 4.0$ .  $Ri$  is the Richardson number defined by:

$$Ri = g(\bar{T}_{12} - \bar{T}_{11})(y_2 - y_1)/(V_{x2} - V_{x1})^2 \bar{T}_1 \quad (3)$$

where  $g = 980.7 \text{ cm/s}^2$ ,  $T_{12}$ ,  $T_{11}$ ,  $v_{x2}$ , and  $v_{x1}$  and dry bulb air temperatures and wind speeds at heights  $y_2$  and  $y_1$  above the surface.  $\bar{T}_1$  is the average of the temperature.  $Ri$  is dimensionless and if  $Ri < 0$ , then the air is unstable, whereas if  $Ri = 0$ , the air is neutral or if  $Ri > 0$ , the air is stable. The 2/3 power ratio of molecular diffusivities of the chemical of interest to that of water vapor corrects the equation for the chemical for which the flux is desired.

The three equations presented above are the working formulas of the CP technique. Claith, *et al.*,<sup>2</sup> employing a similar field technique referred to as the aerodynamic technique, report measurements of the vapor flux rate of S-ethyl N,N-dipropylthiocarbamate (EPTC) from irrigation water in a flooded alfalfa field at Brawley,

CA.<sup>2,3</sup> EPTC was applied at a rate of 3.0 kg/ha at an average concentration of 2.17 ppm to irrigation water. The process is called herbigation. An equivalent of 13 cm (i.e., depth of water) of irrigation water was applied to the 2 ha field surface. The alfalfa plants were approximately 15 to 35 cm high.

Beginning at 0840h on the day of application, wind speed, water samples and air samples were taken. The EPTC emission rate was measured from equipment similar to the CP technique located near the center of the field. Table 1 contains pertinent field data collected during the flooded period and Table 2 contains the chemical and physical data on EPTC for this well documented field test. Water temperature during the test apparently was not recorded.

Table 1.  
EPTC Field Data (3)

Time (h)	Wind Speed * 1 m $V_x$ (m/s)	Conc. in Water $\rho_{A2}$ (ppm)	Flux, $n_B$ (g/ha·h)
0840	---	2.14*	---
1300	---	2.30*	---
1430	1.6	---	---
1450	---	2.08*	---
1500	---	1.92*	---
1600	---	---	35
1630	1.0	---	---
1711	---	1.97†	---
1800	---	---	140
1830	3.0	---	---
1915	---	1.76†	---
2000	---	---	260
2100	2.5	1.44†	---
2200	---	---	65
2300	1.9	---	---
2400	---	---	50
0100	1.6	---	---

\*In head ditch.

†In tailwater.

Table 2.  
EPTC Properties at 30°C (2)

chemical name	S-ethyl N,N-dipropylthiocarbamate
molecular weight	189.3
diffusivity in air	.0582 cm <sup>2</sup> /s
vapor pressure	29.7E-mmHg
solubility in water	320 ppm
Henry's constant	7.29E-3(g cm <sup>-3</sup> in air/g cm <sup>-3</sup> in water)

## MODELS FOR EMISSION RATE PREDICTION

It is highly desirable to have available mathematical models for predicting, in an *a priori* sense, chemical emission rates from existing or planned surface impoundments based on chemical content of the water and known environmental parameters, such as wind speed and temperature. Such models have been proposed and are in various stages of verification. The following review outlines the present status of the model and the extent of verification.

The basic ideas of using the two resistance theory for interphase mass-transfer of volatile chemicals in waste water basins were presented by Thibodeaux and Parker in 1974.<sup>4</sup> The model was modified by Freeman<sup>5</sup> and successfully tested in a laboratory reactor/stripper with acrylonitrile by Freeman and Schroy.<sup>6</sup> Recently, Hwang<sup>7</sup> and Shen<sup>8</sup> have summarized and simplified the elements of the emission model so that it can be applied easily to practical engineering problems. The reader should refer to the above cited works for details of the model.

The model has been field tested for methanol emissions from four aerated basins treating pulp and paper.<sup>1</sup> Methanol is gas-phase controlled, and this aspect of the model has been verified with field measurements using the CP technique. This paper extends the field

test verification of the model to include chemicals that are liquid-phase controlled.

## ANALYSIS OF THE EPTC DATA

As noted above, except for the lack of an exact water temperature, the field data collected and documented by Claith, *et al.*,<sup>2,3</sup> provides sufficient information for testing the emission model. The gas and liquid phase coefficients as a function of wind speed were estimated based on the compiled literature information available on water vapor and benzene.<sup>9</sup> The individual coefficients were then transformed for EPTC using Graham's law of inverse square root of molecular weights. The two resistance theory was used to obtain the overall coefficient,  ${}^1K_{A2}$  and the flux rate was calculated by:

$$n_B = 100 {}^1K_{A2} \rho_{A2} \quad (4)$$

with  ${}^1K_{A2}$  in cm/h,  $\rho_{A2}$ , the concentration in water, in mg/L and  $N_B$  in g/ha·h,

$$1/{}^1K_{A2} = 1/{}^1k_{A2} + 1/H^2k_{A1} \quad (5)$$

with H being Henry's constant.

The calculations appear in Table 3. The individual gas-phase and liquid phase coefficients,  ${}^2k_{A1}$  and  ${}^1k_{A2}$ , respectively, are presented in columns one and two. Comparison of the overall coefficients in column three with those in columns one and two demonstrate that EPTC is dominated by processes on the liquid-phase side of the interface. The water temperature was assumed to be 30°C. The model calculated EPTC flux is compared to the measured flux in Fig. 1. In all cases, the calculated flux exceeds the measured flux. However, considering the uncertainties in temperature, and that the mass-transfer coefficients used to not account for plant stems protruding through the air-water interface, the model does provide a reasonable estimate of the volatilization process. Plants in the water would reduce the effective transport coefficients, thus resulting in low estimations of the flux.

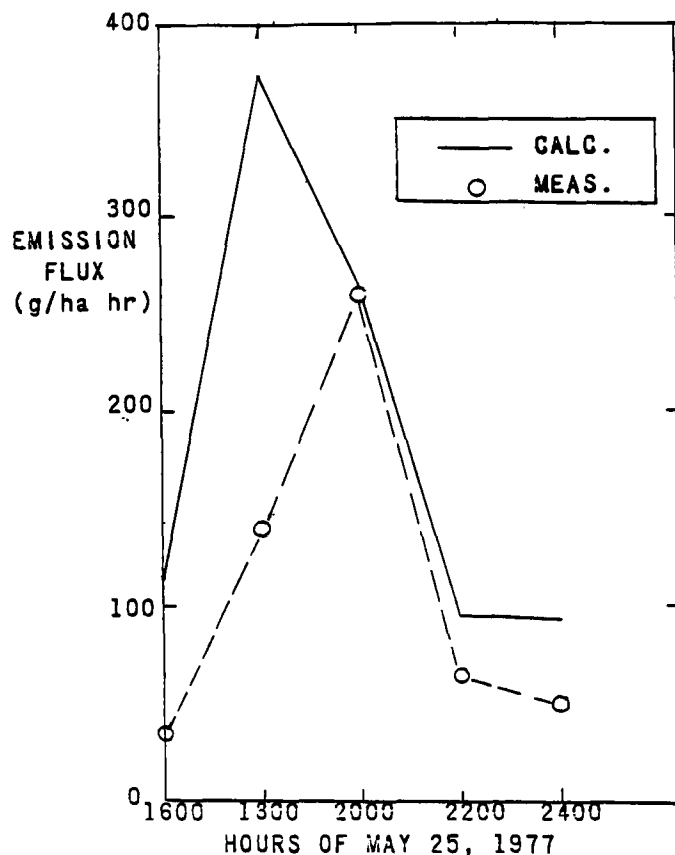


Figure 1.  
Volatilization of S-Ethyl, N,N-Dipropylthiocarbamate  
from a Flooded Alfalfa Field

Table 3.  
Calculated Emission Coefficients and Rates for EPTC

time (h)	Gas-phase coeff. 2k <sub>A1</sub> (cm/h)	Liquid-phase coeff. 1 <sub>1</sub> A <sub>2</sub> (cm/h)	Overall coeff. 1k <sub>A2</sub> (cm/h)	Conc. in water ρA <sub>2</sub> (mg/L)	Evaporative flux n <sub>B</sub> (g/ha/h)
1300	419	0.83	0.65	2.1	137
1600	247	0.83	0.57	2.0	114
1800	765	2.79	1.86	2.0	372
2000	666	2.14	1.49	1.76	261
2200	493	0.83	0.67	1.44	97.1
2300	469	0.83	0.67	1.44	96.2
2400	440	0.83	0.66	1.44	95.00

### DESCRIPTION OF HAZARDOUS WASTE FACILITY SURFACE IMPOUNDMENTS

In Aug. 1981, the CP technique was used to measure the emission of volatile organic chemicals from two surface impoundments in Western New York State. These impoundments routinely receive, store and treat aqueous waste delivered by tanker trucks. In July 1981, the facility received 720m<sup>3</sup> of aqueous waste, neutralized 1790m<sup>3</sup> gal and processed 7900m<sup>3</sup> through the water treatment system. A typical waste liquid analysis appears in Table 4.

Table 4.  
Waste Liquid Analysis

	Weight %
Halogenated organics	0.15
Non-halogenated organics	1.15
Organic salts	0.87
Organic acids	0.07
Metals	1.24
Metal salts	5.20
Inorganics	4.00
Water	87.32

The aqueous waste treatment system includes chemical reduction, chemical oxidation, neutralization, activated carbon and biological oxidation treatment. Depending upon the nature of the aqueous waste, selected operations are chosen for treatment. All operations are batchwise. The aqueous treatment process is only a portion of the operations at the facility, which includes a hazardous waste landfill, drum recovery and solvent recovery operations.

Characteristics of the two surface impoundments studied are listed in Table 5. Pond 1, 2 is an earthen basin with a 1.2 to 1.5 m berm. The plan dimensions of the pond are 85m wide and 253 m long. A partial dike separates the rectangular shaped pond into two sections. A 2m opening, however, allows free exchange of water between the two sections. Section 1 contains 50,000m<sup>3</sup> and section 2 contains 18,400m<sup>3</sup>.

Pond 1,2 is a wastewater biochemical oxidation reactor. Surface aerators maintain the oxygen content to keep the process aerobic. Aerobic conditions seemed to be present during the sample period. The water was light green in color, suggesting algae growth was occurring. Foam generated by the surface aerators was also present.

Table 5.  
Surface Impoundment Data

Characteristic	Pond 1,2	Pond 6
Surface area, m <sup>2</sup>	21,600	4,650
Water volume, m <sup>3</sup>	68,400	4,630
Water depth, m	3.2	1.0
Shape	rectangle	rectangle
No. of surface aerators operating	8	0
Aerator power, hp per aerator	15	---

The non-persistent foam covered 2 to 5% of the surface. A drum storage and drum cleaning operation was situated directly north of Pond 1,2.

Pond 6 is a temporary storage and pre-treatment pond. This pond is rectangular in shape with a 1.8m berm and a plastic liner on bottom. The water was yellowish in color and more odorous than pond 1,2.

### SAMPLING AND ANALYSIS METHOD

The CP technique apparatus consisted of devices installed onto a boat for the simultaneous measurement of dry-bulb temperature and wind speed and obtaining air constituent samples. Placement of the apparatus on a boat allows facing the devices into the wind and proper location on the impoundment surface. The apparatus placement above the water surface is shown in Fig. 2. Temperature measurements were taken at 39, 52, 69, 93, 142, and 211 cm above the water surface. Wind speed was measured at 47, 67, 107, 187, 267 and 347 cm. One liter of air drawn through adsorbent tubes over a 15 min sample time were positioned at 7.0, 14, 24, 55, 104, and 232 cm. A weather vane, atop the wind speed mast, allowed continuous indication of wind direction.

The micrometeorological mast was manufactured by C.W. Thornthwaite Associates (wind profile register system model 106). The temperature and air sampling mast were designed and built at the University of Arkansas. The temperature mast consisted of open-ended cylindrical tubes that (radiation) shielded a clay-in-cup sensor. An electronic tip-thermocouple probe with a 2 sec response time and LED digital display was inserted into each clay sensor for temperature measurements. The sample tube mast consisted of six tube height positioners, six extension tubes and six air rotameters connected to a hand evacuated vacuum tank.

Air samplers were 15 cm stainless steel, 3.2mm O.D. and 2.2mm I.D. tubes. Each tube was packed with 11.5 cm of Tenax, 60/80 mesh and 2.5 cm of silica gel, 40/60 mesh. Air flow was through the Tenax then through the silica gel. The prepared tubes were pre-conditioned by heating to 270-300°C and purged with helium for one hour. The tubes had Swagelok plugs on each end and were

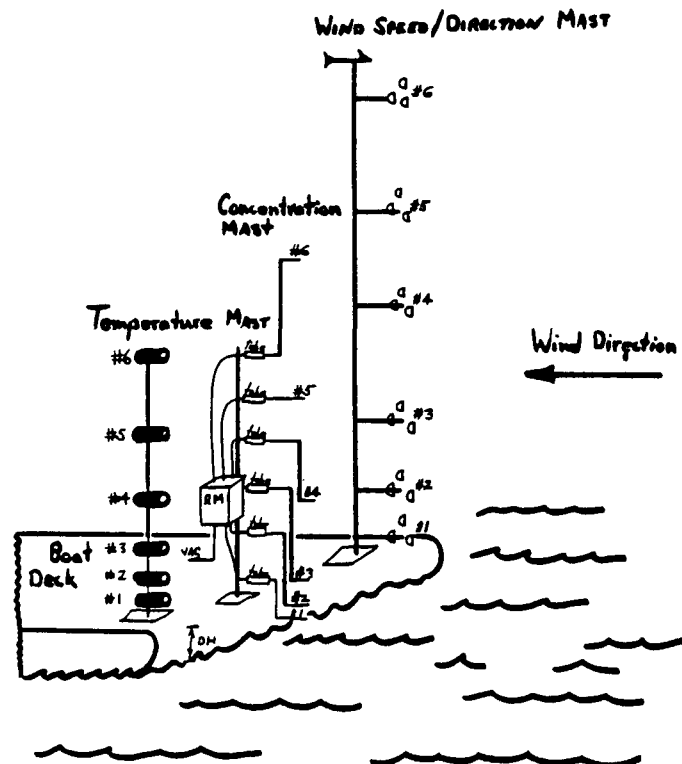


Figure 2.  
Concentration Profile Apparatus

sealed prior to and after sampling. Surface water samples were obtained from each impoundment in one liter, amber teflon-lined cap bottles. Each sample was acidified with HCl immediately to suppress biological activity.

A Varian 3700 Gas Chromatograph was used for all flame ionization detection (FID) analysis. Water samples were analyzed on Chromosorb 102, Chromosorb 101, and Bentonone 34 using various flow rates and temperature programs to obtain optimum separation. Chromosorb 101 was best with temperature held at 45°C for 6 min during trap desorption (@180°C), elevated to 125°C and held for 6 min, then temperature programmed at 4°/min up to 200°C. With a flow of 53 ml/min Nitrogen carrier, the Chromosorb 101 produced the greatest number of well resolved peaks. The resulting peaks were compared to standards of purgeable priority pollutants. The use of three different standards and spikes of these aided in identification. The results were reported at total FID organics in  $\mu\text{g}$  as Benzene. The individual compounds were reported in  $\mu\text{g}$  individual compound. Water sample results were reported in  $\mu\text{g}/\text{l}$ .

A Varian 2800 gas chromatograph equipped with a Hall detector was used for chlorinated organics. The Carbowax B packing served well for the Hall detector analysis. The temperature was held at 35°C for 8 min during trap desorption (at 180°C), then elevated to 220°C at 8°/min and held for a total of 52 min. Samples were again compared to three purgeable priority pollutant standards for identification and quantification. Chlorinated organics were reported as total chlorinated organics in  $\mu\text{g}$  as chloroform. Individual compounds were reported in  $\mu\text{g}$  individual compound. Water sample results were reported in  $\mu\text{g}/\text{l}$ .

Gas Chromatographic analysis of air and water samples was performed at the University of Cincinnati.<sup>10</sup> Two water samples were analyzed on GC/MS by Environmental Consultants, Inc. of Cincinnati.<sup>11</sup> Air sample tubes and water samples were provided to the site operator. GC/MS analysis were performed on the air samples and TC, TOC and TOD on the water samples in the operators laboratory.

## FIELD MEASUREMENT RESULTS AND DISCUSSION

A total of 90 air samples and 12 water samples were obtained from the two impoundments. Fifteen concentration profiles were obtained, nine above pond 1, 2 and six above pond 6. Temperature and wind speed profiles were also obtained. Nine profile tube-sets (i.e., six tubes make a set) were analyzed by GC/FID and six by GC/Hall detector. Four profile tube-sets and the corresponding water samples were delivered to the site operator for split-sample analysis. Remaining tube-sets and water samples were analyzed by the University of Cincinnati, Department of Civil and Environmental Engineering. Selected water samples were also analyzed by Environmental Consultants, Inc.<sup>11</sup>

The major chemicals (identified and confirmed) and concentrations in the water phase of the two surface impoundments are listed in Table 6. These concentrations are a summary of the results of the three laboratories. Approximately 50 other compounds were identified but were not confirmed with standards. The chemical make-up of the water is consistent with tanker truck waste liquid discharged to the impoundments as reported in Table 4. In general the concentration levels in pond 1,2 are lower than in pond 6. This is likely due to "treatment" occurring in pond 1,2 since it was designed for biochemical oxidation. Pond 6 serves as a storage pond and biological treatment is not encouraged.

Several chemicals were identified in the air boundary layer above both surface impoundments; the ranges of concentrations detected near the water surface and at two meters above the surface of both ponds are shown in Table 7. The concentration gradients suggest that the water is a source of the air contaminants. The detailed profile structure for benzene, 1,1, dichloroethane and total hydrocarbon concentration in the air boundary layer above pond 6 is shown in Fig. 3. Such a linear relationship of decreasing concentration with natural logarithm of height above the water indicates that the water is an area source and the boundary layer is turbulent.<sup>1</sup>

Table 6.  
Major Chemicals in Water of Surface Impoundments

Chemical**	Concentration and s.d. (µg/l)	
POND 1,2		
Benzene	0.31 ±	0.31
Toluene	4.1 ±	4.7
Total hydrocarbon*	8.4 ±	2.8
1,1 dichloroethane	34. ±	7.7
Total chlorinated hydrocarbon□	207. ±	37.
Total oxygen demand	235,000. ±	10,000.
Total carbon	73,000. ±	2,300.
Total organic carbon	64,000. ±	0.0
POND 6		
Benzene	16. ±	9.5
Toluene	43. ±	3.0
Total hydrocarbon*	125.	---
1,1 dichloroethane	22. ±	19.
Total chlorinated hydrocarbon□	267.	---
Methylene chloride	124.	---
Chloroform	8.3	---
1,2 dichloroethane	144.	---
1,1,1 trichloroethane	6.8	---
Trichloroethene	33.2	---
Tetrachloroethene	3.3	---
Chlorobenzene	10.3	---
Ethylbenzene	9.0	---
Total oxygen demand	6,300,000.	---
Total carbon	2,150,000.	---
Total organic carbon	2,000,000.	---

\*\*GC/MS results, confirmed with standards.

\*Flame ionization detector, reported as benzene.

□Hall detector, reported as chloroform.

---indicates only single values available.

Table 7.  
Chemicals and Concentration Ranges Above Surface Impoundments

Chemical	Chemical Concentration in Air Sampler ( $\mu\text{g}/\text{l}$ )*	
	Near Water Surface	Two meters above Surface
Benzene	0.2	0.01
Toluene	0.04	0.002
Total Hydrocarbon as Benzene	2.0	0.04
Ethylbenzene	0.01	0.002
1,1 Dichloroethane	0.07	0.02
Total Chlorinated Hydrocarbons as $\text{CHCl}_3$	0.5	0.2

\*Results of University of Cincinnati and site operator laboratories.

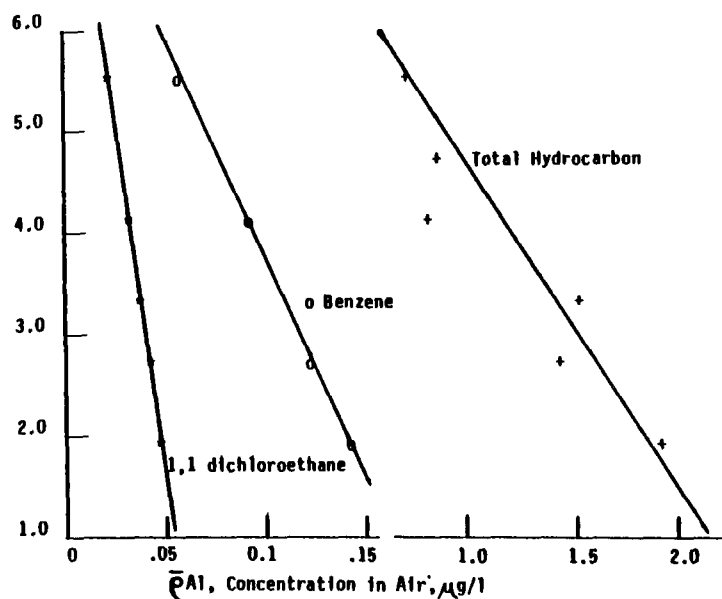


Figure 3.  
Concentration Profiles for Pond 6

**Table 8.**  
**Profile Measurement Summary**

Profile no.	Pond no.	Chemical	n (obs)	$n_g$ Flux* (ng/cm <sup>2</sup> ·s)	$S_p$ Corr. Coeff.	$V_a$ Friction Vel. (cm/s)	$S_v$ Corr. Coeff.	$V_x$ Wind@3.5m (cm/s)	Comments	Lab.†
1	2	Benzene	6	+0.060	-.878	20.4	+.996	282	Aug. 26, 10:45AM, sunny and clear, wind variable from S, SE, SW.	UC
1	2	Total HC	6	+1.05	-.545	20.4	+.996	282		UC
2	2	Benzene	5	-0.38	+.176	11.5	+.998	196	Wind SSW, changing to S. No wind for brief periods.	SO
2	2	Toluene	4	+0.015	-.426	11.5	+.998	196		SO
3	2	1,1 DCE	6	--	--	11.9	+.987	191	No chemical detected to all six levels.	UC
3	2	Total CLH	6	-0.21	+.390	11.9	+.987	191		UC
4	2	1,1 DCE	5	-0.022	+.713	8.74	+.986	151	Wind very low, direction variable from S to E. No wind for brief periods.	UC
4	2	Total CLH	5	-0.33	+.783	8.74	+.986	151		UC
5	2	Benzene	5	-0.54	+.376	19.9	+.979	232	3:00PM, wind shift to north. Good steady wind.	SO
5	2	Toluene	4	-0.019	+.678	19.9	+.979	232		SO
6&8	1&2	1,1 DCE	6	+0.0404	-.764	22.0	+.993	360	North wind, good and steady.	UC
6&8	1&2	Total CLH	6	+0.153	-.412	22.0	+.993	360	North wind, good and steady.	UC
7	1	Total HC	6	-1.02	+.763	22.2	+.993	335	North wind, good and steady.	UC
7	1	Benzene	6	-0.290	+.711	22.2	+.993	335	North wind, good and steady.	UC
9	1	Benzene	5	-0.30	+.593	21.2	+.993	352	North wind, good and steady.	SO
9	1	Toluene	5	-0.038	+.685	21.2	+.993	352	North wind, good and steady.	SO
10	6	Benzene	4	+58.0	-.776	8.9	+.985	159	Aug. 27, 12:12PM Chemical analysis faulty.	SO
10	6	Toluene	5	+3.6	-.687	8.9	+.985	159		SO
11,13,14	6	Benzene	5	+0.095	-.980	12.0	+.985	325	Wind N, NE with drizzle rain.	UC
11,13,14	6	Toluene	6	+0.014	-.222	12.0	+.985	325	Wind N, NE with drizzle rain.	UC
11,13,14	6	Total HC	6	+1.30	-.958	12.0	+.985	325	Wind N, NE with drizzle rain.	UC
12,15	6	Total CLH	3	+0.28	-.998	11.0	+.983	275	Wind N, NE with drizzle rain.	UC
12,15	6	1,1 DCE	5	+0.028	-.990	11.0	+.983	275	Wind changing to east at 2:35PM.	UC

\* Positive denotes emission and negative denotes absorption.

† UC denotes University of Cincinnati Laboratory and SO denotes the site operator laboratory.

A data summary of the CP technique measurements appears in Table 8. This table contains: the profile number (Col. 1), the pond number (Col. 2), the chemical (Col. 3), the number of usable data in the profile (Col. 4), the flux rate of the chemical in the boundary layer (Col. 5), the correlation coefficient for  $S_p$  (Col. 6), the friction velocity at the surface (Col. 7), the correlation coefficient for  $S_v$  (Col. 8), wind speed (Col. 9), comments (Col. 10), and the laboratory which performed the analysis (Col. 11). This data represent field results for Aug. 26 and 27, 1981. Pond 1,2 was surveyed the 26th and pond 6 was surveyed the 27th.

The flux measurements presented in Table 8 need to be interpreted in light of the operation of the ponds and other local sources of volatiles. Both positive (emission) and negative (absorption) fluxes were observed. This occurred for pond 1,2 only. It appears that volatile chemical concentrations were low in the water of pond 1,2 on Aug. 26. Low levels are the result of biological treatment and/or volatilization immediately after placement of a batch of wastewater in the pond. There are other sources of VOC at the facility. A landfill area is located to the east and northeast of pond 1,2. Waste receiving, process area, solvent recovery areas as well as pond 6 were also located northeast of pond 1,2. A site containing waste in drums, covering approximately two acres, was located about 90 m north of pond 1,2.

The emission and absorption measurements values in Table 8 are the result of changing winds. Apparently, winds from the north, northeast and east caused absorption, whereas winds from the south, southwest and west caused emission. Strong organic chemical odors were evident when the wind was from the north. Drum clean-out was occurring at the time and profiles 7 and 9 indicate hydrocarbon absorption. When wind was from the south the background concentration of organics in the air was low. If a shift to the north occurred at sometime within the 15 min sample period air with high background concentration of organics swept over the tubes. The net result was very erratic chemical concentration profiles and low correlation coefficients.

The conditions of the next day (Aug. 27) were ideal for emission measurements on pond 6. Winds were constant and always from the north and northeast with no apparent upwind sources of VOC. These conditions resulted in high correlation coefficients for profiles 10 through 15. The chemical analysis performed on tubes of profile 10 appears to be faulty. Nevertheless emission is indicated.

Profiles 11 through 15 were averaged resulting in high correlation coefficients. Averaging is appropriate due to constant micrometeorological conditions throughout the period. Table 10 contains a summary of the ranges of the chemical flux rates observed above the ponds. Except for 1,1 dichloroethane, the emission rates from pond 6 were greater than pond 1,2. This is to be expected, since the concentration of VOCs in pond 6 is greater.

**Table 9.**  
**Surface Impoundment Transport Coefficient Calculations**

Chemical	Pond	Temp. °C	Henry's Constant  (gcm <sup>-3</sup> /gcm <sup>-3</sup> )	Transport Coefficients (cm/h)				t <sub>1/2</sub> <sup>*</sup> half- life (h)	
				liq. coef. 1K <sub>A2</sub>	gas coef. 2K <sub>A1</sub>	liq. coef. 1K <sub>A2</sub>	gas coef. 2K <sub>A1</sub>		overall 1K <sub>A2</sub>
benzene	1,2	24	.232	3670	148,000	31.4	792	59.0	3.7
1,1 DCE	1,2	24	.191	3810	199,000	18.7	981	50.8	4.3
benzene	6	21	.215	-	-	11.4	741	10.6	6.5
1,1 DCE	6	21	.193	-	-	10.0	909	9.5	7.3

\*Evaporation half-life  $t_{1/2} = .69 \times \text{depth} \div 1K_{A2}$

**Table 10.**  
**Comparison of Calculated and Measured Flux Rates**

Chemical	Pond	Calculated Flux (ng/cm <sup>2</sup> ·s)	Measured Flux (ng/cm <sup>2</sup> ·s)
Benzene	1,2	+ 0.0051	-0.29 to +0.06
Toluene	1,2	+ 0.062	-0.038 to +0.015*
Total HC	1,2	+ 0.14	-1.0 to +1.1 *
1,1 DCE	1,2	+ 0.48	-0.022 to +0.04
Total CLH	1,2	+ 2.7	-0.33 to +0.15 *
Benzene	6	+ 0.047	+ 0.095
Toluene	6	+ 0.12	+ 0.014 *
Total HC	6	+ 0.37	+ 1.3
1,1 DCE	6	+ 0.058	+ 0.028
Total CLH	6	+ 0.064	+ 0.28

\*denoted low correlation coefficient on concentration profile slope.

Based upon the observed concentrations of chemicals in the ponds (Table 6) and suggested modeling guidelines for air emissions,<sup>7</sup> flux rates were calculated. The method of calculation is basically outlined by Equations 4 and 5. This calculation was per-

formed as part of a continuing effort to "field test" proposed emission models. Table 9 contains calculated transport parameters and other calculated results for benzene and 1,1 dichloroethane. Pond 1,2 contained eight, 15 hp (operating) surface aerators at the time the sampling was performed. The effective liquid-phase and gas-phase coefficients for the aerators appear in columns 5 and 6 of Table 9. The natural, wind-induced coefficients appear in columns 7 and 8. Pond 6 had no operating aerators at the time. The calculated overall transport coefficients are in column 9. Inspection of the coefficients suggest that benzene and 1,1 dichloroethane are liquid phase controlled. The overall coefficient in pond 1,2 is five times higher than that of pond 6 due to the surface aerators; see  $K_{A2}$  values in next to last column Table 9. Emission half-life calculation result appears in the last column of Table 9. The times suggest fairly rapid volatilization rates are operative in the ponds.

A comparison of the (CP technique) measured VOC emission rates and model calculated emission rates appear in Table 10. For the flux calculations of total HC (hydrocarbon), benzene properties were used and for total CLH (chlorinated hydrocarbon), 1,1 dichloroethane properties were used. In cases where the measurement statistics of correlation are high the model is in general agreement with the measured values. The range of measured emission rates (with high correlation coefficients) were from 0.028 to 1.3 ng/cm<sup>2</sup>•s. The calculated emission rates ranged from 0.0051 to 27 ng/cm<sup>2</sup>•s. Inspection of the measured vs calculated rates in Table 10 for pond 6 indicates agreement within an average factor of  $\pm 2.5$ . The agreement is  $\pm 2.0$  if only the data for 1,1 dichloroethane and benzene are considered.

Vaporization rates of VOCs from the two surface impoundments are in Table 11. Since the profile measurements on Pond 1,2 were hampered by unfavorable wind and high background concentrations the flux rates were calculated using the effective transport coefficients and the measured concentrations of the volatiles in the water. Fifty kilograms/day of total chlorinated hydrocarbon is indicated for pond 1,2 with 9 kg/d being contributed by 1,1 dichloroethane. Only five kg/d of total hydrocarbon is being emitted from pond 6 with benzene and toluene combined for 0.9 kg/d of the total.

## CONCLUSIONS

Conclusions drawn from this study are generalized with respect to the CP technique and emission modeling and are also of a site specific nature with respect to the hazardous waste facility.

### Site Specific Conditions

- Levels of chlorinated hydrocarbons, including 1,1 dichloroethane, and total hydrocarbons, including benzene, were observed (identified and confirmed) in both the water and air boundary layer of two surface impoundments of a hazardous waste disposal facility.

- Concentration gradients in the air boundary layer above the surface impoundments indicate that the ponds are a source of VOCs; however, periodic windshifts move air with high concentration of VOC from other areas of the facility over the impoundments so that chemical absorption onto the water is indicated.

- VOC emissions from the two surface impoundments surveyed include approximately 51 kg/d of total chlorinated hydrocarbon compounds and 8 kg/d of total hydrocarbon compounds. 1,1 dichloroethane accounted for 9 kg/d and benzene accounted for 0.4 kg/d. Odors were present at the facility and had their origin, in part, from volatile chemicals in the water. Due to the batch nature of the operation and the very short evaporation half-life (4 to 7 hr) of the chemicals, intense odors and higher VOC emission rates are likely immediately after waste containing volatiles are discharged into the impoundments.

- The transport process for the chemicals vaporizing from the impoundments is liquid phase controlled. The surface aerators enhance the natural (wind dominated) transport process by a factor of five in the case of 1,1 DCE and benzene.

**Table 11.**  
**VOC Emission Rates**

Chemical	Pond	Flux Basis (Table 10)	Emission Rate (kg/d)
Benzene		calculated	0.095
Toluene	1,2	calculated	1.2
Total HC	1,2	calculated	2.6
1,1 DCE	1,2	calculated	9.0
Total CLH	1,2	calculated	50.
Benzene	6	measured	0.38
Toluene	6	calculated	0.48
Total HC	6	measured	5.2
1,1 DCE	6	measured	0.11
Total CLH	6	measured	1.1

## General Conclusions

- The CP technique, originally designed for assessing emissions from area sources, is apparently also capable of detecting and quantifying absorption onto area sources. Both vaporization and absorption were observed on pond 1,2. Only vaporization was detected on pond 6.

- Measurements at this site provided the first data to "field test" proposed VOC emission models for chemicals in which the transport process is liquid-phase controlled. Comparison of calculated emission flux rate and the measured flux rate data for 1,1 DCE and benzene indicates that the model predicts within a factor of  $\pm 2$ . Model predictions of the EPTC data, which is also liquid-phase controlled, were +3 times higher than the field measurements. Both these model versus field measurement comparisons are better than that reported for methanol emission from pulp and paper wastewater treatment lagoons.<sup>1</sup>

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# AIR POLLUTION PROBLEMS OF UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

In 1980, about 41 million tons of hazardous wastes were generated by various sources in the United States<sup>1</sup> and almost 80% of these wastes were deposited in lagoons, landfills and open dumps.<sup>2</sup> The cumulative effect of these environmentally unsound practices has been the contamination of many sites across the United States. Numerous case examples of this contamination spreading to local community water supplies and air sheds demonstrate that public health and welfare have been unnecessarily threatened.

Historically, the strategy for management of hazardous wastes has only focused on preventing contamination of water supplies by surface runoff and underground leachate. Only recently has awareness grown that hazardous emissions at the disposal sites can also be a severe hazard. In many sites, air pollution problems are often still not recognized because ambient air monitoring data are lacking.

In this paper, the authors discuss causative factors and control problems inherent in the management of hazardous waste sites. Major health effects of toxic emissions are identified, current regulatory requirements for control are described, methods for predicting toxic emission rates are presented, and available control techniques for minimizing hazardous emissions from those sites are discussed.

## PROBLEMS

Dust emission is one of the more significant but less dramatic air pollution problems at hazardous waste treatment and disposal sites. Many air quality control regions have not met the ambient air quality standards for particulate matter, and dust particles can consist of both soluble and insoluble hazardous materials and can have adsorbed on them molecules of toxic substances thereby creating toxic mixtures. The respirable size of many dust particles also enhances their hazard. Dust emissions from the waste disposal sites may result from:

- (a) Wind erosion of the waste materials
- (b) Re-entrainment of particulate matter by vehicle traffic
- (c) Excavation of waste materials
- (d) Wind erosion of the soil cover

Another air pollution problem at hazardous waste treatment and disposal sites is waste volatilization, the process of conversion from a liquid or solid state to a gaseous or vapor state. This process occurs at all landfills and waste lagoons.<sup>3,4</sup> The rate of waste volatilization is highly dependent upon the physical and chemical properties of the waste, site design and operation, surrounding environment and meteorological conditions.

The vaporized contaminants of particular environmental concern are halogenated organics and aromatic hydrocarbons. Unlike fugitive dusts, a hazardous vapor may not be removed from the atmosphere for a relatively long period of time, and the toxicological properties can represent an unusually severe health threat. A study of physical and chemical removal processes of 43 chemicals

revealed that for a volatile chemical, such as acrylonitrile, vinylidene chloride, ethylene dichloride, perchloroethylene and benzo(a)pyrene, chemical removal residence times were estimated to range between 3 to 70 days based on reaction with hydroxyl radicals and ozone(5). That means vaporized contaminants may travel from rural areas to metropolitan areas, causing more than a localized problem.

Moreover, the hazardous properties of most organic compounds will probably remain unless destroyed by reactions. The undestroyed hazardous vapors and gases may be adsorbed or absorbed on small particles in the atmosphere and then eventually will fall out on land and in waters. Subsequently, they can be re-emitted into the atmosphere again through a cyclic process illustrated in Fig. 1.

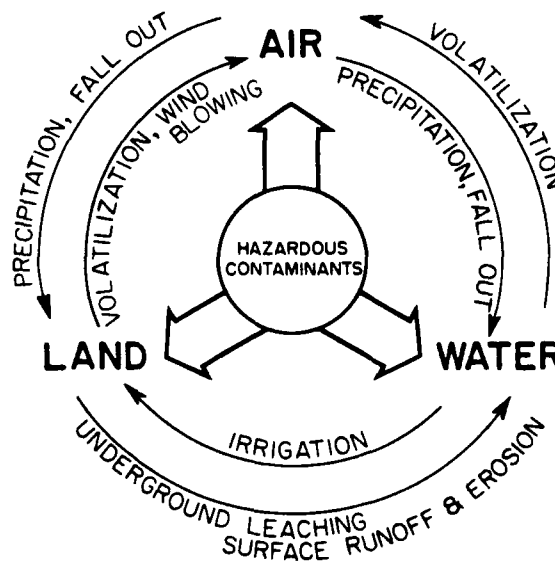


Figure 1.  
Hazardous Constituent Cycle

## HEALTH EFFECTS

The human health effect of fugitive dust and toxic vapors can be acute or chronic. An acute effect is a sudden, recognizable illness directly attributable to dust and chemical exposures. For example, dust can irritate the respiratory system or occur in sufficient quantity to physically overwhelm the respiratory system's natural defense mechanisms. Similarly, some gases, such as methane or carbon dioxide, can dilute the oxygen available to the lungs sufficiently to cause asphyxiation. In other cases, such as inhalation of carbon monoxide, the mechanism of asphyxiation is biochemical. Other materials can be severe irritants or cause serious

responses involving the immunological system with subsequent systemic shock, swelling of limbs, or various other neurological disorders.

More frequently, however, the dust and vapors will contribute to the occurrence of chronic diseases, the accelerated failure of organ systems or development of genetic disorders, such as cancer and teratogenesis. This illness can develop over long periods of time or the onset can be delayed for years or even decades, a time span known as the latency period. Lung cancers attributable to asbestos exposures during World War II, for example, have been reported in increasing numbers during recent years. Occurrence of the diseases will depend upon numerous risk factors, such as genetic characteristics, smoking or dietary habits, subsequent or previous environmental exposures, and the type and intensity of exposure.

Usually, however, generalizations can be made. Dust is associated with chronic bronchitis, emphysema, and, in some cases, lung cancer. Toxic vapors or soluble particulates will also affect specific organ systems. For example, mercury vapors will impair the central nervous system; benzene will suppress the capacity of bone marrow to form blood cells and can eventually contribute to occurrence of leukemia; cadmium and other heavy metals can affect the kidneys.

The possible roles of toxic vapors and hazardous particles in causation of cancer and cardiovascular disease are more complex. Carcinogens, for example, are generally classified into three categories:

- The direct-acting or primary carcinogens will produce tumors in a specific organ or where exposure occurred. However, these carcinogens in small quantities can usually be detoxified and excreted before cancers develop.
- The secondary or pro-carcinogens normally have target organs, such as the liver, and often will be transformed into the active agent by metabolic processes. Often these compounds require promoters.
- Promoters activate or stimulate the carcinogenetic effects of carcinogens absorbed by tissues from previous exposures. Examples would be croton oil or phorbol esters. Thus, if a person were exposed to croton oil but had not been previously exposed to a carcinogen, one would assume that no tumor would develop. If a person were exposed to a recognized secondary carcinogen, such as benzo(a)pyrene that is present in trace amounts in almost all industrial and urban environments, and then the person is exposed to croton oil, rapid development of tumors can be expected.

Considerable progress is being made in identifying the carcinogens that may be present in hazardous wastes but identification of promoters is considerably more difficult.

The prediction of health effects from chemical exposures is always complicated by the differences in responses between individuals. Each person will be more resistant or susceptible than another person because risk factors will differ. Furthermore, hazardous waste vapors and dusts are mixtures of chemicals, and are not pure, individual chemicals like those used in research or even in industrial environments that have provided the locale for most of the current toxicology knowledge. At this stage, estimates of human health effects from hazardous waste sites must be based upon identification of specific toxic chemicals, estimates of human exposure to these chemicals, and then some comparison with levels measured in toxicology research or found in epidemiological investigations. However, these estimates of possible effects represent crude, often incomplete approximations and additional effects may often be found.

## REGULATORY REQUIREMENTS

Thousands of landfills and surface impoundments used for disposal or treatment of hazardous wastes are operating with interim status under Section 3005(e) of the Resources Conservation and Recovery Act (RCRA). These interim regulations and standards

promulgated on May 9, 1980, and Jan. 12, 1981, primarily attempt to protect against contamination of surface and underground water supplies. Air pollution problems associated with hazardous waste facilities are not adequately addressed. RCRA regulatory requirements<sup>6</sup> promulgated to reduce hazardous air emissions from hazardous waste sites include:

- Waste piles containing hazardous waste must be covered or otherwise managed to prevent wind erosion
- Migration of air contaminants from the site must be controlled
- The vertical and horizontal escape of gases must be controlled by a gas collection and control system if one is present in the landfill
- Bulk or noncontainerized liquid waste must not be placed in a landfill with few exceptions, such as use of liners or pretreatment of the waste

The air monitoring requirements for new hazardous waste sites under RCRA include:

- An air monitoring system to yield air samples for analysis and to provide sufficient ambient air quality data to perform the required comparison and evaluations
- An air emission sampling and analysis plan which describes the sampling and analytical techniques and procedures
- An air emission evaluation to compare the anticipated effect of the waste site on ambient air quality with the provision of the site permit
- Records of all analyses and evaluations of ambient air quality, wind direction, and speed

The number and location of the monitors will depend upon the size of a site, meteorological conditions, prevalent winds, and the surrounding population density and distribution. Meteorological data are needed to facilitate the interpretation of the ambient monitoring data.

Air monitoring is primarily concerned with the detection of individual hazardous contaminants; however, indicators for toxic compounds, such as total hydrocarbons, total halogenated compounds, or total chlorine content, are used for air quality assessments. Further analysis for composition of hazardous air emissions at the location is required if monitoring detects the release of a significant amount of such indicator compounds. Measurements at the time of a maximum emission rate are preferable but they should reasonably be representative overall of emission levels. However, both average and worst case approaches to analyze the confidence in making evaluations would be useful.

The New York State Department of Environmental Conservation (DEC) currently requires hazardous waste land disposal facilities to have five cells based on chemical properties of the waste to be disposed.<sup>7</sup> These cells are to be hydrologically isolated:

- General cell
- Flammable waste cell
- Pseudometal cell
- Heavy metal cell
- Halogenated organic cell.

The primary reason for subdividing the landfill into cells is to match the construction material used in the receiving cell with the corrosive and other physical characteristics of the waste. Subdivision in the landfill also promotes safe handling during disposal operations, permits accurate record keeping of waste deposition and facilitates environmental monitoring for leakage and emission. Furthermore, use of cells can reduce the rate of gas generation within the entire landfill and, correspondingly diminish overall hazardous air emissions.

## AMBIENT AIR QUALITY ASSESSMENT

The purpose of ambient air quality assessment is to assure that emission levels of air contaminants into the atmosphere will be within acceptable limits for protection of public health and the environment. Ambient concentrations of air contaminants at or near a source of emissions are generally obtained by actual measurement or monitoring. However, under current logistic constraints, such as limited resources of money, manpower, and time

required for answers, prediction methods for toxic emissions from hazardous waste sites may be applied as a screening tool for ambient air quality assessment in the absence of monitoring data.

Prediction methods for average emission rates of major organic contaminants are available and are discussed in the next section. To convert emission rates (mass/time) to ambient concentrations (mass/volume), an appropriate atmospheric dispersion model must be applied. Numerous atmospheric dispersion models are available, but none were designed for estimating ambient concentrations from area sources, such as hazardous waste disposal sites. Among the available atmospheric dispersion models, the computer programmed PAL model<sup>8</sup> appears to be the best for this application. PAL is a multisource Gaussian-Plume atmospheric dispersion model used directly in the computation for point, line, and curved path sources. It is suitable for computing ambient concentrations nearby a receptor located at least 100 meters downwind of area sources. Concentration calculations are based on hourly meteorology, and averages can be computed for averaging times from one to 24 hours.

### EMISSION PREDICTION METHODS

For fugitive dust emissions produced by wind erosion of waste piles, about 2.5 to 10% of the waste may become airborne depending on the waste type and properties, wind velocity, and surface geometry. This range of air emission was originally developed for estimating emissions generated by agricultural soils.<sup>9</sup>

Dust emissions from unpaved haul roads by vehicle traffic are affected by the road surface texture on the road, road material, surface moisture, vehicle speed and vehicle type. Emissions can be predicted using the following equation described elsewhere:<sup>9,10</sup>

$$E = (0.81S)(v/30)(365 - N)/365 \quad (1)$$

where:

E = Emission factor (lb/vehicle-mile);

S = Silt content of road surface material (% by weight of particles less than 75  $\mu$  diameter);

V = Average vehicle speed (miles/hr); and

N = Mean annual number of days with 0.01 in. or more of rain-fall.

This equation valid for four-wheeled vehicles with speeds in the range of 30-50 miles/hour. It seems reasonable to adjust Equation (1) by a multiplier factor of W/4 applied to vehicles with more than four wheels where W = number of wheels on a vehicle.

Waste volatilization from landfills and surface impoundments have been studied by a number of researchers.<sup>11-19</sup> They have developed several prediction models for emission estimation by incorporating numerous variables and extensive input data into complicated calculations with multiple unit conversions. Based on their studies and experimental data, Equations (2-6) were recommended as screening tools after many variables were consolidated into few so that the input data could be kept to minimum and restricted to those data that could be readily obtained.

Emission rates of organic compounds from industrial waste buried sites can be predicted, assuming that diffusion in the vapor phase is the only transport process operating. If transport in moving water and degradation of the organic compound in the site are considered insignificant, the emission rate of a specific organic compound based on Fick's law can be estimated<sup>19</sup> using the following equation:

$$E_i = D_i C_{si} A P_t^{4/3} W_i (1/L) \quad (2)$$

where:

$E_i$  = emission rate of a specific compound in the waste (g/sec)

$D_i$  = diffusion coefficient of a specific compound ( $\text{cm}^2/\text{sec}$ )

$C_{si}$  = saturation vapor concentration of the compound ( $\text{g}/\text{cm}^3$ )

A = exposed area ( $\text{cm}^2$ )

$P_t$  = total soil porosity (dimensionless)

L = effective depth of soil cover (cm)

$W_i$  = weight fraction of a specific compound in the waste

The soil porosity can be calculated by the following equation:

$$P_t = 1 - d_b/d_p \quad (3)$$

where:

$d_b$  = soil bulk density ( $\text{g}/\text{cm}^3$ )

$d_p$  = particle density ( $\text{g}/\text{cm}^3$ ).

Dump sites are landfills which have no covering material and cause greater volatilization problems. Based on Arnold's<sup>11</sup> diffusion equation, the volume of vapor generation of a pure organic compound under steady state conditions can be calculated<sup>19</sup> using the following equation:

$$dV/dt = 2 C_e W (DLv/\pi F_y)^{1/2} W_i \quad (4)$$

where:

$dV/dt$  = emission rate ( $\text{cm}^3/\text{sec}$ )

$C_e$  = equilibrium vapor pressure

W = width of the dump site (cm)

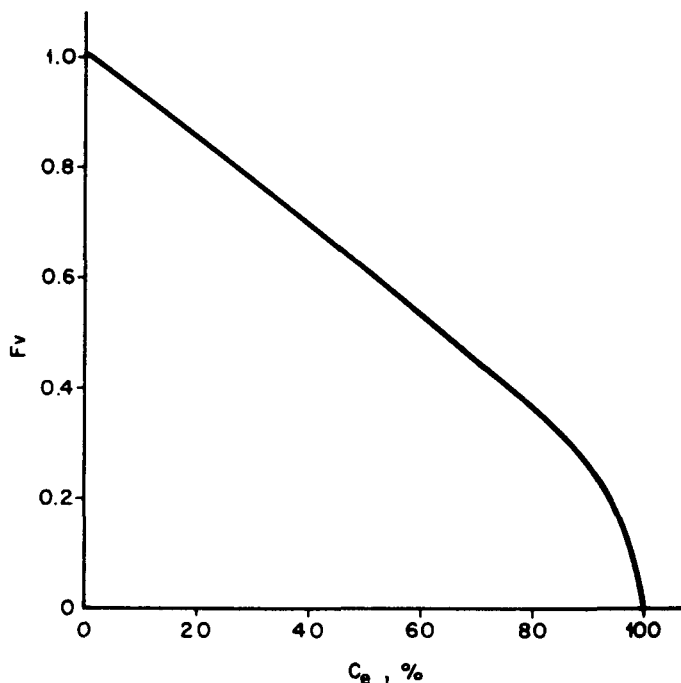
D = diffusion coefficient ( $\text{cm}^2/\text{sec}$ )

L = longest dimension of the dump site (cm)

v = wind speed (cm/sec)

$F_y$  = correction factor (see Fig. 2)

$W_i$  = weight fraction of a specific compound in the waste



Data Source: Reference 19

Figure 2.  
To Find Correction Factor  $F_y$

A strong wind can increase the emission rate; however, it also increases the dilution factor. Thus, the net-effect of wind speed on ambient concentration becomes compensative and depends on location of the receptor.

The rate of waste volatilization from industrial lagoons or ponds can be estimated<sup>4</sup> using the following empirical equations:

$$(ERP)_i = (18 \times 10^{-6}) (K_L)_i A C_i \quad (5)$$

where:

$(ERP)_i$  = emission rate potential of a compound (g/sec)

$(K_L)_i$  = liquid-phase mass transfer coefficient of a compound ( $\text{g-mol}/\text{cm}^2\text{-sec}$ )

A = lagoon surface area ( $\text{cm}^2$ )

$C_i$  = concentration of the compound in wastewater (mg/l).

Although Equation (5) appears relatively simply, its solution is difficult primarily because we have only limited experimental data for determining the liquid-phase mass transfer coefficient ( $K_L$ ) of organic compounds. However, there are methods to determine

( $K_L$ ) of organic compounds. Most of these methods involve complex equations and mathematical models which are too complicated to be applied by field and practicing engineers for quick and practical solutions. The following is a simplified equation recently developed:<sup>4</sup>

$$(K_L)_i = 4.45 \times 10^{-3} (M_i)^{-0.5} (1.024)^{t-20} (u)^{0.67} (H)^{-0.85} \quad (6)$$

where:

$M_i$  = molecular weight of the compound (g/mole)

$t$  = surface water temperature (°C)

$u$  = surface velocity = 0.035 wind velocity (cm/sec)

$H$  = water depth of the lagoon (cm)

The above six emission-related prediction equations should be applied cautiously since they are suitable only for screening purposes in extreme situations where emission rates and risks are clearly acceptable or unacceptable. Therefore, it would be advisable to analyze the level of confidence by making estimations using both average and worse case approaches.

## CONTROL TECHNIQUES

As with all air pollution problems, dilution and dispersion of hazardous air emissions into the atmosphere is still a vital method of control. But for less-reactive hazardous air contaminants, this approach of dilution and dispersion should be applied with extreme caution to meet the acceptable ambient air quality guidelines.

Fugitive dust emissions from haul roads used to transport wastes may be controlled by watering, chemical stabilizing, reducing vehicle speed, or paving these roads. Of course, dust emissions can effectively be controlled by paving these roads with concrete or asphalt. This approach is expensive and, therefore, has not been used on temporary roads at most waste treatment and disposal facilities. Main haul roads intended for long-term use are normally paved, however. Control efficiencies of available methods for fugitive dust emissions are shown in Table 1:<sup>10</sup>

Table 1.  
Control Methods for Unpaved Roads.

Control Method	Efficiency, %
Paving	85
Treating surface with penetrating chemicals	50
Working soil stabilizing chemicals into roadbed	50
Vehicle speed control@	
30 miles/hr	25
20 miles/hr	65
15 miles/hr	80

@Based on the assumption that uncontrolled speed is typically 40 miles/hr. Between 30 to 50 miles/hr emissions are linearly proportional to vehicle speed.

Emissions from industrial waste lagoons can be minimized by design considerations, such as increasing lagoon depth and decreasing lagoon surface area or constructing wind barriers at the upward location where the prevailing wind occurs in summer and autumn seasons. The best approach would be to remove volatiles from the waste entering into the lagoon. Steam stripping is one of the control alternatives for removal of volatiles from wastewater. For hydrocarbon mixtures, control alternatives may be recycling or recovery of volatiles by conventional distillation processes or disposal by incineration. Air emissions can be substantially reduced by covering the waste lagoon with an oil film. However, this approach can interfere with aerobic processes which are important for biological treatment in waste lagoons.

Control of landfill gas emissions is more difficult than control of leachate because prediction of the migration route for landfill gas is more complicated and difficult than for leachate. At present, landfill gas is generally vented directly to the atmosphere. This practice may cause significant adverse effect on air quality. Un-

less the quantity and composition of gaseous emissions are known to be insignificant, gas collection and control systems should be installed to prevent hazardous air emissions.<sup>19</sup>

To determine if gas collection and control systems will operate efficiently, one should first investigate whether the gas migration is primarily a pressure or diffusion problem. If the predominant mechanism is pressure flow, one would normally choose a passive venting system with adequate control to remove the pressure gradient, assuming the cover is relatively impermeable. On the other hand, if the primary gas migration process is a diffusion flow, a passive venting system would probably not be effective and the gas will eventually escape from the landfill cracks unless a forced venting system is installed to maintain a slightly negative pressure within the landfill.<sup>3,19</sup>

A practical and effective control of gas generation and emission for new landfills is pre-treatment of the wastes. The usual objectives of pretreatment are to destroy, recover, or convert hazardous components of the wastes into forms suitable for reuse or innocuous forms that are acceptable for land disposal. Gas generation can also be reduced by eliminating all volatile organic wastes and liquids from landfilling. Keeping the liquids from entering and leaving landfills would eventually minimize gas generation and gas emissions. This can be accomplished by using liners that may be concrete, asphalt, certain plastics, or a mixture of natural soil and sodium bentonite. Sodium bentonite swells more than ten times its original size when it comes into contact with water. When combined with natural soil, it creates an impermeable layer.

As a remedial action at existing landfills, the use of covering materials known as "capping," has been proven to be an effective method for temporary solution of a problem that needs immediate action. An example of such remedial action was the Caputo disposal site located near South Glens Falls, N.Y. Assorted materials, such as topsoil, papermill sludges and manure, were used to cover the site and prevent PCB volatilization during the summer months in 1980. These materials were readily available, economical, and easy to apply. Furthermore, papermill sludge and manure have a high capacity for gas and vapor adsorption. Because they are organic material, they are also relatively combustible and can be later incinerated.

One of the important measures in controlling hazardous air emissions is to avoid co-disposal of certain wastes in the same landfill cell or lagoon. Examples of such wastes are acids with metals or solvents with certain highly toxic aromatic hydrocarbons. In some cases, waste stabilization or solidification may be necessary to reduce their mobility and emissions.

## SUMMARY AND CONCLUSIONS

•Dust emission and waste volatilization have been identified as the major air pollution problems at hazardous waste sites. But the degree and extent of such problems have not been well defined because of lacking air monitoring data.

•Emissions of fugitive dust may cause a localized problem but toxic vapor releasing from waste disposal sites may travel in the atmosphere a long distance from rural to urban areas. Effects of such emission on human health and the environment may be significant.

•Current regulations are not adequate to control hazardous air emissions. Air pollution control seems to be a weak linkage of hazardous waste legislation.

•In the absence of air monitoring data, emission prediction methods and atmospheric dispersion models may be used for ambient air quality assessment of waste disposal sites. The accuracy of the emission prediction methods and atmospheric dispersion models, however, depends on the availability of experimental data because the theoretical basis and analytical tools are insufficient.

•Both dust emission and waste volatilization can be minimized by available technology at a cost that is widely accepted in public-works projects. Thus, air quality should not be degraded unless the degree of degradation is determined, evaluated, and found to be acceptable. To do otherwise would be to blindly allow hazardous emissions without knowing the consequences.

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# THE INVESTIGATION OF MERCURY CONTAMINATION IN THE VICINITY OF BERRY'S CREEK

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## INTRODUCTION

One of the largest anthropogenic sources of mercury in the world can be traced to an uncontrolled hazardous waste site located in the Hackensack Meadowlands of New Jersey (Fig. 1). From both a technical and legal perspective, this site has been one of the most intensely studied hazardous waste sites, thereby providing a useful model for the study of landfill investigation and remedial action programs.

Enforcement and investigation activities, completed to date, encompass most of the tasks that must be completed for a typical uncontrolled hazardous waste site case. These include:

- Site identification/site history
- Site investigation
- Initial assessment of potential site related environmental/public health effects
- Initiation of litigation against past/present landowners

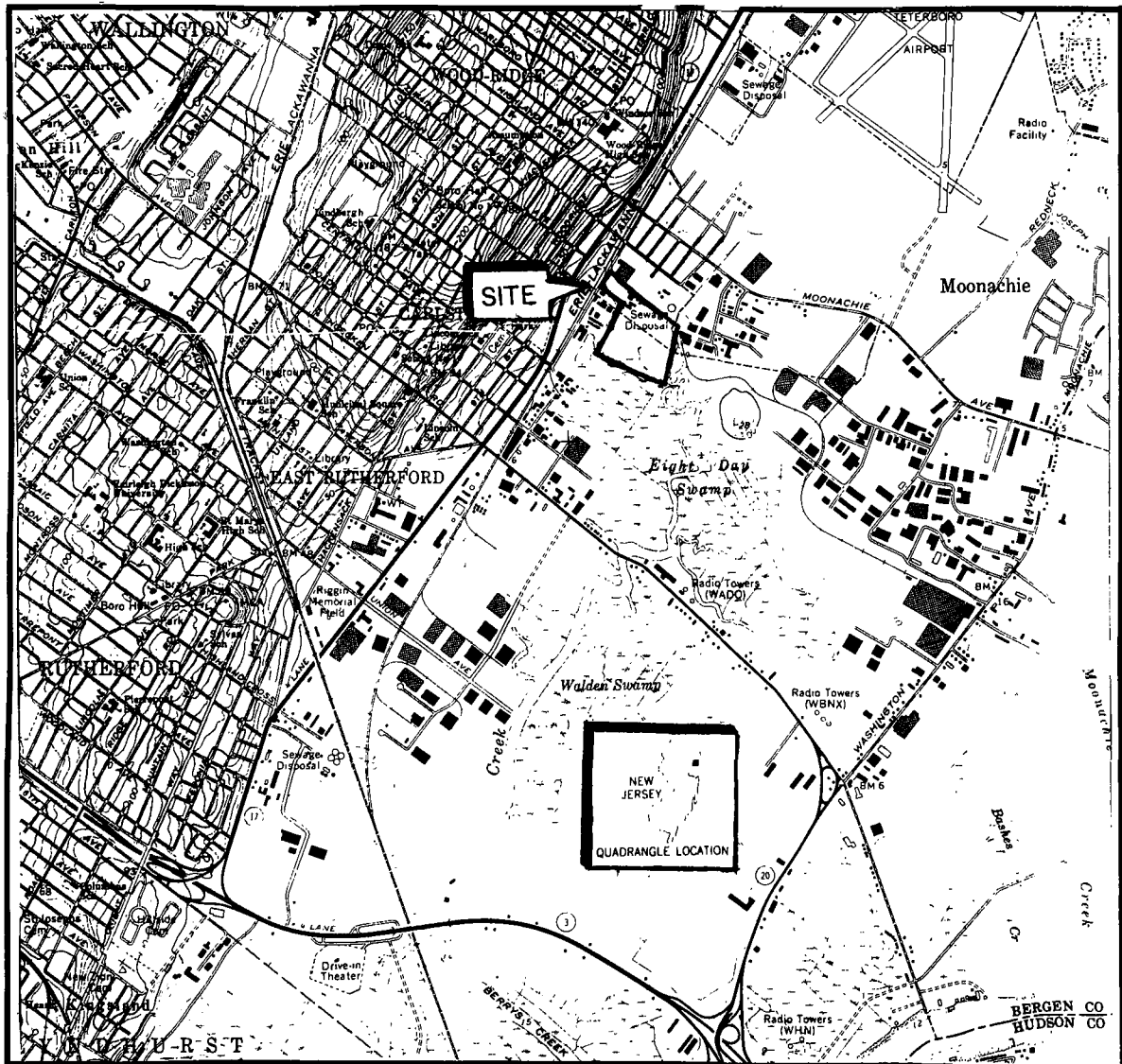


Figure 1.

Location of mercury site in boroughs of Wood Ridge and Carlstadt, Bergen County, in the Hackensack Meadowlands, N.J.



- Rendering of a court decision

The remaining tasks in this investigation include:

- Obtaining permits for remedial action work
- Implementation of a remedial action plan

A summary of the work completed to date is described below.

### SITE IDENTIFICATION AND SITE HISTORY

The mercury dump site is located on a 40 acre tract of land in the New Jersey Hackensack Meadowlands. A more detailed site location map is provided as Fig. 2. The site is bounded on the east by Berry's Creek, a tidal tributary of the Hackensack River. As shown in the figure, Berry's Creek is sectioned near the site by a tidegate installed prior to 1930 and replaced in 1978. The surrounding area is zoned for light and heavy industry, with residential areas located

within 1,000 ft to the north and west of the site.

From 1930-1974 a mercury processing plant operated on a 7 acre portion of the 40 acres. During those years, property and plant ownership changed hands, but plant operations remained directed to the manufacture of fungicides, insecticides, red and yellow oxides of mercury, phenyl mercuric acetate, and other organic and inorganic forms of mercury. The plant also had a distilling operation in which contaminated mercury was purified and recovered from both plant wastes and from outside customers.

Although a major portion of the tract was originally wetland, approximately 19 acres between Berry's Creek and the plant site was used as a dump site primarily for the disposal of the plant's industrial and chemical wastes.

The history of state/federal regulatory and enforcement actions against the operators of the plant is a long and detailed one. Beginning in 1956 with state enforcement actions, the site came under increasing federal scrutiny with the creation of the USEPA in 1970. At that time, it was thought that the major problem associated with the site was the active discharge of mercury into Berry's Creek surface waters. Subsequent to the reduction of these discharge levels, and the discovery that the soils near the site were highly contaminated with mercury, lead enforcement responsibilities were returned to the state.

Plans by a local developer to construct two warehouse buildings (which have since been constructed) on the site where the process building was located, resulted in the collection of a series of soil samples by regulatory agencies.<sup>1</sup> Concentrations of mercury above 1% were detected in some areas.<sup>2</sup> This discovery, and the failure of local parties to agree to terms for the entombment and/or cleanup of the site, led the State to commence a law suit in April 1976, against all past and present land owners, to determine the liability for site cleanup. A decision in favor of the State was rendered on Aug. 27, 1979.

### SITE INVESTIGATION

Site investigation activities included the collection of air, water, soil, and sediment samples to determine the magnitude and extent of mercury contamination at the site and within surrounding wetlands. Additionally, since mercury particularly in the methylated form, can move into the food chain, samples of biota were collected to insure the lack of an immediate threat to public health.

The investigation was coordinated and directed by the N.J. Dept. of Environmental Protection (NJ-DEP). As indicated, the data that will be presented were collected by several institutions including NJ-DEP, USEPA, Hackensack Meadowlands Development Commission (HMDC), N.J. Marine Sciences Consortium (NJMSC), and Jack McCormick Associates, Inc. (JMA).

Extensive sampling of air, water, soil and sediment indicated that the soil on and adjacent to the 40 acre tract of land is highly contaminated with mercury. Furthermore, a zone of mercury contamination was found to extend approximately 13,000 ft southward from the site, within the Upper Berry's Creek tidal basin, to the Route 3 bridge. The increasing degree of contamination with proximity to the site indicates that the site is the source of mercury contamination in the adjacent areas.

A summary of the soil and sediment sampling data is given in Table 1. In a series of 31 core samples collected by JMA on the 40 acre site, concentrations of mercury ranged up to 123,000 ppm. In at least 13% of the samples, concentrations greater than 1000 ppm were found.<sup>2</sup> Similarly, high levels of mercury were found by HMDC within the tidal marshes adjacent to Berry's Creek. Among 13 soil core samples collected north of the Route 3 bridge, four samples (31%) had peak mercury concentrations of over 1000 ppm. In contrast, among 36 core samples collected elsewhere in the Meadowlands district, only one soil sample had greater than 100 ppm as a peak mercury concentration.<sup>3,4</sup>

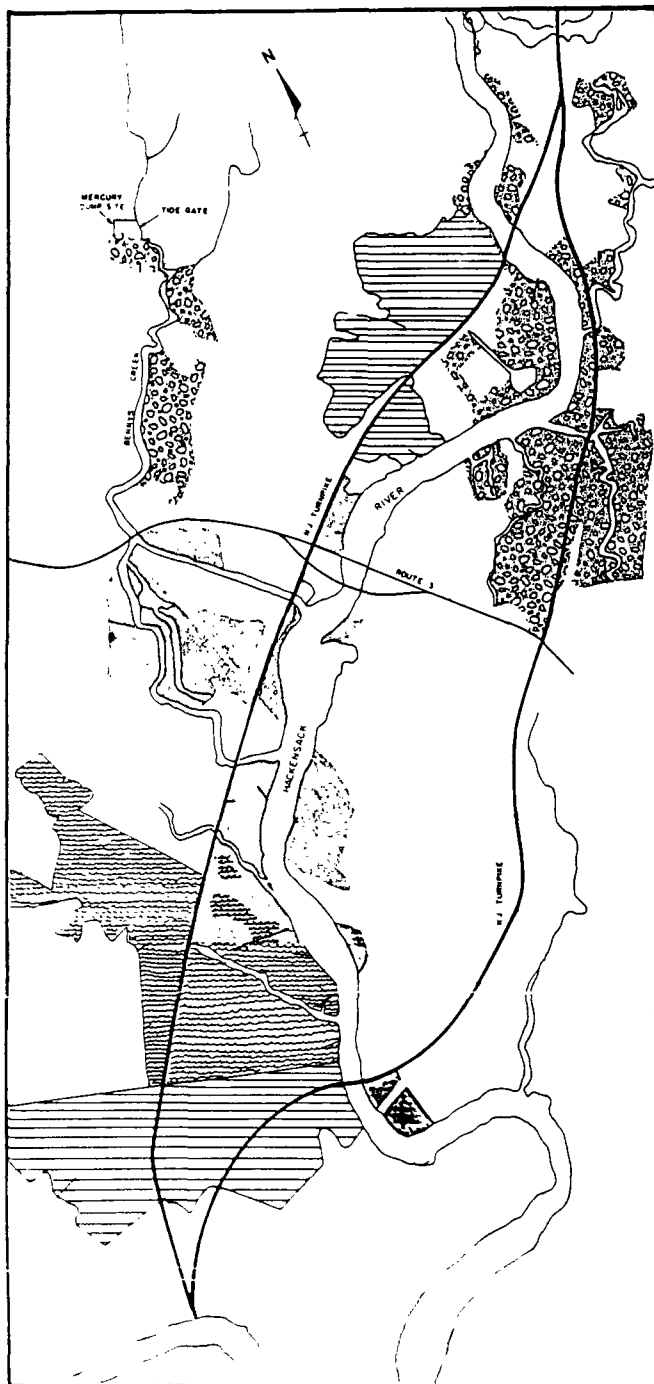


Figure 2.

Detailed map of Berry's Creek in the Hackensack Meadowlands District

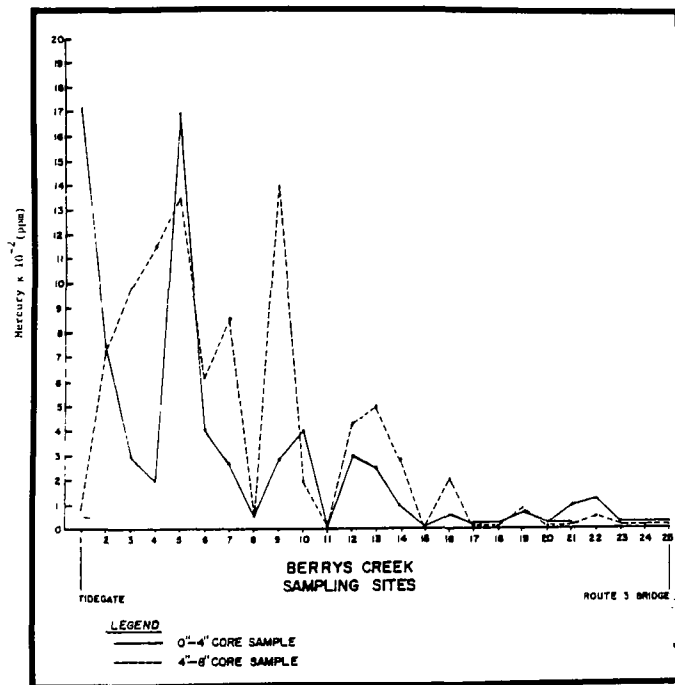
**Table 1.**  
**Data Summary-Soil and Sediment Sample Collection**

			% samples within Hg concentration range			
Sample Desc. Description		No. of Sam- ples	Peak Hg Conc. (ppm)	0.1-100 (ppm)	101-1000 (ppm)	1000 + (ppm)
Soil core sam- ples collected 40 acre Hg site to depth of 18 ft		31	123,000	55 %	32 %	13 %
Peak Hg concen- trations in marsh core sam- ples collected to depth of 18 in.	a. Within Upper Berry's Ck tidal basin north of Rt. 3 bridge	13	2,006	15 %	54 %	31 %
	b. All other Meadowlands locations	36	158	97 %	3 %	
Peak Hg concen- tration in chan- nel sediments to depth of 18 in.	a. Within Upper Berry's Ck 28 tidal basin North of Rt. 3 bridge	28	1,730	46 %	39 %	14 %
	b. All other Meadowlands locations	30	97	100 %		

The correlation of mercury concentrations in marsh soils with proximity to the site is illustrated by Fig. 3, where peak mercury values within three different ranges of mercury concentrations are plotted for each of the sampling locations.<sup>5</sup>

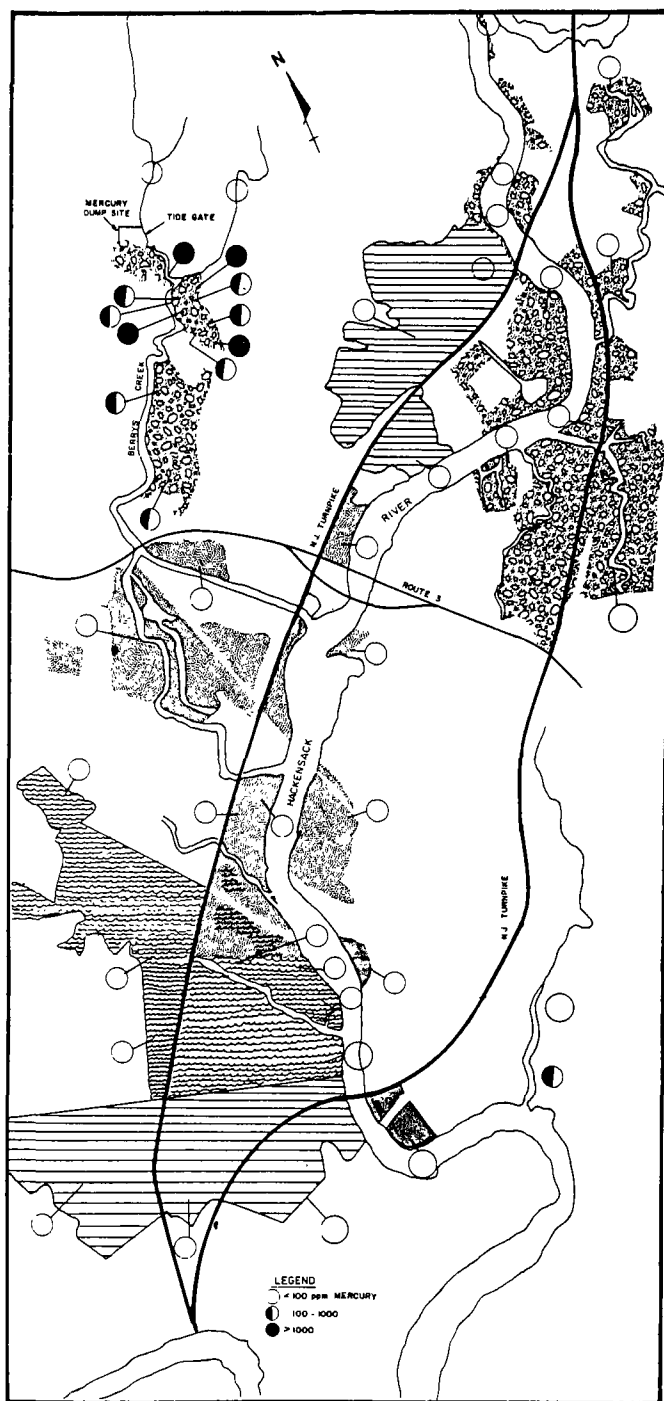
Results from an HMDC study of channel sediments collected from Berry's Creek and other creeks in the Meadowlands are consistent with the data obtained from marsh soils. The concentration of mercury within Berry's Creek ranged to 1730 ppm, with greater concentrations found nearer to the site. Among 28 core sediment samples collected between the tidegate and the Route 3 bridge, over 53% of the samples had peak mercury values in excess of 100 ppm. In contrast, none of the sediment samples collected from other creeks had peak concentrations exceeding 100 ppm.

The data indicate that the concentration of mercury in Berry's Creek channel sediments falls off rapidly with distance from the site. This is shown in Fig. 4 where the concentration of mercury in 0 to 4 in. and 4 to 8 in. deep core sample intervals are plotted against distance from the site.



**Figure 4.**

Mercury concentrations in 25 channel core samples collected from Berry's Creek (Route 3 bridge to tidegate)



**Figure 3.**

Geographical distribution of peak mercury concentrations in the marsh sediments of the Hackensack Meadowlands District

Above background levels of mercury were found in the surface water of Berry's Creek.<sup>4</sup> Filtered and unfiltered water samples were collected monthly by HMDC at high and low tides, at eight separate Meadowlands locations, with three locations in the Upper Berry's Creek tidal basin. Essentially no mercury was found in the filtered water samples. However, among the unfiltered samples, 36% of the Berry's Creek samples were in excess of 1.2  $\mu\text{g}/\text{l}$ . In contrast, in the remaining sampling locations only 6% of the samples exceeded this level. The surface data are summarized and compared to data collected from other New Jersey locations in Table 2.

A study of organic and inorganic mercury concentrations in the ambient air above the 40 acre site was also performed.<sup>7</sup> Ambient air quality was monitored by USEPA over a 5 day period at three on-site locations and within one adjacent warehouse building. Samples

were collected for 8, 12, and 24 hr periods using silver foil columns to trap elemental mercury (via amalgamation). No organic mercury was found in this study. However, elemental mercury concentrations ranged from 0.29  $\mu\text{g}/\text{m}^3$  to 3.3  $\mu\text{g}/\text{m}^3$  (Table 3).

**Table 2.**  
Frequency Distribution of Mercury Concentrations (mg/l) in New Jersey Surface Waters Compared with Those Found in the Hackensack River and Berry's Creek.<sup>1</sup>

Range Hg (ppb)	Sampling Sites N.E. N.J. n (%)	Hackensack R. (excluding Berry's Creek) n (%)	Berry's Creek n (%)
n.d.-0.1	103 (70%)	33 (30%)	3 (3%)
0.1-0.2	16 (11%)	33 (30%)	1 (2%)
0.2-0.3	22 (15%)	15 (13%)	2 (3%)
0.3-0.4	2 (1%)	9 (8%)	5 (8%)
0.4-0.5	1 (1%)	6 (5%)	6 (9%)
0.5-0.8	1 (1%)	7 (6%)	9 (14%)
0.8-1.2	0	1 (1%)	17 (26%)
1.2 +	0	6 (6%)	24 (36%)

These average mercury concentrations found in the ambient air were not judged high enough to indicate any immediate threat to nearby residents or workers. Nonetheless, when compared with recommended occupational exposure limits of (50  $\mu\text{g}/\text{m}^3$  for a 40 hour work week) and adding safety factors for 24 hour potentially continuous exposure of non-worker populations, a precautionary study of mercury levels in local residents and workers was undertaken by the N.J. Dept. of Health (described below).

### MERCURY CONTAMINATION IN BIOTA

Between 1978 and 1980, as part of the site investigation, the DEP sponsored several studies of mercury contamination in aquatic and terrestrial biota.<sup>3,7</sup> The purpose of these studies was to assess the impact of mercury contamination on local biota, particularly those species trapped and consumed by area residents.

**Table 3.**  
Concentrations of Mercury in Ambient Air ( $\mu\text{g}/\text{m}^3$ ) at Four Locations at a Mercury Dump Site in Woodridge, Bergen County, New Jersey During August 1978

Station & Dates	24-hr values ( $\mu\text{g}/\text{m}^3$ )	12-hr values ( $\mu\text{g}/\text{m}^3$ )	8-hr values ( $\mu\text{g}/\text{m}^3$ )
Site 1			
8/14			0.38
8/15			0.74
Site 2			
8/10-11	1.02	---	0.55
8/11-12	0.46	0.47	0.38
8/12-13	0.52	0.79	0.44
8/13-14	1.01	1.65	0.72
8/14	---	1.54	---
8/14	---	---	---
*mean	0.76		
Site 3			
8/10-11	---	---	1.68
8/11-12	0.29	0.21	0.25
	0.29		
8/12-13	0.39	0.18	0.50
	0.27		
8/13-14	1.02	0.38	1.37
	0.75		
8/14-15	2.85	1.00	3.26
*mean	1.03		
Site 4			
8/12-13	0.20		
8/13-14	2.09		
8/14-15	2.21		
*mean	1.50		

In a large study conducted in 1978 by HMDC, 479 specimens of fish comprising 14 species, 94 specimens of aquatic invertebrates,

36 mammals, and 35 avian specimens were analyzed. Average mercury concentrations for each vertebrate class and for selected invertebrate species are reported in Table 4. Fish and invertebrates in the Meadowlands district exhibit slightly higher mercury contamination relative to background levels.<sup>8</sup> However, the average mercury concentrations were well within levels acceptable for human consumption (1 ppm). Similar results were obtained in two later studies of finfish and shellfish completed by the NJMSC in 1980.

The only permanent resident finfish that can be found in abundance in the waters of the Upper Berry's Creek tidal basin is the Common Mummichog of Killifish. Although these organisms are not consumed by man, they are a useful indicator of relative contamination in that they can be trapped easily and spend most of the lives swimming within the same general area. In the study undertaken by HMDC, Killifish collected downstream on Berry's Creek had greater average concentrations of mercury than those collected upstream. In two separate Killifish studies performed by NJMSC, conflicting data were received regarding the relationship of mercury concentrations with proximity to the mercury site. Only one species, the fiddler crab, was found to consistently exhibit a body burden gradient with proximity to the site. Monitoring of aquatic organisms is continuing.

**Table 4.**  
Concentrations of Mercury (ppm) in Tissues of Organisms Collected in the Hackensack Meadowlands, New Jersey during 1978

Vertebrate Class	No. of Samples	Muscle	Liver	Kidney	Fur	Feather
Fish	479	0.451				
	27		0.566			
	23			0.696		
Mammals	27				0.725	
	34	0.027				
	36		0.168			
	34			0.462		
Birds	33					3.2
	35	0.358				
	34		1.1			
	34			1.1		
Invertebrates						
Fiddler crab	28	0.231				
Blue claw crab	10	0.253				
Grass shrimp	54	0.234				

Tissue concentrations of mercury in the mammals and birds collected in the Hackensack Meadowlands compare favorably with levels observed in terrestrial herbivores and omnivores.<sup>9</sup> Generally, lower values were observed than those reported in most other studies of mercury contamination.<sup>10</sup> Among the birds and waterfowl, mercury concentrations were greater in the aquatic birds than those restricted to a terrestrial habitat. This would indicate that the movement and transport of mercury through the Meadowlands occurs primarily in the aquatic environment. Hence, those species most contaminated by mercury will be those who depend on the aquatic foodweb.

Examination of mercury burdens in specific body tissues indicates that mercury accumulation occurs in the kidney and fur of mammals. Similarly, levels of mercury in avian species were found in decreasing concentrations in the feather, kidney, liver and muscle tissue. Generally the amount of mercury observed in feathers was three times that found in other tissues.

### INITIAL HEALTH ASSESSMENT

It is clear that mercury has contaminated the physical environment surrounding the Berry's Creek ecosystem. In order to minimize the potential for health risks to humans, several routes of exposure have been examined. Because local residents utilize a public supply water and because the physical/chemical characteristics of mercury limits the migration of mercury contaminated groundwater, water supply is not considered an impor-

tant risk. Exposure due to contaminated soils have been minimized through the fencing of the property and through public awareness. Although above background levels of mercury were found in the local biota, the levels are within acceptable federal standards.

Exposure to unsafe levels of mercury vapor in surrounding residences was also thought to be improbable by both the DEP and the NJ Department of Health. Nonetheless, blood, hair, and urine samples were collected for mercury analysis by the NJ-DOH from over 300 individuals in nearby residences and businesses.<sup>11</sup> The results of these tests in 1979 indicated that there was no acute health hazard to the population residing in the area from the mercury contamination. Only low levels of mercury, typical of the U.S. population at large, were detected in the blood, hair, and urine samples. For example, it can be expected that less than 10 µg/l of mercury can be found in the average person's blood, but levels as high as 30 µg/l can be found in up to 5% of the U.S. population. Near the mercury site, ninety (90%) percent of the tested individuals in the area had blood mercury levels below 10 µg/l with the high level observed at 15 µg/l. Similarly, with the exception of four individuals, the levels found in urine samples were well within an acceptable and non-hazardous range. (The aforementioned individuals are all members of the same family in which a bottle of metallic mercury brought home from school was thought to have been the major source of exposure.) Nevertheless, within this general range of acceptable and non-hazardous low levels of mercury detected in the urine samples, the NJ-DOH was able to ascertain that residents who have frequent exposure to the site have slightly higher urine mercury levels than residents with no exposure.

## HISTORY OF LITIGATION

During 1972, an investigation of marsh sediments in Berry's Creek tidal marsh revealed unusually high concentrations of mercury and other heavy metals.<sup>12</sup> Subsequent studies in 1974 and 1976 sponsored by the N.J. Sports and Exposition Authority (NJSEA) confirmed the earlier findings. Furthermore, elevated mercury levels were found to exist in areas outside Berry's Creek.<sup>13,14</sup>

During 1974, the demolition of the mercury processing plant created an oily slick on the surface waters of Berry's Creek. Analysis of water samples by HMDC, NJ-DEP, and USEPA revealed concentrations of mercury more than 57,000 times that allowed in surface waters. The completion of two studies by JMA and HMDC in 1977 and 1978, funded by NJ-DEP, confirmed heavy contamination at the mercury site and adjacent marshes in Upper Berry's Creek. The accumulated evidence of mercury contamination, some of which has been summarized above, spurred a law suit, *State of New Jersey vs. Ventron Corp. et al.* which went to trial in May 1978, and on Aug. 27, 1979, a decision in favor of the State of New Jersey was rendered. On Nov. 17, 1979, an order and judgment was issued which declared the defendants liability for pollution abatement on the contaminated properties and cleanup of Berry's Creek.

A cleanup plan was submitted to the court by the state during Feb., 1980. It was recommended that the creek be dredged downstream to the Route 3 bridge. For the disposal of the dredged sediments, the state recommended the use of the contaminated properties as a dewatering and disposal facility. On Dec. 10, 1981, the Appellate Division of the Superior Court of New Jersey unanimously affirmed the lower court's ruling that the defendants caused the mercury contamination and that they were responsible for the cleanup of the present contamination found in the area.

During June 1981, the DEP submitted its application to the New York District, Army Corps of Engineers for a permit to dredge. On

Apr. 16, 1982, following the Corps's public notice of Feb. 1, 1982, a session was held to discuss the preliminary scope of work for the required Environmental Impact Statement (EIS). Hence, the EIS is presently being prepared to determine the environmental feasibility of the dredging of Berry's Creek.

The lawsuit regarding the contamination of its mercury site and Berry's Creek began in 1976 and still continues. The manpower and financial resources required for this lawsuit have been enormous, and have brought the issue to a decision of liability and cleanup, with an appeal before the Supreme Court of New Jersey still remaining, and the permit process just beginning. Because of the many facets of this case, it should be examined more closely by those who will be cleaning up other similar sites under "Superfund".

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# PRACTICAL INTERPRETATION OF GROUNDWATER MONITORING RESULTS

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## INTRODUCTION

Normally, groundwater investigations involve the installation of monitoring wells on and around the site, collection of samples from these wells, analysis of the samples for selected constituents, and comparison of the results to determine the extent of the contamination. The usual approach is to compare results from upgradient (off-site or background) wells with downgradient wells.

The problem is that many times the results of the analyses are not clear. This is particularly true for organic compounds (like priority pollutants) measured by GC/MS at the  $\mu\text{g/l}$  level. Commonly, differences and anomalies are experienced which are difficult to interpret and explain. For example: Suppose  $10 \mu\text{g/l}$  of trichlorethylene (TCE) is found in Well A and  $22 \mu\text{g/l}$  TCE is found in Well B. Is the water in Well A really different from that in Well B?

Given that the analytical results of the groundwater investigation form the basis for public health risk assessments and the basis for costly remedial action, it is absolutely essential that the analytical interpretation and results be correct. This point cannot be overemphasized. The results of the groundwater investigation are often used to determine whether there is a risk to the public health and also to determine what remedial actions are necessary. These are important decisions and must be made on the basis of sound data and clear interpretations.

Statistical methods are powerful tools which greatly enhance the ability to understand and interpret the results of groundwater analyses and allow the investigator to define the confidence and certainty of the results. Most scientists and engineers are aware that statistical tools are available. Yet, these tools are seldom utilized because workers do not know or understand how to use them, do not believe they add any real value, and/or do not believe the added cost (for replicate analysis) is justified. In this paper, the author explains the practical application of statistical methods in the design of groundwater investigation programs and interpretation of the results of those programs.

## OBJECTIVE

The principal objective of a groundwater investigation at a known or suspected hazardous waste site is to design and implement a cost-effective program that will reveal, with a known degree of certainty, whether and where the groundwater is contaminated. In the context of the investigation, this means that one wants to know "if the water in Well A is truly different from Well B." One wants to be confident the results are correct and spend no more money than is really necessary. Statistical design and interpretation is the only way to meet this objective.

If one takes water samples from the same well on two separate occasions (or from two separate wells at the same time) and analyzes the samples, the measured concentration will nearly always be different in the two samples. There are three principal sources of this variability:

- Variability resulting from actual changes in concentration of the analyte in the groundwater (or differences in concentration due to differences in location)
- Variability introduced as a result of the sampling procedure
- Variability in the analytical procedure

To determine whether the groundwater is contaminated, one must somehow subtract or otherwise take into account the variability from the sampling and analysis and simply compare the actual con-

centrations. Proper application of statistics makes this distinction possible.

## THE "t" TEST

There are various statistical tools that can be used to design investigations and analyze experimental results. Many of these are relevant to groundwater systems. However, the Student's t test or, simply, t-test, has been widely used. It is popular because it is simple, applicable to many situations, easily understood and interpreted. Also, and perhaps most important, it has recently become part of the Resource Conservation and Recovery Act of 1976 (RCRA) regulations relating to groundwater monitoring and reporting systems.

The t-test is used to compare the concentration of an analyte in one well (say Well A) with that in another well (say Well B). The first step is to establish a hypothesis regarding whether the water in these wells is the same or different. For this example, assume that the water in Well A is the same as that in B. The next step is to take and analyze some samples from these wells for the analyte of interest. Now calculate the t-statistic using the following formula:

$$t = \frac{x_B - x_A}{\left[ \frac{s_A^2}{n_A} + \frac{s_B^2}{n_B} \right]^{1/2}} \quad (1)$$

where

- $x_A$  = mean concentration of analyte in Well A
- $x_B$  = mean concentration of analyte in Well B
- $s_A^2$  = the variance of analyte concentration in Well A
- $s_B^2$  = the variance of analyte concentration in Well B
- $n_A$  = number of samples taken from Well A
- $n_B$  = number of samples taken from Well B

This calculated t value is compared to a tabulated value of t (Table 1) at a known probability level, usually 5% or 1% (equivalent to a 95% or 99% confidence level). If t-calculated is less than

Table 1.  
Values of t

Degrees of Freedom	Probability Level			
	0.2	0.1	0.05	0.01
1	3.078	6.314	12.706	63.657
2	1.886	2.920	4.303	9.925
3	1.638	2.353	3.182	5.841
4	1.533	2.132	2.776	4.604
5	1.476	2.015	2.571	4.032
6	1.440	1.943	2.447	3.707
7	1.415	1.895	2.365	3.499
8	1.397	1.860	2.306	3.355
9	1.385	1.833	2.262	3.250
10	1.372	1.812	2.278	3.169
15	1.341	1.753	2.131	2.947
20	1.325	1.725	2.086	2.845
25	1.316	1.708	2.060	2.787
30	1.310	1.697	2.042	2.750
60	1.296	1.671	2.000	2.660
120	1.289	1.658	1.980	2.617
Infinity	1.282	1.645	1.960	2.576

Source: Abridged from Steel and Torrie'

t-tabulated, then the original hypothesis is correct and one concludes that the water in Well A is the same as the water in Well B. If t-calculated is greater than t-tabulated, then the original hypothesis is incorrect: Well A is different from Well B. An example calculation is shown in Table 2.

**Table 2.**  
Example Calculation of t-Statistic

Benzene Conc. in Well A ( $\mu\text{g/l}$ )	(Conc. in A) <sup>2</sup>	Benzene Conc. in Well B ( $\mu\text{g/l}$ )	(Conc. in B) <sup>2</sup>
22	484	39	1,521
52	2,704	45	2,025
35	1,225	80	6,400
42	1,764	50	2,500
$\Sigma X_A = 151$	$\Sigma X_A^2 = 6177$	$\Sigma X_B = 214$	$\Sigma X_B^2 = 12,446$
$x_A = 37.8$		$x_B = 53.5$	
$s_A^2 = \frac{\Sigma X_A^2 - (\Sigma X_A)^2/n_A}{n_A - 1}$		$s_B^2 = \frac{\Sigma X_B^2 - (\Sigma X_B)^2/n_B}{n_B - 1}$	
$s_A^2 = \frac{6177 - (151)^2/4}{4-1} = 159$		$s_B^2 = \frac{12,446 - (214)^2/4}{4-1} = 332$	
$s_A = 12.6$		$s_B = 18.2$	

Test the hypothesis that Benzene in A = Benzene in B at 5% level

$$t = \frac{x_B - x_A}{\left[ \frac{s_A^2}{n_A} + \frac{s_B^2}{n_B} \right]^{1/2}} = \frac{53.5 - 37.8}{\left[ \frac{159}{4} + \frac{332}{4} \right]^{1/2}} = 1.427$$

df = degrees of freedom =  $n_A + n_B - 2 = 6$

From Table 1, the value of t at df = 6 and 0.05 probability is 2.447; hence, t-calculated (1.427) is less than t-tabulated (2.447).

Conclude: Original hypothesis is correct. The benzene concentration in Well A is the same as the benzene concentration in Well B.

In this example, four samples are taken from two different wells: Well A is upgradient of the source of contamination and Well B is downgradient from the source of contamination. The benzene concentration has been measured in these four samples. The calculated t is 1.427; the tabulated t is 2.447. Since the calculated t is less than the tabulated t, one concludes that the original hypothesis is correct: the benzene concentration in Well A is the same as that in Well B. This statistical conclusion is especially important for this example because, simple visual comparison of the mean benzene concentration in Well A (38  $\mu\text{g/l}$ ) with that in Well B (54  $\mu\text{g/l}$ ) leads to the opposite (and incorrect) conclusion that Well B contains more benzene. Thus, the t-test allows one to state with a known degree of confidence whether or not there is a real difference between the water in Well A and the water in Well B.

## TYPES OF ERRORS

Because statistical tests are based on probability, there is some chance that one will reach the wrong conclusion. It is therefore important to know and understand the types of errors which can occur. There are two kinds of errors: Type I and Type II.

### Type I Error

The Type I error is made when one rejects the original hypothesis and that is in fact correct. The probability of such an error is designated by  $\alpha$  (Greek alpha). In the example,  $\alpha$  is 0.05, so there is only a 5% chance of a Type I error.

### Type II Error

The Type II error is made when one accepts the original hypothesis and it is not true. The probability of such an error is designated by  $\beta$  (Greek beta). In the example,  $\beta$ , which is a function of the number of samples and the sample variance, was not calculated. It is possible that a Type II error has been committed in the example problem because the sample size is too small to show the significant difference that may exist.

The relationship between the t statistic, the conclusion reached, and the types of error involved is shown in Table 3. In hazardous waste site investigations, avoiding both types of error is important. One needs to know, with a high degree of certainty, whether or not there are real differences in the quality of the groundwater.

Since  $\beta$  is related to the number of samples needed and the cost of the investigation and monitoring program are also related to the number of samples, it is important to consider this parameter.

## NUMBER OF SAMPLES

In choosing the sample size, one must guard against both the Type I and Type II errors. One would like the probability of committing these errors to be small. Typically the  $\alpha$ -level, the probability of committing a Type I error (concluding the two wells are different when, in fact, they are the same) is chosen to be 0.05. One would also like the same level of protection against the probability of committing a Type II error (concluding the two wells are the same when, in fact, they are different). It is reasonable therefore to also set  $\beta$  equal to 0.05.

**Table 3.**  
Decisions and Associated Errors

Original Hypothesis: Analyte concentration in Well A is the same as that in Well B.

t statistic	One Concludes	True Situation	Decision is	Error Type	Probability of Error
t-calc > t-tab	A $\neq$ B	A $\neq$ B	Correct	None	---
t-calc > t-tab	A $\neq$ B	A = B	Wrong	Type I	$\alpha$
t-calc < t-tab	A = B	A $\neq$ B	Wrong	Type II	$\beta$
t-calc < t-tab	A = B	A = B	Correct	None	---

The sample size can be determined by using the following equation:<sup>2</sup>

$$n = [U_{1-\beta} + U_{1-\alpha/2}]^2 \left[ \frac{s}{x_A - x_B} \right]^2 \quad (2)$$

where:

- n = number of samples needed
- $U_{1-\beta}$  = standard normal deviate for probability  $1-\beta$  (Table 4)
- $U_{1-\alpha/2}$  = standard normal deviate for probability  $1-\alpha/2$  (Table 4)
- s = standard deviation of the analyte in the wells
- $x_A$  = mean concentration of analyte in Well A
- $x_B$  = mean concentration of analyte in Well B

Having established levels of  $\alpha$  and  $\beta$ , the values of U are obtained from Table 4. If values of U are known, n depends on values in the right hand expression of equation 2:

$$\left[ \frac{s}{x_A - x_B} \right]^2$$

If one lets  $d = x_A - x_B$ , then the number of samples is a function of the ratio  $s/d$ .

The problem is how to determine s and d so that one can complete the calculation and find the number of samples needed. The quantity d is especially important. One must select the minimum difference between  $x_A$  and  $x_B$  which is to be considered significant. In other words, how small a difference between the chemical concentrations in each well does one wish to be able to detect? This is the margin the analyst wishes to be protected against for both Type I and Type II errors.



Ideally, one should conduct a small pilot sampling program to obtain estimates of the means and variances of the chemicals of interest. Usually the pilot program contains three or four samples from the same well, enough to calculate the mean and variance. Such a pilot program would provide estimates of  $s$  and  $d$ . One can then calculate  $n$  more precisely and conduct a full-scale sampling program based on the results of the first stage.

Table 4.  
Standard Normal Deviate,  $U$ , as a Function of Probability

Probability ( $1-\beta$ or $1-\alpha/2$ )	Corresponding $U$
0.80	0.842
0.90	1.282
0.95	1.645
0.975	1.960
0.99	2.326
0.995	2.576

By way of illustration, assume the example problem in Table 2 provides the results of the pilot program. In this example one wants to use the expression from Eq. 2:

$$\left[ \frac{s}{x_A - x_B} \right]^2 \text{ or } \frac{s^2}{(x_A - x_B)^2}$$

As shown in Table 2,  $s_A^2$  does not equal  $s_B^2$  so one needs to calculate a pooled  $s$  (Table 5). With the pooled  $s^2 = 281$ , one calculates  $n = 15$ . Now double  $n$  and distribute the number of samples between A and B in proportion to the standard deviations (Table 5). For this example  $n_A = 12$  and  $n_B = 18$ . This means to be able to distinguish a difference of  $16 \mu\text{g/l}$  between Well A and Well B and be 95% certain one has done so correctly, one needs to take a total of 12 samples from Well A and 18 samples from Well B.

Table 5.  
Calculation of the Number of Samples Required to Distinguish a Significant Difference in Benzene Concentration Between Well A and Well B at  $\alpha = \beta = 0.05$

1. Using the data from Table 2, calculate the pooled variance

$$\text{pooled } s^2 = \frac{(\sum x_A^2 + \sum x_B^2) - \frac{(\sum x_A + \sum x_B)^2}{n_A + n_B}}{n_A + n_B - 1}$$

$$\text{pooled } s^2 = \frac{[6117 + 12,446] - \frac{[(151 + 214)^2]}{8}}{4 + 4 - 1}$$

$$\text{pooled } s^2 = 281$$

2. Calculate  $n$  using equation (2).

$$n = (1.645 + 1.96)^2 \left[ \frac{281}{246} \right]$$

$$N = 14.8 \text{ round to } 15$$

3. Double  $n$  to account for two wells,  $2n = 30$

4. Distribute  $2n$  between wells in proportion to their standard deviation

$$n_A = \frac{s_A(30)}{s_A + s_B} + \frac{12.6(30)}{12.6 + 18.2} = 12$$

$$n_B = 30 - 12 = 18$$

Now, it may not be possible to conduct a pilot program and one must estimate  $s$  and  $d$  without having data from the site under consideration. If this situation exists, it is easier to consider  $d$  (the minimum difference one wishes to be able to detect) as a percentage

of the standard deviation,  $s$ . If  $d$  is defined in terms of  $s$ , then one can easily calculate  $n$ .

For example, suppose one wants to be able to detect a difference equal to one standard deviation. In this example,  $s = d$ , so  $s/d = 1$ . If  $\alpha = 0.05$  and  $\beta = 0.05$ , then substituting into equation 2 gives the following:

$$n = [u_{1-\beta} + u_{1-\alpha/2}]^2 \left[ \frac{s}{d} \right]^2$$

$$n = (1.645 + 1.96)^2 (1)^2$$

$$n = 12.99$$

or

$$n = 13$$

Similarly, if one wants to determine a difference equal to half of the standard deviation ( $d = s/2$ ) with the same  $\alpha$  and  $\beta$ , then  $n = (1.645 + 1.96)^2 (2)^2 = 52$ . Obviously, as the minimum detectable difference decreases, the sample size increases dramatically. If 52 samples are too many, but one still wants to be able to detect a difference equal to half of the standard deviation, then one can increase  $\alpha = 0.2$  and  $\beta = 0.2$ , the sample size is now 18 instead of 52. The sample size calculated as a function of different values of  $\alpha$ ,  $\beta$ , and  $s/d$  is shown in Table 6.

Common sense should be used in selecting the minimum detectable difference. At a hazardous waste site, one could say one wants to know if there is any difference at all between Well A and Well B. If one assumes any difference means detecting  $1 \mu\text{g/l}$  difference, then one quickly arrives at an astronomical number of samples being required. For example, if  $s$ , the standard deviation for an analyte, were  $10 \mu\text{g/l}$ , and  $d = 1 \mu\text{g/l}$  and  $\alpha$  and  $\beta$  both equal 0.05; then the number of samples required would be 1300. Clearly this is an impractically large number. One must therefore consider some larger difference as the minimum acceptable difference, or some larger probability of reaching the wrong conclusion.

What level of difference would be acceptable for organic priority pollutants at levels between about 10 and  $200 \mu\text{g/l}$  and how many samples would be needed to show differences between two wells? At these low levels, the variability due to sampling and analysis may be about the same order of magnitude as the actual variability of the analyte in the water. Therefore if one sets  $d = s/2$ , one should be able to distinguish any variability due to the analyte. Where  $d = s/2$  and  $\alpha$  and  $\beta = 0.05$ ,  $n = 52$ . This is probably too large a number. If one lets  $d = s$  (that is  $d/s = 1$ ) and  $\alpha$  and  $\beta = 0.05$ , then  $n = 13$  (Table 6). This is still a large number, especially if no pilot program has been conducted. Again using data in Table 6,  $d = s$ , and  $\alpha$  and  $\beta = 0.1$ , then  $n = 7$ . This may be a reasonable number. Obviously other combinations are possible. The important point is to select a difference which has some importance or significance.

## WHERE AND WHEN TO SAMPLE

Common questions asked in the design of an investigation are: "how many wells do I need; how often should I sample; and how long do I need to continue a monitoring program?" In some sense, these questions all relate to that just addressed: how many samples do I need?"

The number of wells depends upon the homogeneity of the site. The statistical analysis presented here applies to any portion of an aquifer that is reasonably uniform with respect to its geological and chemical properties. As long as the geological and chemical observations demonstrate that water quality conditions are reasonably uniform, the number of wells required will be independent of the size of the area studied.

The number of wells for a homogeneous area is not a function of land size or area. Thus a large area of 100 acres with a homogeneous aquifer can be adequately sampled by one well. Repeated sampling from that one well over time will be adequate to provide the necessary number of samples needed to accomplish the

**Table 6.**  
Sample Size, n, for Various Values of  $\alpha$ ,  $\beta$ , and s/d

s/d	$\beta$ $\alpha$	0.2				0.1				0.05				0.01			
		0.2	0.1	0.05	0.01	0.2	0.1	0.05	0.01	0.2	0.1	0.05	0.01	0.2	0.1	0.05	0.01
0.25				1	1			1	1	1	1	1	1	1	1	2	2
0.33			1	1	2	1	1	1	2	1	2	2	2	2	2	3	3
0.5		1	2	2	3	2	2	3	4	2	3	4	5	4	4	6	6
0.67		2	3	4	6	3	4	5	7	4	5	6	8	6	7	10	11
0.75		3	4	5	7	4	5	6	9	5	6	8	10	8	9	12	14
1.0		5	7	8	12	7	9	11	15	9	11	13	18	13	16	21	24
1.25		7	10	13	19	13	14	17	24	14	17	21	28	21	25	33	38
1.5		10	14	18	27	15	20	24	34	20	25	30	40	30	36	47	54

statistical analysis. Stated differently, 12 wells sampled once from a homogeneous unit will allow the same statistical interpretation as one well sampled 12 times. In the latter case, the sampling must be done at intervals sufficient to allow the water in the well to exchange with other water in the aquifer. Drawing 12 samples consecutively from the same well in the same day will give one information about the sampling and analytical variability, but will not tell one about the variability of water quality in the aquifer. Therefore one "background" well may be sufficient. In practice, more than one well may be installed in a single homogeneous unit. Installing more than one well allows one to evaluate the validity of assuming a homogeneous unit. It also allows one to get more data from the same unit without having to wait long periods of time between sampling.

More than one well is usually necessary in the area downgradient from a hazardous waste source. Wells are installed to identify where there are significant differences or discontinuities in water quality as compared to water quality in the upgradient or background wells. More wells are required because the location of contaminant paths are unknown. In this case, the number and location of wells required is clearly a function of how big one thinks the plume is, how far one thinks it has travelled, and where one thinks it is located. The placement of these wells is not directly related to any statistical analysis. Finding the path of contaminated groundwater by installing wells is somewhat like finding the studs in a wall by pounding nails in the wall until you hit something solid.

How does one tell whether the downgradient well is contaminated? It is accomplished by taking n number of samples over time and comparing the results of this well to the results of the background well(s) using the t-test. It is perfectly acceptable practice to combine data sets from different wells and from different time periods if they are demonstrated to be samples drawn from the same homogeneous unit. For example, it was suggested earlier that a pilot study is useful to get an estimate of sample means and sample variances as well as test out the sampling protocol. Consider the example problem used in Table 2 and Table 5. The number of samples required was 12 from Well A and 18 from Well B. But 4 samples already have been taken from each so only 8 additional samples from Well A and 14 additional samples from Well B are needed.

A pilot program has other advantages besides providing an estimate of means and variances. The pilot program allows one the opportunity to confirm the appropriate sampling methods and to modify procedures to improve the ease and efficiency of sampling.

## COST CONSIDERATIONS

The overall cost of a sampling and monitoring program is a function of the number of samples taken and it is possible to estimate the number of required samples necessary to provide statistical reliability. But what will such a program cost? Is the cost reasonable? Suppose the cost is too high. How can a less costly program be designed yet still have a known degree of statistical reliability?

The cost of the sampling and analytical program is given by the following equation:

$$C_P = W + K + A \quad (3)$$

where:

- W = Cost of installing wells
- K = Cost of sampling from wells
- A = Cost of analyzing samples

Each of these terms is defined by the following expression:

$$W = C_m + w C_w \quad (4)$$

$$K = k C_{km} + kwr C_k \quad (5)$$

$$A = kwr C_a \quad (6)$$

where:

- $C_m$  = mobilization cost associated with installing the wells
- $C_w$  = the unit cost of installing each well
- w = the number of wells
- k = the number of sampling trips
- r = the number of samples per well
- $C_{km}$  = the mobilization cost associated with going out to take samples
- $C_k$  = the unit cost to take one sample
- $C_a$  = the unit cost to analyze one sample

Substituting equations (4), (5), and (6) into equation (3) gives:

$$C_P = C_m + w C_w + k C_{km} + kwr C_k + kwr C_a \quad (7)$$

The number of samples, n, is given by the expression:

$$n = kwr$$

If  $r = 1$  (one sample per well per trip) and substitute n in equation 7, one obtains:

$$C_P = C_m + n \left[ \frac{C_w}{k} + \frac{C_k}{w} + C_k + C_a \right] \quad (8)$$

Equation 8 is an expression that relates the cost of the sampling program to the number of samples. A plot of the cost of the monitoring program as a function of the number of samples taken is given in Fig. 1. The lines in this plot show that the cost increases very rapidly as the sample size increases and show that (for this example) it is more cost effective to have fewer wells and sample longer, than to have more wells and sample for a short period of time.

Consider now the example problem discussed earlier in Table 2 and Table 5. To be able to distinguish a difference of 16  $\mu\text{g/l}$  between Well A and Well B with 95% confidence, one needs to take 12 samples from Well A and 18 samples from Well B. What will

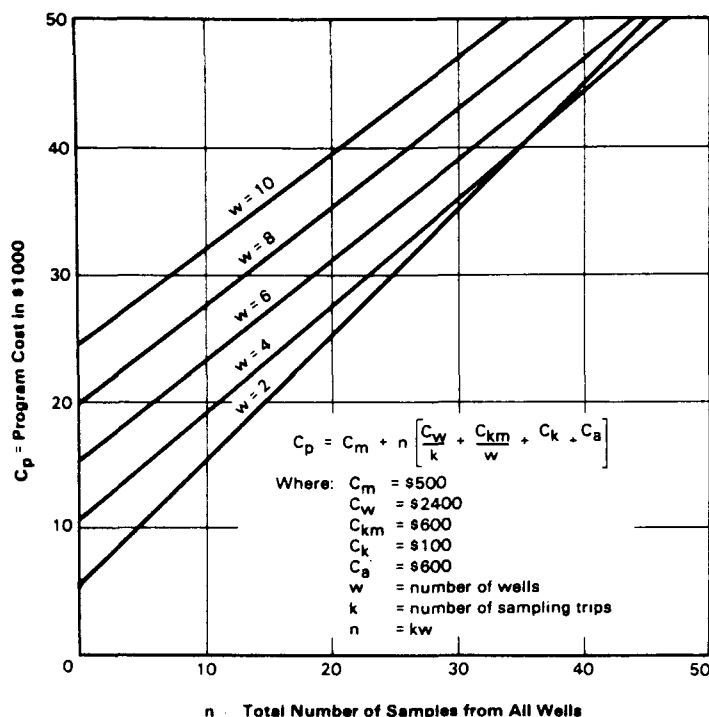


Figure 1.

Program Cost as a Function of the Total Number of Samples Taken

this program cost? Using the line in Fig. 1 for which  $w = 2$  and  $n = 30$ , the program cost is about \$35,000. Assume this cost is too high and one is prepared to pay about \$20,000, what happens? With a program cost of \$20,000, one can take a maximum of 14 samples with two wells (say 7 from each well). What does that do to the statistics?

Taking seven samples from each well will obviously change the interpretation of the data. Initially, a difference of  $16 \mu\text{g/l}$ ,  $s/d = 1.05$ , would be determined using Table 6,  $n = 15$  at  $s/d = 1.0$  when  $\alpha = \beta = 0.05$ . But now  $n = 7$ . If  $s/d = 1.05$ , then one must increase (mathematically) the chance of making an error. For example, at  $s/d = 1.0$  (Table 6), there are two places where  $n = 7$ . One where  $\alpha = 0.1$  and  $\beta = 0.2$  and the other where  $\alpha = 0.2$  and  $\beta = 0.1$ . Thus one can still see a difference of  $16 \mu\text{g/l}$  but one will not be as confident as one was originally.

One can also consider the alternative situation. Hold  $\alpha = \beta = 0.05$ , but accept a larger difference between Well A and Well B. Enter Table 6 at  $\alpha = \beta = 0.05$  and  $n = 7$  (between 6 and 8) to find  $s/d = 0.70$ . This means one can distinguish a difference of  $d = s/0.70 = 16.8/0.70 = 24 \mu\text{g/l}$  with 95% confidence.

Thus, for a savings of \$15,000 one can either lessen the certainty of the conclusions or broaden the significant difference which one is willing to accept. In this example it is probably reasonable to proceed with the less expensive program.

One must also ask, "why do we need any additional sampling beyond that done in the pilot program?" In the example, the 8 samples collected cost about \$13,500 (Fig. 1). Why should an additional \$6,500 be spent to increase the number of samples to 14? The answer is found in Table 6. There are several places where  $n = 4$ , but not at  $s/d = 1.05$ . One simply cannot with any certainty distinguish a difference as small as  $16 \mu\text{g/l}$  with these few samples. The best one can do is distinguish  $24 \mu\text{g/l}$  at  $\alpha = 0.1$  and  $\beta = 0.2$  or  $34 \mu\text{g/l}$  at  $\alpha = \beta = .05$ . Both are likely not to be useful or meaningful comparisons. As a result, the additional \$6,500 for the extra samples allows meaningful differences to be distinguished between Well A and Well B with a high degree of confidence for a reasonable amount of money.

## SUMMARY

The foregoing discussion explains the value of statistics in conducting groundwater investigations at hazardous waste sites, particularly where low levels of organic priority pollutants are of concern. In these investigations, the t-test is an appropriate tool which allows the investigator to make comparisons between two wells (or two groups/sets of wells) with a known level of confidence and known probability of being wrong. The generic steps in doing an investigation using the t-test are these:

1. Conduct a small pilot program to estimate the mean concentration of the analyte in each well, to calculate the variance of each well, and to adjust the sampling protocol. Usually 3 or 4 samples over time are necessary from each well.
2. Choose the minimum acceptable probability of being wrong (i.e., select  $\alpha$  and  $\beta$ ).
3. Establish  $d$ , the minimum acceptable difference in mean concentration between the two wells which is considered significant (i.e., considered real, meaningful, and useful.)
4. Calculate the estimated number of samples required.
5. Develop the cost equation or cost curve which relates program costs to the number of samples.
6. Using the original estimate of the number of samples, calculate the anticipated cost of the program.
7. Determine if the estimated cost is reasonable. If not, reevaluate the choice of  $\alpha$ ,  $\beta$ , and  $d$  until a reasonable balance is achieved between sampling costs and useful results.
8. Do the additional sampling required, pooling the results of the pilot program with the full-scale program.
9. Calculate the t-statistic for each analyte and determine whether there are significant differences.

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# APPLICATION OF GEOPHYSICS TO HAZARDOUS WASTE INVESTIGATIONS

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## INTRODUCTION

Geophysical techniques, originally developed from mineral exploration, have become the primary investigative methods in many hazardous waste studies. The types of studies include the location of dumps, trenches and spills, etc., the characterization of subsurface contamination, primarily leachate plumes, and the evaluation of the geohydrologic environment in the vicinity of existing or planned hazardous waste facilities. Field investigations typically include remote sensing, drilling and the installation of monitoring wells, as well as geophysics.

In this paper, the authors describe, through case histories and examples, the use of surface and borehole geophysics including electrical, seismic, and magnetic techniques.

Surface geophysical techniques, due to their non-penetration of the subsurface and their rapid execution, are ideally suited to the detection of dumps, trenches, spills, etc. Spills usually alter groundwater conductivity near the surface and are, therefore, detectable with surface electrical surveys. Waste trenches can be detected due to either the presence of fill replacing the natural soil, the presence of trash such as barrels which may or may not be related to the contaminant, or by the presence of the contaminant itself. Geophysical techniques most commonly used to locate subsurface contamination sources are:

- Electrical surveys—
  - Resistivity surveys
  - Electromagnetic (EM) Surveys (conductivity)
- Ground penetrating radar
- Magnetic surveys

Electrical surveys are usually designed to measure the electrical resistivity of subsurface materials by making measurements at the surface. The resistivity method imposes an electrical field on the survey area and, by measuring the surface expression of the resulting potential field, calculates the resistivity of the subsurface material.

The electromagnetic method induces an electric field in the subsurface from a cycled magnetic field at the surface. The resistivity of the subsurface material is then measured by recording the magnetic field induced at a surface coil by the time varying subsurface electric field and comparing it with the original magnetic field. In both techniques, subsurface resistivities are computed from surface measurements.

Resistivity and electromagnetic equipment used in waste investigations are portable and capable of rapid surveying. Practical considerations dictate the choice of techniques (resistivity or EM) and often both are used in the same survey.

Ground penetrating radar is a relatively new technique which has strong application to the detection of waste containers, pipes and trenches in hazardous waste investigations. Ground penetrating radar offers the highest level of detail available from any surface geophysical technique due to the high frequency energy used. Its depth of penetration is shallow relative to other geophysical techniques. Clay and conductive groundwater limit penetration depths.

Portable magnetometers are very useful in locating magnetic objects such as steel drums, car bodies, and pipes. The magnetic survey measures the earth's magnetic field over a relatively small

area. Near surface magnetic objects are located by their perturbation of the earth's magnetic field.

## CASE 1

A recent project in the Coastal Plain involved evaluating an abandoned oil reclamation facility for its impact on the groundwater and designing a cleanup program. Some of the waste material was exposed at the surface (drums and other trash), and oil covered vegetation and lagoon surfaces.

The location of areas of fill where similar material has been buried and the location of barrels within that fill were investigated by surface geophysics. Electrical resistivity and electromagnetic surveys were used to delineate fill areas, and magnetometer and metal detector surveys in conjunction with the surface electrical surveys delineated concentrations of steel drums within the fill. The existence of clayey surficial soils and high conductivity groundwater precluded the use of ground penetrating radar at this location. Two distinct areas were located: one area had abundant metallic objects but did not appear to be a source of groundwater contamination, and one area of no metallic objects but a very definite source of groundwater contamination.

## CASE 2

In the western U.S., in the Basin and Range Province, electrical resistivity surveys were used to delineate waste trenches whose exact lengths were not known. The target of the survey was not the contaminant itself, but the contrast of the electrical properties between the in-place and re-worked intermontane sediments. A profile perpendicular to the trenches that exhibit the apparent resistivity values obtained by a gradient method that was used to outline the trenches is shown in Fig. 1. Radar would have been successful here, but at an increased cost.

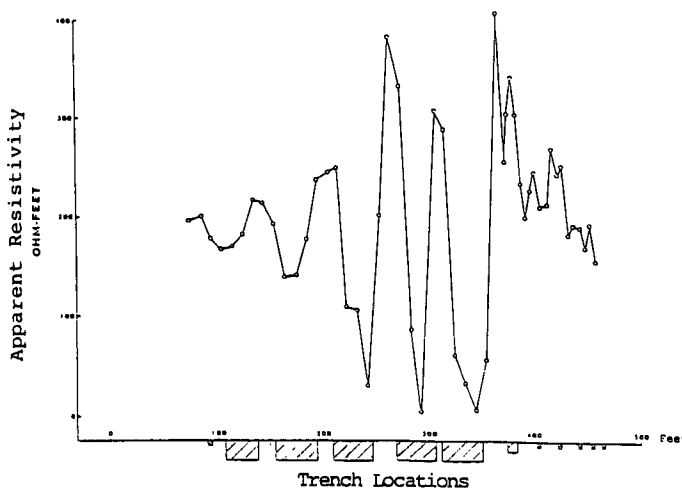
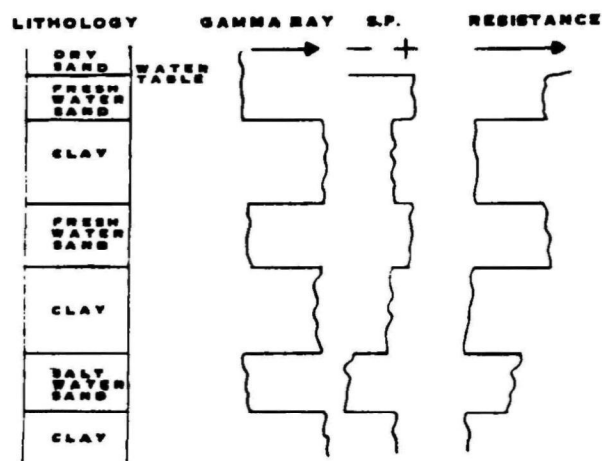


Figure 1.  
Resistivity profile across waste trenches in Basin and Range Province showing location of major trenches. A gradient method was used to differentiate between the in-place and reworked intermontane sediments. In this case, the contaminant was not a good geophysical target; the difference between disturbed and non-disturbed material provided the geophysical contrast.



Figure 2.

Truck mounted geophysical logger which is capable of sophisticated functions such as acoustic, density, porosity, and temperature logging as well as conventional electric gamma and SP logging.



SCHEMATIC RESPONSE OF GAMMA RAY, S.P. AND RESISTIVITY LOGS TO A COMMON GROUND WATER ENVIRONMENT

Figure 3.

Typical down-hole log responses to hydrogeologic situations differentiating sands from clays, and fresh water from salt water.

The evaluation of the hydrologic environment in the vicinity of an existing or planned hazardous or municipal solid waste facility or a waste impoundment, requires the evaluation of permeability, porosity and water quality in the vicinity of the facility for input to groundwater modeling or other analysis. Surface and subsurface geophysics can optimally locate facilities by determining the continuity of confining layers and permeable zones and through extrapolation of permeability and water quality. These techniques reduce the cost of and the amount of borings needed and provide a positive basis for extrapolation between them. Surface electrical and seismic surveys and borehole electrical, nuclear, and acoustic logging are commonly used.

Borehole geophysics has been widely used in the exploration for groundwater during the last 20 years and in groundwater contamination studies more recently. Correlation vertically within borings and horizontally between them, estimation of formation lithologies and the quantitative measurement of porosity, permeability, and water quality are the prime groundwater uses of borehole geophysics. Geophysical logging units in the groundwater industry are designed for shallow small diameter holes primarily drilled in fresh water. The equipment is usually mounted in a small truck and some very basic units are hand portable.

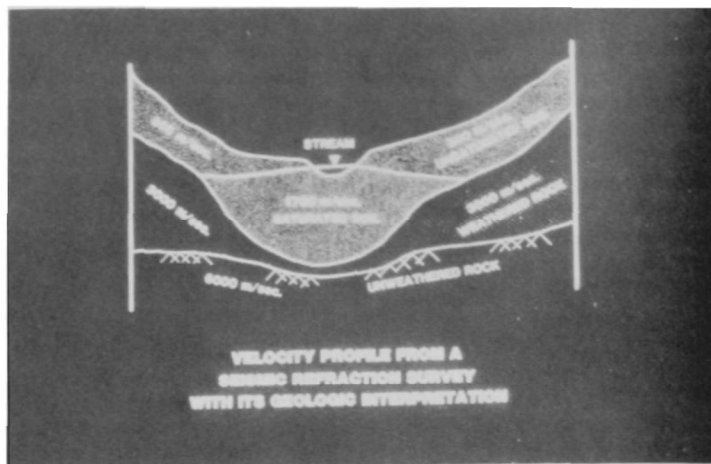


Figure 4.

Interpreted seismic refraction profile in the Piedmont showing cross-sectional area of groundwater flow channel.

The seismic refraction technique determines the acoustic velocities of subsurface materials which are generally a function of the elastic moduli, saturation and porosity of subsurface materials. A common groundwater exploration situation is that of low permeability bedrock overlain by unconsolidated material. The exploration targets are the depth and configuration of bedrock and depth of the water table, as well as an estimate of aquifer porosity. Refraction seismology can be used in this situation because the geologic condition yields a multi-layered velocity profile with velocity increasing with depth.

### CASE 3

The selection of geophysical techniques to characterize hydrologic environments is primarily a function of the geologic setting. In Fig. 4, a hydrologic cross section through a stream in the Georgia Piedmont south of Atlanta is shown. In this type of geologic setting, seismic refraction is best suited to characterize the hydrologic environment because the degree of weathering and water saturation strongly alters the seismic velocity of the material. Electrical techniques would not be optimal here due to the relatively high resistivity of the subsurface in general.

### CASE 4 AND 5

The hydrogeologic setting of shallow aquifers in the Gulf Coast is characterized by unconsolidated sediments. The geologic cross sections from the Gulf Coast (Fig. 5) can be considered reasonably representative of coastal plain geologic settings in general. Surface electrical methods are well suited in this geologic setting as the electrical resistivity of the low permeability clays and the high permeability sands contrast strongly.

In Case 4, in Louisiana, a blanket sand obscured the faulted geology below and drilling without the aid of geophysics would have been expensive and possibly inadequate. Case 5, in Mississippi, was one of highly permeable buried channels with no surface expression. Surface electrical surveys allowed them to be mapped rapidly and avoided. Electrical and other borehole geophysical logs were run in all borings made in conjunction with these surveys and allowed for interpreted results which were better than those which would have been obtained from surface or subsurface surveys alone.

Borehole geophysical data allows the computation of hydrologic parameters continuously in the borehole at a cost usually less than that associated with sampling and laboratory testing. Other hydrogeologic settings which have traditionally been explored by means of geophysics are bedrock channels, salt water intrusion and the location and water quality of deep groundwater in arid areas.

The monitoring of leachate plumes from groundwater con-



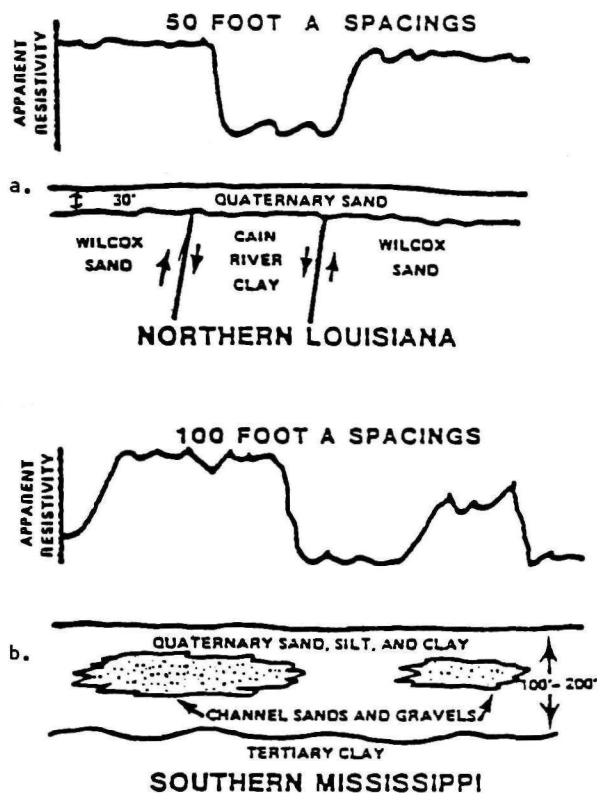


Figure 5.

a. Resistivity profile outlining subsurface, faulted, sand and clay units in Louisiana. No surface trace of faulting was visible.

b. Resistivity profile showing locations of buried channels in Mississippi. No surface indication of these channels was evident.

tamination sources can best be carried out by surface conductivity of groundwater, the configuration and concentration of the contaminant plume can be determined with surface resistivity or electromagnetic surveys combined with a few borings whose locations are guided by the surface resistivity results.

Repeating an existing surface electrical survey in the vicinity of a groundwater contaminant source can be used to monitor the movement of the contaminated groundwater with time. This can provide a valuable addition to long term monitoring of groundwater contamination.

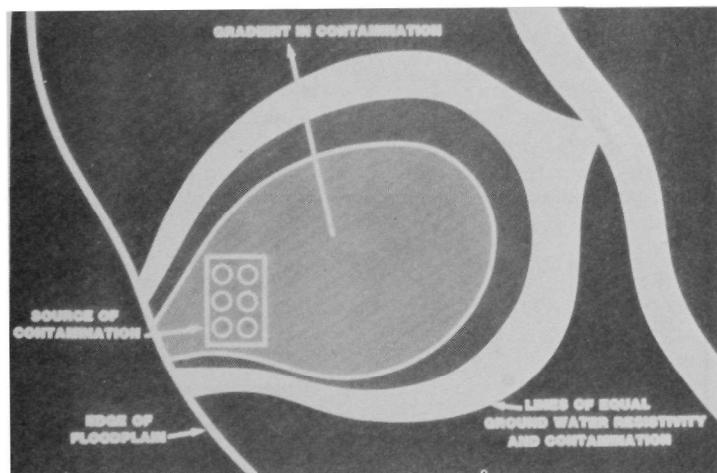


Figure 6.

Contaminant plume, outlined by electrical resistivity or electromagnetic conductivity techniques, which might occur in an alluvial environment.

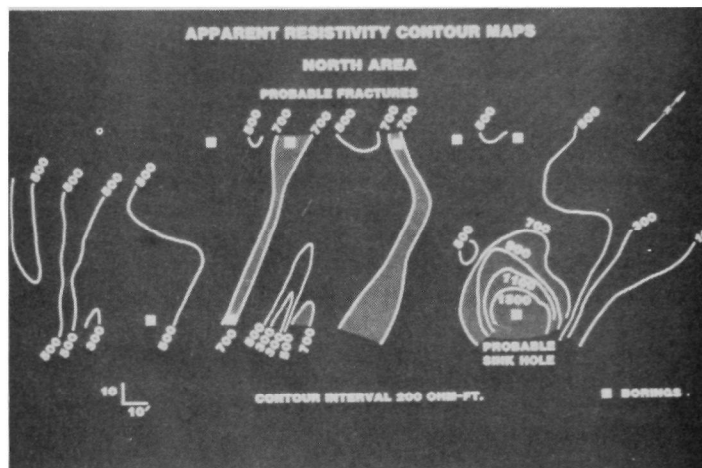
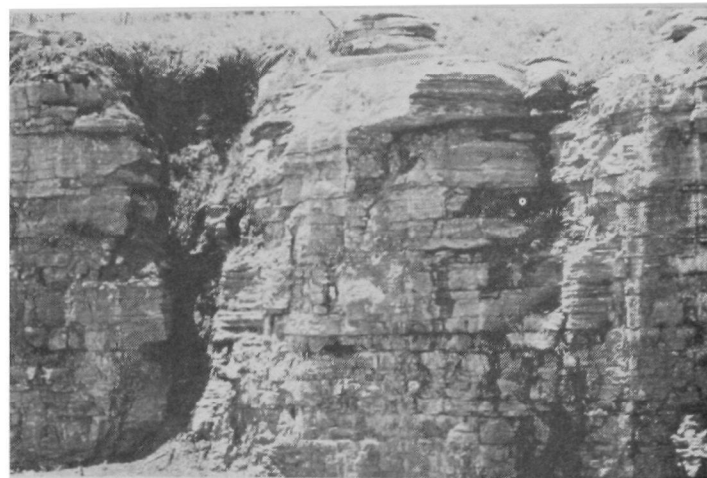


Figure 7.

a. Exposure of limestone in the Appalachian Plateau province exhibiting large vertical joints which may affect subsurface flow.

b. Apparent Resistivity contour map produced at a site covered with 20 feet of alluvial material, which outlines 2 vertical joints and a sinkhole. The bigger fracture had contaminant in it.

An idealized leachate plume characterized by a surface electrical survey is shown in Fig. 6. The contaminant has lowered the resistivity (or conversely raised the conductivity) of the groundwater and thus the underlying sand itself. The result is that contours of interpreted resistivity of the subsurface sand are also contours of the degree of its contamination.

#### CASE 6

In the Appalachian Plateau Province, in an area of limestone bedrock, underground contaminant transport may be controlled by vertical joints in the rock. In Fig. 7, an exposure of limestone with vertical joints and an apparent resistivity contour map produced nearby is shown. Two fractures and one sinkhole were located beneath about 20 ft of overburden. Subsequent drilling into one of the fractures encountered contaminant and isolated the transport mechanism of a plume.

#### CONCLUSIONS

Geophysics can play an important role in hazardous waste or groundwater contamination studies. The advantages offered by geophysics are its measurement of continuous *in-situ* subsurface hydrologic properties and the economy derived from the reduction in required drilling and associated laboratory testing. To achieve these advantages, the overall exploration program should be designed to use the exploration elements, typically including drilling, remote sensing and geophysics, in a complementary way.



# CASE STUDY OF CONTAMINANT REVERSAL AND GROUNDWATER RESTORATION IN A FRACTURED BEDROCK

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## INTRODUCTION

Groundwater contaminated with trichloroethylene (TCE) was discovered in the vicinity of a manufacturing plant in southeastern Pennsylvania where contamination had resulted from a series of spills. Subsequent to this discovery, the plant contracted with SMC Martin to study the extent and magnitude of the TCE contamination in the vicinity of the plant and to develop an appropriate method for cleanup. SMC Martin's approach to this study included the following principal objectives:

- Assessment of the extent and magnitude of TCE contamination in the area
- Definition of the groundwater flow system controlling the transport of TCE in the vicinity of the plant
- Development and implementation of a groundwater recovery and restoration program
- Maintenance of a monitoring system to determine the effectiveness of the recovery and restoration program

A rapid response to cleanup of the groundwater was desirable due to the potential for contamination of residential wells in the vicinity of the plant. However, the study was constrained by the availability of locations for well placement and limited client resources. As is typical of most industrial projects, the client and the regulatory agency were interested in a cost effective and efficient solution to the problem, which is rarely possible in the complex hydrogeologic conditions of southeastern Pennsylvania. However, the uniquely simplistic fracture system controlling groundwater flow in the area resulted in a well-defined contaminant migration path which permitted a direct approach to contaminant reversal and groundwater restoration.

## PHYSICAL SETTING

The plant is located in southeastern Pennsylvania and lies within the Triassic aged, Newark-Gettysburg Basin. The property is drained by an intermittent tributary of a moderately-sized creek.

The area is underlain by the Lockatong Formation, a gray argillite. The Lockatong is considered to be a poor aquifer due to its low yield (4 to 40 gal/min with an average yield of approximately 7 gal/min).

The plant primarily depends on public water for its water supply but also uses an in-plant well rated at 2 gal/min for cooling system make-up water. Domestic water supplies adjacent to the plant are, for the most part, low-yielding private wells.

## FIELD INVESTIGATION

Prior to installing a monitoring well system, water samples were collected from nearby residential wells (sampling points #27, #28, #30, and #37 on Fig. 1), surface water (#24 and #26), the plant discharge (#20), the plant well, and sumps used by the company to remove groundwater that has infiltrated through the basement floor of the plant. Analysis of these samples indicated that TCE appeared to be restricted to the plant property.

A sample from the plant well had 4,700  $\mu\text{g/l}$  TCE, considerably above the Pennsylvania Department of Environmental Resources (PaDER) recommended drinking water limit of 4.5  $\mu\text{g/l}$ . Samples collected from the domestic wells exhibited no evidence of TCE contamination. It appeared that the plant well and the sumps located in the basement of the plant were creating a cone of depression in the vicinity of the plant preventing the migration of TCE off site.

At this time, inspection of topographic maps and aerial photographs of the area indicated that a fracture trace existed in the area extending northeast under the creek below stream sampling point #24 and southwest under the plant in the direction of sampling point #37, a residential well (Fig. 1). To verify whether the fracture extended under the plant, Monitor Wells #3 and #6 were installed into the fracture zone and Monitor Wells #1 and #4 along the flanks of the suspected trace. The wells were drilled in Oct. 1979 at the locations shown on Fig. 1. Due to problems encountered during drilling, Monitor Well #5 was abandoned before completion and Well #2 could not be drilled where desired due to problems of accessibility.

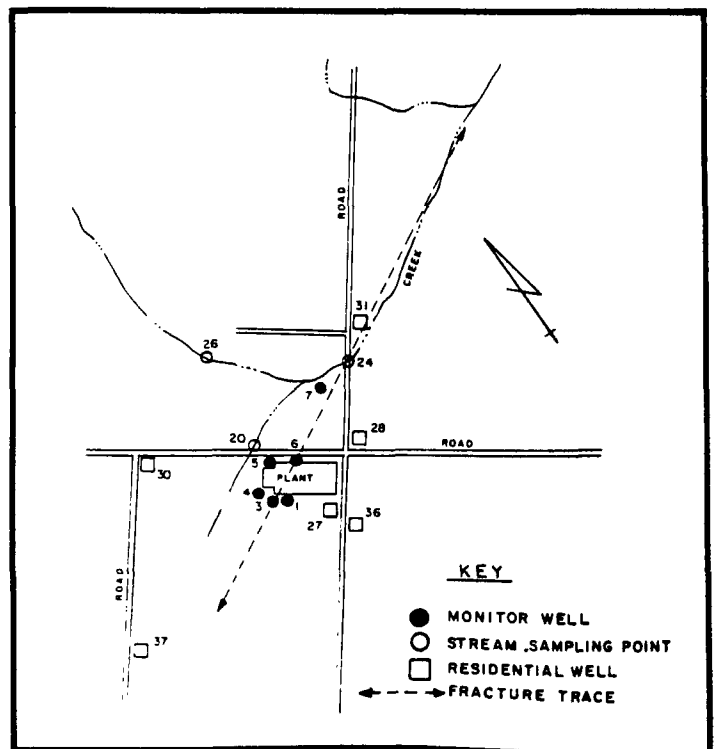


Figure 1.  
Map of the plant, sampling points, and the fracture trace

All wells are open-hole completions, with 20 ft of 6 in. steel casing, grouted to prevent surface water infiltration. Monitor Well #1 was drilled to a depth of 90 ft. Monitor Wells #3, #4, and #6 were all drilled to a depth of 200 ft for potential use as recovery wells.

The first samples were collected from the monitoring wells in Nov. 1979. A sample taken from Monitor Well #6 contained 230,000  $\mu\text{g/l}$  TCE. Well #6 was installed at the location where TCE had previously been delivered. This location is the principal source of TCE contamination. TCE concentrations in samples from Monitor Wells #1, #3, and #4 were 150, 430, and 2.1  $\mu\text{g/l}$ , respectively.

During the Nov. sampling, two additional residences were sampled (#31 and #37). They were selected due to their proximity along the fracture trace and the likelihood that they would be the most readily contaminated residential wells if contaminant migration was occurring along the fracture. The sample from Well #37 had no TCE; however, the sample from Well #31 contained 3,000  $\mu\text{g/l}$  of TCE. The presence of TCE in Well #31 indicated a hydraulic connection between this well and the plant as no other possible source of TCE could be found in the area.

The residents using this well were immediately notified of the contamination in their well and a duplex carbon filter was installed in Dec. 1979. The residents were also provided with bottled water for drinking between the period of notification and the date of installation of the carbon filter system.

TCE was also detected in stream samples collected in the vicinity of the plant. The plant discharge at sampling point #20 contained 1,100  $\mu\text{g/l}$  of TCE. The creek upstream from the plant (sampling point #26) contained no TCE. The creek at sampling point #24 downstream from the plant discharge showed a decrease in TCE levels (150  $\mu\text{g/l}$ ) due to dilution by the stream.

Prior to initiation of a recovery program, Monitor Well #7 was installed between the plant and Well #31 as near to the fracture trace as possible to further define the hydraulic connection between Monitor Well #6 and Residential Well #31. Routine monitoring was initiated at a total of 18 sampling points to assess the effectiveness of TCE recovery. Samples were collected weekly during the first year, biweekly in the second year, and are currently being taken once a month. Water levels in the monitor wells were taken during every sampling round.

## GROUNDWATER RECOVERY AND RESTORATION

The potential for contamination of water supplies mandated that a groundwater recovery and treatment program be initiated at the plant. Treatment alternatives included granulated activated carbon, direct aeration, and counter-current air flow stripping. The latter was chosen for its low operating cost and high efficiency.

An air stripper is an engineered device which enhances the efficiency of stripping volatile compounds from liquid streams. The contaminated water flows downward by gravity over a porous bed of ceramic, plastic or metal packing (typically 1/4 to 1 in. diameter) and is contacted by an upward-flowing stream of air.

The stripper installation was completed with Monitor Well #6 used as the recovery well, and the system became operational in May 1980 with an average pumping rate of 11 gal/min. Prior to start up of recovery, depth to water measurements in Monitors Wells #1, #3, #4, #6, and #7 were 1.3, 14.5, 14.1, 12.4, and 1.74 ft, respectively. It appeared from these measurements that Monitor Well #3 was downgradient from the recovery well (Monitor Well #6). However, the almost continuous pumping of the sumps in the basement of the plant disturbs the natural hydraulic gradient and makes it difficult to determine the actual direction of flow in the immediate area of the plant. As mentioned earlier, it appeared that the basement sumps were creating a cone of depression centered on the plant.

After start up of pumping of the recovery well the depths to water for Monitor Wells #1, #3, #4, #6, and #7 were 4.4, 67.2, 18.1, 86.8, and 2.7 ft, respectively. Pumping from the recovery well affected the water levels in Monitor Wells #1 and #4, but the effect

was only slight when considering the 52.7 ft drop in the water table at Monitor Well #3. Also, Monitor Wells #1 and #4 are spaced only 50 ft to either side of Monitor Well #3.

Therefore, the fracture system as it is encountered by the monitor wells is quite simple and Monitor Well #3 is in direct hydraulic connection with the recovery well. The effect of pumping from the recovery well on Monitor Well #7 was slight if not negligible. This was a result of not being able to place this well on the fracture trace due to the inaccessible nature of the area along the trace between the plant and the contaminated residential well. In fact, the water level in this well indicates shallow groundwater is discharging to the creek.

The water table elevations show that pumping from the recovery well has resulted in a elongated cone of depression extending along the fracture. To date, the pattern of water table elevations has continued with only minor overall changes due to prolonged drought conditions in the area.

As mentioned previously, surface and groundwater samples were collected to determine the effectiveness of the groundwater recovery program. The results of TCE analyses on samples taken from Monitor Wells #3, #6, and #7, the contaminated residential well (#31) and the stream (sampling point #24) are plotted on Figs. 2 and 3. The TCE concentrations in samples from Monitor Wells #1 and #4 showed little change throughout the recovery operation and

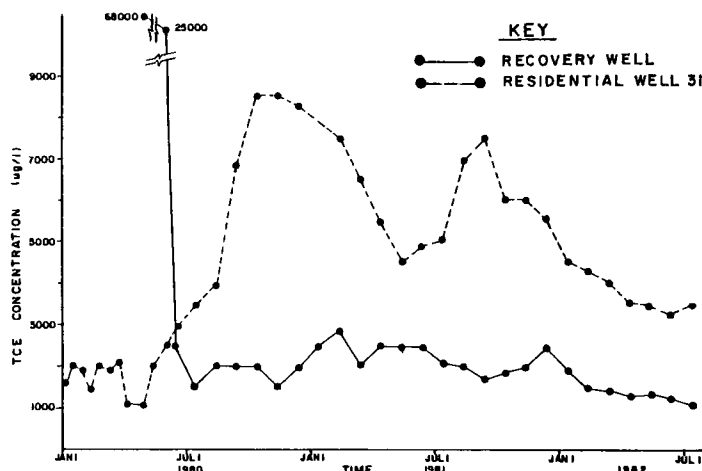


Figure 2.  
Plot of TCE concentrations versus time for samples from the Recovery Well (#6) and Residential Well #31

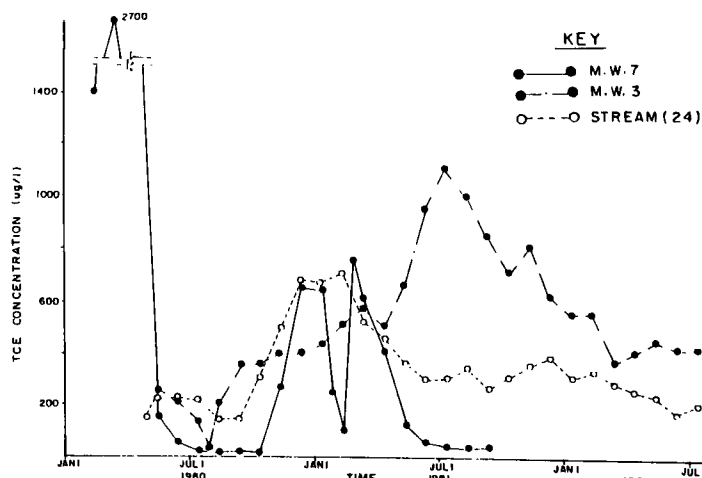


Figure 3.  
Plot of TCE concentrations versus time for Monitor Wells #7 and #3 and the stream at sampling point #24

were not plotted. The TCE concentrations for these samples remained about 100 and 400  $\mu\text{g/l}$ , respectively, throughout the study period.

Water samples from Well #31 have been obtained before, between, and after carbon filtration. This filter system effectively removed the TCE from the water. The well water before filtration contained in excess of 3,000  $\mu\text{g/l}$  TCE. Subsequent to initiation of pumping from the recovery well, TCE levels in Well #31 decreased to 1,500  $\mu\text{g/l}$  in Apr. 1980 and then increased to a peak value of 11,000  $\mu\text{g/l}$  in Dec. 1980 (Fig. 2). From Dec. 1980 to May 1981, TCE concentrations in Well #31 decreased to 4,500  $\mu\text{g/l}$  then steadily rose again to 7,500  $\mu\text{g/l}$  in Sept. 1981. Since that time, the TCE concentrations have decreased to their present levels.

The initial TCE concentration in the recovery well after pumping was initiated was 68,000  $\mu\text{g/l}$  in May 1980 and decreased to 2,000  $\mu\text{g/l}$  by July 1980. With the exception of two periods of increasing TCE concentrations in the recovery well—one peaking in Feb. 1981 and the other in Dec. 1981—the TCE concentrations in the recovery well have steadily decreased.

The increases in TCE concentration in samples from the recovery well can be correlated to the two prominent increases which occurred in samples taken from the residential well (#31). This shows that prior to start-up of the recovery program, the most severe TCE contamination had already migrated downgradient along the fracture in a series of pulses past Well #31. The delay between the peaks in the graphed results on Fig. 2 are a result of the time needed for the TCE-contaminated groundwater to pass along the fracture from Well #31 to the recovery well. The lesser magnitude of the peaks in the graph of the recovery well is most likely due to dilution by water being pulled into the recovery well from the vicinity of Monitor Well #3.

TCE concentrations in samples taken from Monitor Wells #7 and #3 and from samples collected from the creek at point #24 are plotted versus time on Fig. 3. The plot of the TCE concentrations from the creek approximately mirror those from Well #31 and the recovery well with peak concentrations in Jan. and Dec. 1981. The creek at this location serves as a discharge point along the fracture and further substantiates the presence of an elongate cone of depression drawing the plume back toward the recovery well. Dilution from the creek is responsible for the significantly reduced concentrations in these samples versus those taken from Well #31 and the recovery well.

The plot of TCE concentrations for samples from Monitor Well #7 show that the groundwater at this point had a TCE concentration of 2,700  $\mu\text{g/l}$  prior to start up of the recovery program. Upon initiation of recovery, the TCE concentrations in the samples from this well decreased to about 20  $\mu\text{g/l}$  in Aug. 1980 and then rose to a series of peak concentrations in Jan. and Mar. 1981. Since that time, the TCE concentration has decreased and remained at 20  $\mu\text{g/l}$ . Data from this well are difficult to interpret due to the well's proximity to the creek. Although its peak concentration in Jan. and Mar. 1981 reflects the peak seen in the plot of the concentrations for the creek at point #24, it is difficult to determine if the variability in the data is in response of the well's proximity to the creek.

The plot of the TCE concentrations from samples taken from Monitor Well #3 shows an increase from initiation of pumping at the recovery well until July 1981 when a peak TCE concentration was observed. Since that time, the TCE concentration has decreased to its present level. This pattern indicates that prior to recovery an additional plume had extended beyond Monitor Well #3 indicates that groundwater is migrating in both directions along the fracture from the plant. This may be due to the presence of a groundwater divide under the plant or pumping in the vicinity of Residential Well #37.

The air stripper had a TCE removal efficiency which continually exceeded 99% up to June 1981. Since that time, no TCE has been detected in the stripper effluent or in samples taken from the plant discharge at stream sampling point #20.

## CONCLUSIONS

Recovery and restoration of TCE-contaminated groundwater is continuing at a plant site in southeastern Pennsylvania. The lateral extent of groundwater contamination has been controlled by a simple fracture system extending from the plant. By pumping groundwater from a recovery well which penetrates the fracture, it has been possible to draw the contaminated groundwater back toward the recovery well where TCE is being removed by a counter-current air stripper.

The presence of two pronounced peaks of TCE concentration in samples collected from several points along the fracture indicates that the contaminant plume had migrated away from the plant in a series of pulses. To date, cleanup and recovery of the contamination is continuing successfully.

# COST EFFECTIVE PRELIMINARY LEACHATE MONITORING AT AN UNCONTROLLED HAZARDOUS WASTE SITE\*

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## INTRODUCTION

The passage of the Comprehensive Environmental Response Compensation and Liability Act of 1980, commonly referred to as Superfund, brought about much needed authority for the mitigation of uncontrolled hazardous waste sites. The notification requirements of this legislation concerning past waste disposal practices caused a deluge of potential hazardous waste site identifications. In Region IV alone, there were in excess of 1300 notifications submitted. This vastly increased the number of sites to be evaluated under Superfund accentuating the need for a quick, reliable means of screening hazardous waste sites. The screening process involves many criteria including a determination of the occurrence and movements of leachate. Leachate detection can be accomplished by using indirect methods such as electrical resistivity or by using the direct method of drilling and sampling.

The constraints of the drilling and sampling method of leachate monitoring are very apparent when the intent of the screening process is to quickly identify the more serious waste sites. The subcontracting capability for well drilling operations, although available through Ecology and Environment, Inc., USEPA's Field Investigation contractor, is often prohibitive for screening efforts due to: (1) the time associated with subcontracting procedures, (2) the high cost of well installation, and (3) the response time in receiving analytical results. Electrical resistivity, an indirect subsurface exploration method, then becomes an attractive means of cost effective preliminary leachate monitoring.

The advantages of the resistivity technique are: (1) the minimal equipment cost, (2) the data produced are immediately available, and (3) with sufficient background information, the interpretation can provide a high degree of reliability. These advantages are illustrated by the recent application of resistivity techniques at a hazardous waste site.

## SITE HISTORY

The site was used as an industrial manufacturing facility from the 1950s to the mid-1970s. After manufacturing operations ceased, the site was leased and used as an unpermitted storage site for industrial wastes. When the site was discovered by USEPA there were in excess of 2000 55-gal drums stored above ground at the site (Fig. 1). Analytical data from drum samples revealed the waste to be spent solvents, sludges, and heavy metals. The drums, in various states of deterioration, were scattered over several acres. Some drums appeared full and sound while others were leaking or empty. A partial listing of the numerous contaminants detected in drum samples included the following compounds:

1,1-dichloroethane      Naphthalene  
1,1,1-trichloroethane      Barium

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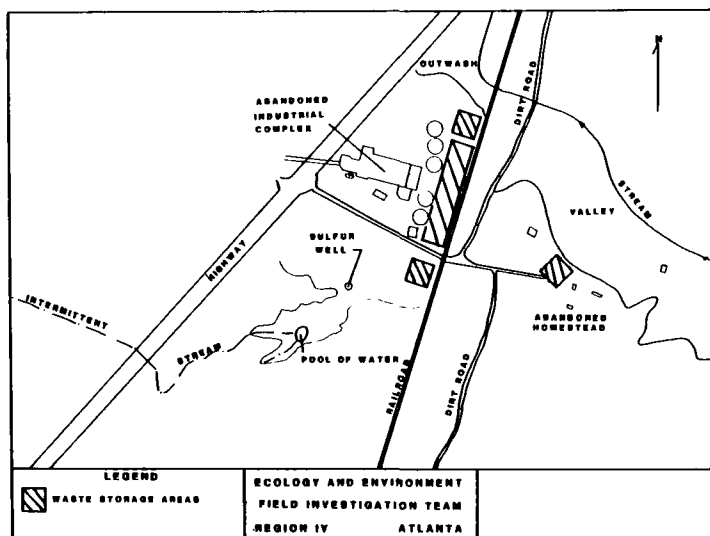


Figure 1.  
Location of Waste Storage

Chloroform	Cadmium
Benzene	Chromium
Phenol	Mercury
Toluene	Lead

Most of the runoff from the leaking drums followed a south-westerly course away from the site along a gently sloping draw, evidenced by the stained soil and stressed vegetation observed along the flow path. An isolated area of contamination also existed at the abandoned homestead where approximately 100 drums had been perforated and the contents allowed to drain out on the ground.

Of potential significance to groundwater quality is the existence of an abandoned oil and gas well. The well proved unsuccessful but did produce, under flowing conditions, water reportedly containing hydrogen sulfide gas. The well was finally plugged with cement grout prior to any drum storage on the site. The well water is suspected of impacting the groundwater quality of this site.

After the enactment of Superfund, federal authority was granted for a planned removal action at the site. All drums and a majority of the contaminated soil were removed and disposed of at an approved facility. However, there remained the concern that contaminants from the leaking drums had contaminated the local aquifer. A highly productive well field, serving from 65,000 to 75,000 people in the surrounding area, withdraws water from the aquifer less than 5000 ft from the site.

## HYDROGEOLOGY

The hydrogeology of the case site is relatively simple. The alluvial type deposits which are common to the area are composed of clay,

silt and fine-grained quartz sand which overlay quartz sand and gravel with clay lenses. Shale bedrock is approximately 90 ft deep.

The regional groundwater flow direction is generally toward the southwest. Groundwater levels at the site encountered during limited USEPA shallow drilling and pit digging were 5 to 10 ft deep. Localized groundwater flow directions may vary due to past excavations and fill operations and the outwash stream valley north-east of the site.

### RESISTIVITY SURVEYS

To efficiently determine the presence, and extent, of the suspected leachate plume at the case site, resistivity surveys were performed at various data points (Fig. 2). The first survey, conducted while drums were on site, consisted of five soundings ranging in proposed depths of investigation between 30 and 150 ft deep. To

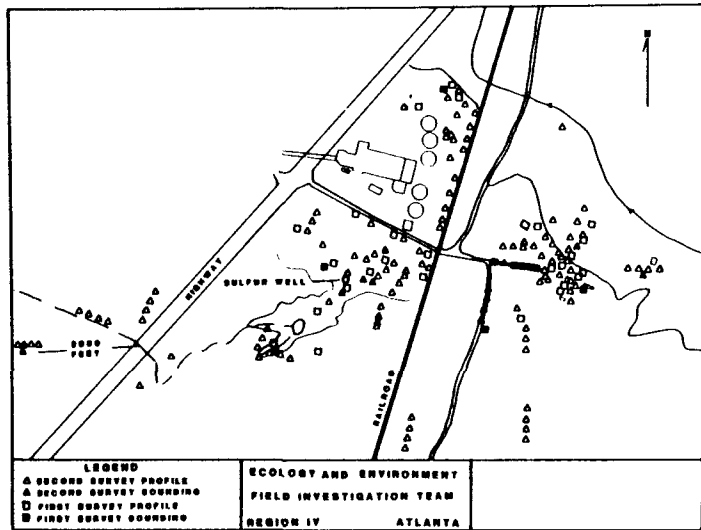


Figure 2.  
Location of Resistivity Data Points

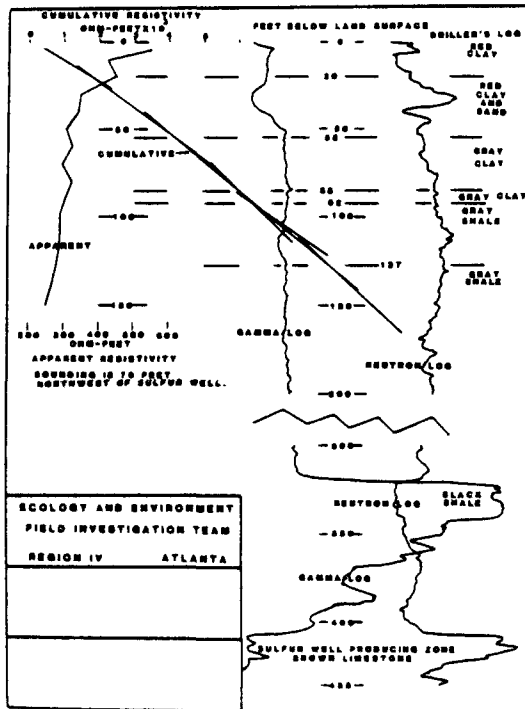


Figure 3.  
Comparison of Sounding, Geophysical Logs, and Driller's Log

insure that the resistivity measurements could be reliably interpreted, control readings were made at a previously logged well. A good correlation was obtained between the modified Wenner array sounding method, the driller's log, and the geophysical logs of the abandoned oil and gas well (Fig. 3). For example, the sounding indicated major cumulative resistivity slope changes at 20, 55, and 92 ft. Both the driller's log and the geophysical logs indicated changes at comparable depths.

During the first survey profiles were conducted at 31 locations. The standard Wenner array profile method<sup>2</sup> was used with electrode "A" spacings of 10 and 25 ft. Apparent resistivity values outside the topographic draw southwest of the buildings ranged from 116 to 257 ohm-ft whereas inside the draw the values ranged from 11 to 105 ohm-ft. These low values indicate groundwater contamination (Fig. 4). By comparing Fig. 1 and Fig. 4, the correlation can be seen between waste storage at the head of the draw, the once flowing sulfur well and low apparent resistivity values in the draw. Assumed groundwater flow and surface-water drainage from the head of the draw are also southwest along the draw. These factors contribute to the preliminary evaluation that leachate is moving from the waste storage area at the head of the draw south-

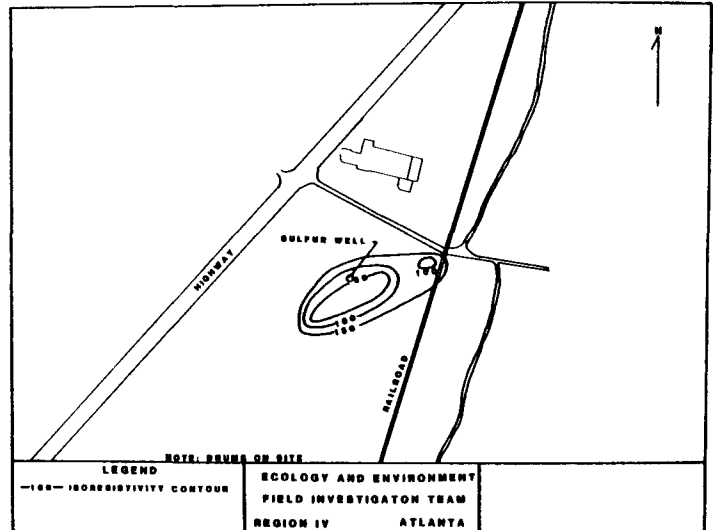


Figure 4.  
Apparent Resistivity Map First Survey

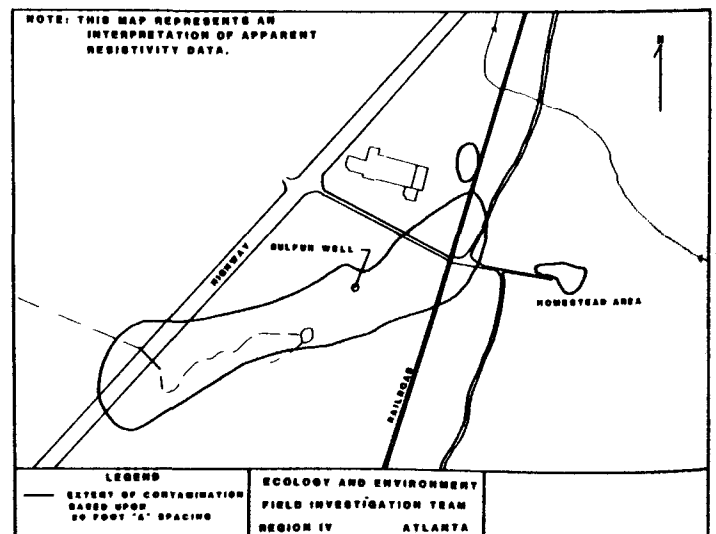


Figure 5.  
Extent of Groundwater Contamination 20 foot "A"  
Spacing Second Survey

west along the draw. This preliminary evaluation was supported by a second resistivity survey after the drums were removed.

The second resistivity survey consisted of additional soundings and profiles at 126 locations (Fig. 2). In order to detail the horizontal and vertical extent of interpreted groundwater contamination, electrode "A" spacings of 20, 40, 60, and 80 ft were chosen. The extent of contamination using electrode "A" spacings of 20, 40, 60, and 80 ft is shown in Figs. 5, 6, 7 and 8. Again, by comparing Fig. 1 with Fig. 5 the correlation between waste storage areas and interpreted shallow groundwater contamination is very apparent.

Using the 40 ft "A" spacing profile the interpreted contamination corresponds with that at the 20 ft "A" spacing but is less

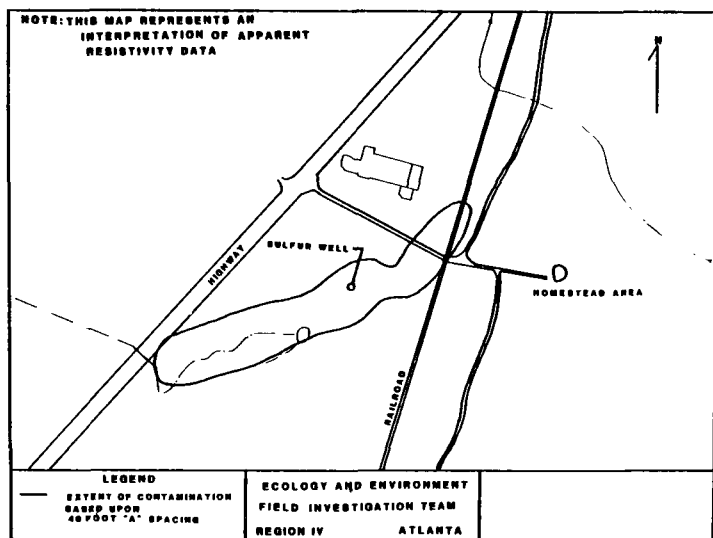


Figure 6.  
Extent of Groundwater Contamination 40 Foot "A"  
Spacing Second Survey

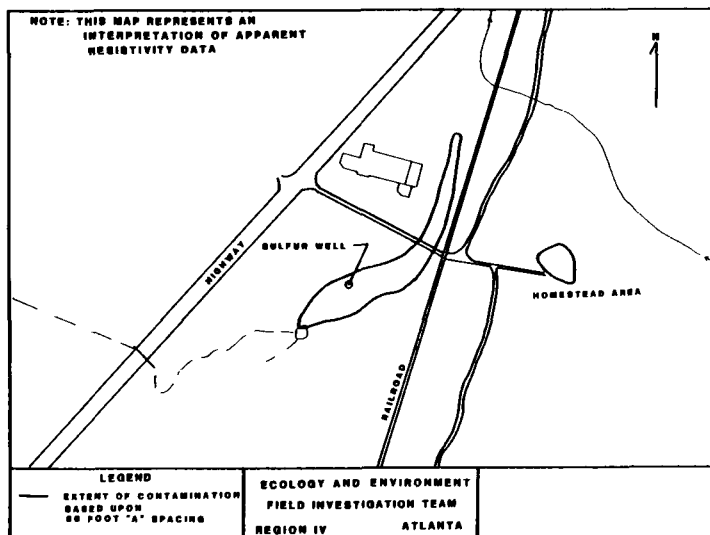


Figure 7.  
Extent of Groundwater Contamination 60 Foot "A"  
Spacing Second Survey

extensive. Using the 60 ft "A" spacing the interpreted contamination varies in size and direction due to probable variations in alluvial lithology, permeability and localized groundwater flow

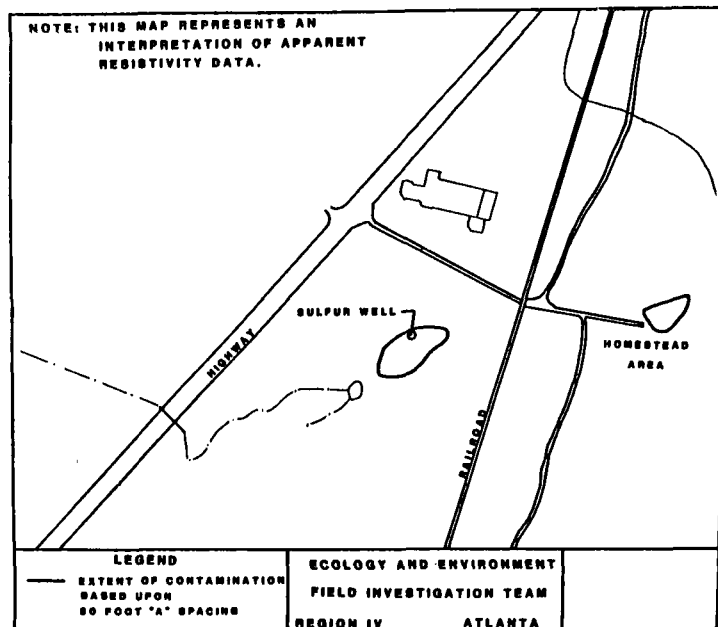


Figure 8  
Extent of Groundwater Contamination 80 Foot "A"  
Spacing Second Survey

patterns. Using the 80 ft "A" spacing the interpreted contamination is limited to zones directly underneath the homestead drum storage area and the sulfur well.

## CONCLUSIONS

The study described in this paper consisted initially of an evaluation of site history, waste analyses, and hydrogeology. During the study, no control wells were drilled, requiring that the resistivity data interpretation be based upon existing subsurface data and experience at other sites similar in history and waste types. The first survey was completed in two days by a crew of three people. After the data interpretation and drum removal another survey was planned to detail the extent of the leachate. The second survey was completed in four days by a crew of three people.

As a preliminary method of leachate monitoring, resistivity proved to be a very cost-effective method in screening this site. By comparison, a drilling and sampling method to achieve the same results would probably have cost several thousand dollars more. The time delay in requesting drilling proposals, contract approvals, actual drilling work and laboratory analyses would probably have delayed management decisions on future work by several weeks. In addition, a second series of monitoring wells would probably be required for the most effective monitoring program.

The locations of waste sources and interpreted leachate occurrences and movement based on the resistivity studies correlated very well. The influence of the water from the flowing sulfur well on the resistivity data is not definitely known but is believed to be of great significance. By using the resistivity method the need for monitoring wells was established and a limited number of wells can be placed effectively. Once monitoring wells have been drilled and sampled, further management decisions can be made to determine the need for future tracking of the leachate.

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# VADOSE ZONE MONITORING CONCEPTS AT LANDFILLS, IMPOUNDMENTS, AND LAND TREATMENT DISPOSAL AREAS

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## INTRODUCTION

The Resource Conservation and Recovery Act of 1976 was enacted to promote the protection of public health and the environment through various regulatory, technical assistance and training programs in dealing with hazardous waste disposal site operations. Subpart M, 265.278, entitled "Unsaturated Zone Monitoring," specifically defines vadose zone monitoring requirements for land treatment.

A major concern at all hazardous waste disposal sites, including abandoned, active, and planned sites, is the possibility of polluting an underlying groundwater system. Because of this concern, requirements were included in the Hazardous Waste and Consolidated Permit Regulations, issued on May 19, 1980. The regulations require a minimum of four groundwater sampling wells at impoundment, landfill, waste pile, and land treatment sites. The regulations also stipulate the location of such wells relative to site boundaries and specify the parameters to be determined on water samples. Vadose zone monitoring (i.e., "leachate" monitoring, as defined in the regulations) is required only at land treatment areas. The rationale generally used for excluding vadose zone monitoring at impoundments, landfills, and waste piles is as follows: (1) the primary monitoring tool in the vadose zone is the suction lysimeter, (2) suction lysimeters provide only point samples, (3) suction lysimeters cannot be installed in existing facilities without removing the waste deposits, and (4) suction lysimeters tend to clog.

The regulations do not at this time address the possibility of alternative vadose zone monitoring methods at hazardous waste impoundments, landfills, waste piles, and land treatment areas. In actuality, a host of alternative methods are available.<sup>1</sup> By judiciously selecting from these methods, an effective vadose zone monitoring system could be assembled at impoundments, landfills, and other waste disposal sites. Operation of such a system would lead to an "early warning" of potential pollution and allow for the initiation of remedial measures. An early warning system is desirable in regions where the vadose zone may be hundreds of feet thick and the travel time of pollutants may be in the tens of hundreds of years. In such regions, when samples from monitor wells indicate the presence of pollutants, the groundwater system will have been essentially destroyed. An early warning system is of equal or even greater importance for regions underlain by shallow potable systems because of the short travel time and reduced potential for pollutant attenuation.

## VADOSE ZONE DESCRIPTION

The geological profile extending from ground surface to the upper surface of the principal water-bearing formation is called the vadose zone. The term "vadose zone" is preferable to the often-used term "unsaturated zone" because saturated regions are frequently present in some vadose zones.<sup>2</sup>

The topsoil is the region that manifests the effects of weathering of geological materials, together with the processes of eluviation and illuviation of colloidal materials, to form more or less well-developed profiles.<sup>3</sup> Water movement in the topsoil usually occurs in the unsaturated state, where soil water exists under less-than-atmospheric pressures. A great deal of literature on the subject is available in periodicals and textbooks. Within the topsoil, saturated zones may develop over horizons of low permeability. A number of references on the theory of flow in perched water tables are available.<sup>4,5</sup> Soil chemists and soil microbiologists have also attempted to quantify chemical-microbiological transformations during soil-water movement.<sup>6,7</sup>

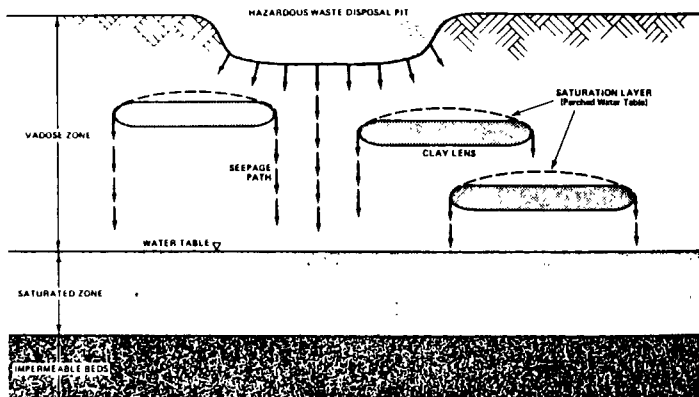


Figure 1.  
Vadose zone including saturated and unsaturated flow

Weathered topsoil materials gradually merge with the underlying earth materials. The zone beneath the topsoil and overlying the water table, in which water in pore spaces coexists with air, or in which the geological materials are unsaturated, is known as the vadose zone (Fig. 1). Perched water tables may develop above interfaces between layers having greatly different textures. Saturated conditions may also develop beneath recharge sites as a result of prolonged infiltration. In contrast to the large number of studies on water movement in the topsoil, parallel studies in the vadose zone have been few. The term "no-man's land of hydrology" was coined to describe the limited knowledge of this zone.<sup>8</sup>

## CATEGORIZATION OF VADOSE ZONE MONITORING METHODS

A vadose zone monitoring program for a waste disposal site includes premonitoring (preoperational) activities followed by active (operational) and post-closure monitoring programs. Basically, premonitoring activities consist of assessing hydraulic properties of the vadose zone, specifically storage and transmissive prop-

erties, and the geochemical properties relating to pollutant mobility (Table 1). The results of the premonitoring program will provide clues on the potential mobility rates of liquid-borne pollutants through the vadose zone, the storage potential of the region for liquid wastes, and the likelihood that specific pollutants will become attenuated. Premonitoring activities are discussed in detail in a separate report.<sup>9</sup> A premonitoring program will also provide valuable information for the design of a vadose zone monitoring system.

The active and post-closure monitoring programs will comprise a package of sampling and nonsampling methods selected from an array of possible methods. Sampling methods provide actual liquid or solid samples from the vadose zone, whereas nonsampling methods provide inferential evidence about the movement of liquid-borne pollutants. Complete descriptions of sampling and nonsampling methods for active and post-closure monitoring programs have been developed.<sup>10</sup>

### CRITERIA FOR SELECTING ALTERNATIVE VADOSE ZONE MONITORING METHODS

A guiding principle for selecting methods for a monitoring program (premonitoring/active/post-closure monitoring) was aptly stated as follows: "...for an efficient, long-term operation of an

operational monitoring network, the devices to be used must be simple enough to be used by trained but not educationally skilled personnel."<sup>11</sup> If the device meets these criteria and also if it is inexpensive, one does not need to look further. In practice, selection of a method from a group of alternatives is governed by additional site-specific and function-specific requirements. The 14 criteria for selecting alternative vadose zone monitoring methods are given in Table 2.

### CONCEPTUAL VADOSE ZONE MONITORING DESCRIPTIONS

Development of a groundwater monitoring program for a hazardous waste disposal facility is an integrative process. The primary elements to be considered, e.g., categorization of waste, waste disposal methods, hydrogeologic setting, and monitoring equipments, have been discussed.<sup>10</sup>

In general, site and waste characteristics will dictate the disposal method and thereby suggest the most effective monitoring program for a given location.

### LANDFILLS

A typical landfill is constructed by using either the area or trench method. With the area method, waste is deposited directly on the

Table 1.  
Premonitoring of the Vadose Zone at Hazardous Waste Disposal Sites.

Property	Purpose of Monitoring	Approach	Alternative Methods
1. Storage	1. To determine overall storage capacity of the vadose zone.	1. Relate storage capacity to depth of water table or depth to confining layer.	1. Examine groundwater level maps. 2. Measure water levels in wells. 3. Examine drillers' logs for depth to water table or confining layer. 4. Drill test wells.
		2. Estimate available porosity.	1. Estimate from grain-size data. 2. Drill test wells and obtain drill cuttings. 3. Neutron moisture logging (available porosity = total porosity - water content, by volume).
	2. To determine regions of potential liquid accumulation (perched groundwater).	1. Characterize subsurface stratigraphy.	1. Examine drillers' logs. 2. Drill test wells and obtain samples for grain-size analyses. 3. Natural gamma logging.
		2. Locate existing perched groundwater zones.	1. Examine drillers' logs. 2. Drill test wells. 3. Neutron moisture logging.
2. Transmission of liquid wastes.			
a. Flux.	1. To determine infiltration potential.	1. Measure infiltration rate in the field.	1. Infiltrimeters. 2. Test plots.
	2. To estimate percolation rates in vadose zone.	1. Measure unsaturated hydraulic conductivity for use in Darcy's equation.	1. Instantaneous rate method. 2. Laboratory column studies.
		2. Measure or estimate saturated hydraulic conductivity for use in Darcy's equation.	
		a. Use core samples or grain-size data.	1. Permeameters 2. Estimate from grain-size data using a catalogue of hydraulic properties of soils.
		b. Measure saturated hydraulic conductivity in shallow regions.	1. Pump in method. 2. Air entry permeameter. 3. Infiltration gradient. 4. Double tube method.
		c. Measure saturated hydraulic conductivity in deep regions.	1. USBR open end casing test. 2. USBR open hole method. 3. Stephens-Neuman method.
b. Velocity	1. To estimate the flow rate of liquid pollutants in the vadose zone.	1. Estimate from field data on flux.	1. Use flux values obtained as above; divide flux values by water content values at field capacity.
		2. Tracer studies.	1. Field plots, coupled with a depth-wise sequence of suction samplers, using conservative tracer.
3. Pollutant mobility.	1. To estimate the mobility of potential pollutants in the vadose zone.	1. Characterize solids' samples for properties affecting pollutant mobility: cation exchange capacity, clay content, content of hydrous oxides of iron, pH and content of free lime, and surface area.	1. Obtain solids' samples (e.g., by drilling test holes) and conduct standard laboratory analyses.
		2. Estimate from laboratory or field testing using liquid wastes.	1. Batch testing. 2. Column studies. 3. Field plots.

Table 2.  
Criteria for Selecting Alternative Vadose Zone Monitoring Methods.<sup>14</sup>

Item	Criteria
1	Applicability to new, active, or abandoned sites
2	Applicability to laboratory or field usage
3	Power requirements
4	Depth limitations
5	Multiple use capabilities
6	Data Collection system
7	Possibility of continuous sampling
8	Sample/measurement volume
9	Reliability and life expectancy
10	Degree of complexity
11	Direct versus indirect sampling/measurement
12	Type of media
13	Effect of sampling/measurement on flow regime
14	Effect of hazardous waste type on results

ground surface. Run-on must be diverted away from the active portion of the landfill. Run-off from the facility must be collected and, if it is a hazardous waste, treated accordingly as specified under the RCRA, Part 261. If the landfill material is subjected to dispersal by wind, it must be covered or otherwise managed so that hazardous waste is controlled. With the trench method, waste is deposited at one end of a trench and covered at the end of the day as required. For this example, it is assumed that hazardous wastes are disposed of using the trench method.

During construction of the facility, data on the vadose zone at the site may have been compiled and should be reviewed as part of the premonitoring effort. This information, along with Soil Conservation Service (SCS) soil maps and well cuttings from geologic formations penetrated by monitoring wells, should be examined to determine the thickness, structure, and chemical characteristics of the vadose zone. Water table levels should be plotted to determine existing hydraulic gradients and the thickness of the vadose zone. If vadose zone samples have been saved from site development, several laboratory techniques are available for estimating hydraulic conductivity (K). Saturated K values can be determined using permeameters and from the resultant K values, assuming the hydraulic gradients are unity, the flux at the site can be estimated from Darcy's equation. Saturated K values for different layers can also be determined using the relationship between grain size and K developed from grain-size distribution curves. Additional laboratory methods for measuring unsaturated K values include the "long-soil column," pressure plate methods, and other column techniques.

Storage potential for water-borne pollutants can be inferred from storage coefficients developed from pump tests in perched water systems within the vadose zone. These data can be generated at minimal cost if wells and observation piezometers are available from preliminary work at the site. Aerial photographs should be reviewed for evidence of springs and seeps caused by modifications of the water table under landfills and potential threats to surface water quality at the site. Rainfall data and ambient surface water quality for the site should be known. Surface structures designed to control run-on and run-off from the waste material should be inspected to ensure compliance with the RCRA.

Data on the chemical characteristics of the vadose zone are vital in developing and understanding pollutant attenuation. In particular, the percentage of colloidal-sized particles, e.g., clay minerals, and pH of a representative soil-moisture extract should be determined. In porous geologic materials, these particles can exchange ionic constituents absorbed on the particle surfaces. The nature of the surface charge of these particles is a function of the pH. At high pH, a negatively charged surface occurs, while at a low pH, a positively charged surface is developed. The tendency for adsorp-

tion of anions or cations is therefore dependent on the pH of the soil water solution found in the vadose zone. This information will be useful in estimating pollutant attenuation based on expected leachate constituents. In addition, the redox (oxidation-reduction) potential or Eh of perched groundwater, soil-moisture extract, and/or leachate should be measured. With the pH and Eh of the vadose zone known, Eh-pH diagrams can be constructed showing stability fields for major dissolved species and solid phases. These diagrams are useful in understanding the occurrence and mobility of minor and trace elements. Construction of the Eh-pH diagram has been described in detail.<sup>12,13</sup>

Ambient groundwater quality is an important data base to establish during the premonitoring effort. At old existing sites, care must be taken to ensure that water data unaffected by the landfill have been sampled to determine background quality. Of particular interest as indicator parameters are TDS, COD, conductivity and BOD<sub>5</sub> that have been found in high concentrations in solid waste leachate studies. In addition, temperature, color, Cl, and Fe are listed as indicator parameters.<sup>14</sup>

The continued operation of a landfill either by the area or trench method requires additional land for disposal of new waste material. Therefore, each site is composed of a combination of existing and projected waste cells. Monitoring activities for these areas will differ in that the cost effective placement of a specific type of monitoring equipment for new cells may not be possible for existing cells. For example, a resistivity network installed under the protective liner of the landfill to determine leachate migration through the liner could be easily incorporated in the earthwork required for development of the new waste cell. This type of installation would not be possible under an existing cell. Segregation of wastes by toxicity may dictate alternate monitoring networks around selected waste cells. Depending on the toxicity level of the waste material and its vertical proximity with groundwater aquifers, the use of nondestructive aquifer monitoring methods (i.e., geophysical techniques) may be preferable to sampling methods that require boreholes through the potentially polluted strata. These boreholes have been known to short circuit liquid-borne wastes to the water table through the annular well space of an improperly completed monitor well.

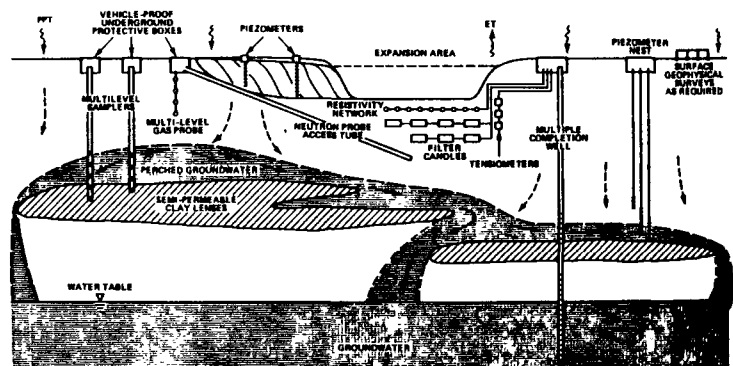


Figure 2.  
Generic monitoring design for existing hazardous waste landfill

A generic monitoring design for an active/new hazardous waste landfill is shown in Fig. 2. Elements of the design include utilization of both nonsampling and sampling methods. Nonsampling methods include: (1) neutron moderation probes, (2) tensiometers, (3) a resistivity network underlying new waste cells, and (4) surface and borehole. All of these geophysical methods could be used as required for detection or definition of pollutant plumes. Sampling methods include: (1) multiple completion wells, (2) multilevel samplers, (3) suction samplers, (4) piezometers, and (5) gas samplers. Technical description, field implementation, and range of application and limitations of these techniques have been discussed.<sup>15</sup>

## SURFACE IMPOUNDMENT

Unlike the preceding generic landfill model where existing and projected waste cells were evaluated for one facility, two separate cases for generic surface impoundments were examined: Case 1, a new unused facility (see Fig. 3) and Case 2, an active site.<sup>16</sup> This format was necessary because surface impoundment operations do not include the subsequent disposal of new waste materials on additional lands. Following construction of the impoundment, no additional land is required until the facility is closed and a new site developed. Therefore, access for instrument emplacement differs between the two sites. A premonitoring effort was undertaken to characterize the waste water and vadose zone properties. The conceptual program included surface water, vadose zone and saturated zone monitoring techniques.

To accommodate measurement of intake rates in the lagoon, a stilling well with water stage recorder was mounted on the end of a platform. During operation of the lagoon, intake rates can be determined by the instantaneous rate methods, in which water-level declines, measured in the lagoon during a brief shutdown period, are related to volumetric relationships for the lagoon.

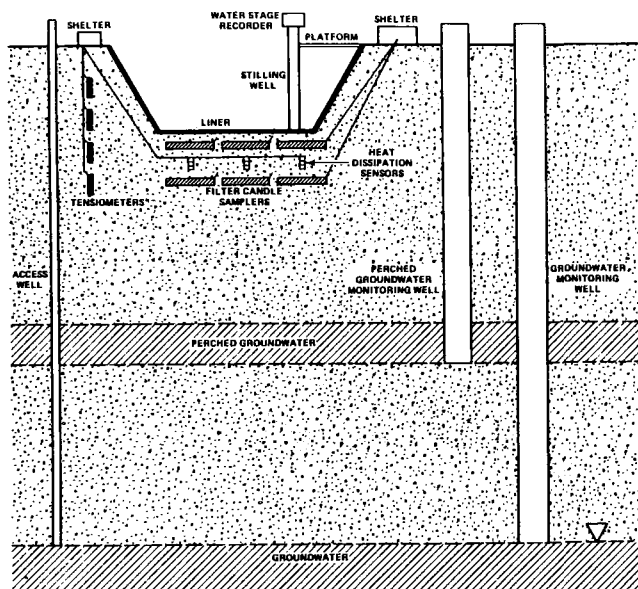


Figure 3.

Water quality monitoring design for a new surface impoundment

Sampling units were installed beneath the base of the lagoon, as shown in Fig. 3, to sample percolating water in case of failure at the liner. The sampling units were, of course, installed before laying down the liner. The sampling units selected for this package were filter candles, laid horizontally. Filter candles contact a larger area than point samplers, such as lysimeters. The individual units were laid within sheet metal troughs. Because of the importance of detecting wastewater movement below a failed liner, back-up units were installed beneath the shallower units. In addition, other units were installed at the same depths at other locations in the pond. Such duplication can be regarded as "planned redundancy," to avoid the sampling problems described earlier in this paper. Inlet and outlet lines from the samplers were terminated in an above-ground shelter containing sources of vacuum-pressure, sample bottles and other appurtenances. Provisions are included to permit obtaining either discrete or continuous samples.

The second "line of defense" for direct sampling of percolating wastewater consists of monitoring wells installed in the perched groundwater body. These wells are particularly valuable in the

event that water movement beneath the pond occurs at matric pressures below the limit of the filter candles (i.e., about -0.8 atm). Ideally, these monitor wells should be of large enough diameter to permit the installation of permanent submersible pumps.<sup>17</sup> Sampling should be initiated as soon as the wells are completed to obtain baseline water quality values.

Indirect methods selected for detecting the percolation of wastewater from the lagoon consist of tensiometers, heat-dissipation sensors, and access wells for neutron moisture logging. The tensiometers and heat dissipation units are useful in estimating both storage changes and hydraulic head gradients. In addition, the tensiometers will indicate the appropriate negative pressure to apply to the filter candles during sampling, to avoid affecting unsaturated flow paths. The heat-dissipation sensors provide information on hydraulic gradients at negative pressures below the failure point of tensiometers. The selection of heat-dissipation sensors in this example was arbitrary. To conform with the principle of "planned redundancy," batteries of psychrometers/hydrometers and/or electric resistance blocks also could be installed. The tensiometer readings will be recorded manually by a field technician. However, the signal from the other matric-potential sensors could be automatically recorded.

Neutron moisture logging in the access wells will show the lateral spread of wastewater in the vadose zone in case of liner failure, provided that storage changes occur in the geologic profile. The wells also can be used to monitor changes in groundwater levels and for obtaining water samples from the vicinity of the water table.

For active (and abandoned) lagoons it will not be possible to install monitoring units beneath the base of the impoundment. Consequently, such units must be installed on the periphery of the facility. A stilling well and water storage recorder are installed to aid in determining intake rates by the instantaneous rate method. A cheaper technique would be to position stilling wells on the sides of the lagoon. For active ponds it will be possible to estimate flux and velocity in the vadose zone. Dividing this value by representative water content values gives an estimate of velocity.

Sampling techniques consist of clustered suction cup lysimeters, in a common borehole, and a perched groundwater well. Non-sampling techniques consist of tensiometers and access wells for neutron logging. As in the case of the new lagoon, it is advisable to install other nonsampling units such as psychrometers/hygrometers for monitoring in the dry range, where tensiometers become inoperative. A complete discussion of the rationale and methods used for Case 1 and Case 2 has been developed in an EPA report.<sup>16</sup>

## LAND TREATMENT FACILITIES

As defined in the Hazardous Waste and Consolidated Permit Regulations,<sup>18</sup> a land treatment facility is "...that part of a facility at which hazardous waste is applied onto or incorporated into the soil surface." The objective of land treatment is to enhance the microbial decomposition of waste pollutants, or to otherwise retard their mobility by soil physical/chemical reactions. According to some authors,<sup>19</sup> land treatment of wastes involves the following three steps following application and incorporation: (1) mixing the waste with surface soil to aerate the mass and expose waste to soil microorganisms, (2) adding nutrients or amendments (optional), and (3) remixing the soil and waste periodically to maintain aerobic conditions.

Techniques for selecting, managing, and operating land treatment facilities were reviewed by several authors.<sup>20,19,21,22</sup> USEPA requirements for surface water control, record keeping, waste analyses, monitoring, use at food chain crops, and closure are included in "Standards Applicable to Generators of Hazardous Waste".<sup>23</sup> In contrast to the monitoring requirements for hazardous waste impoundments and landfills, vadose zone monitoring is required at land treatment areas. The designated techniques are pore-water sampling and solids sampling.

A typical land treatment facility is illustrated in Fig. 4. As shown, the facility contains a lagoon for storing incoming wastes. Conceivably, such a lagoon would be lined to minimize seepage and would include monitoring facilities, such as described previously for impoundments. The field is diked to prevent uncontrollable run-off. Whatever run-off occurs is collected into a sump.

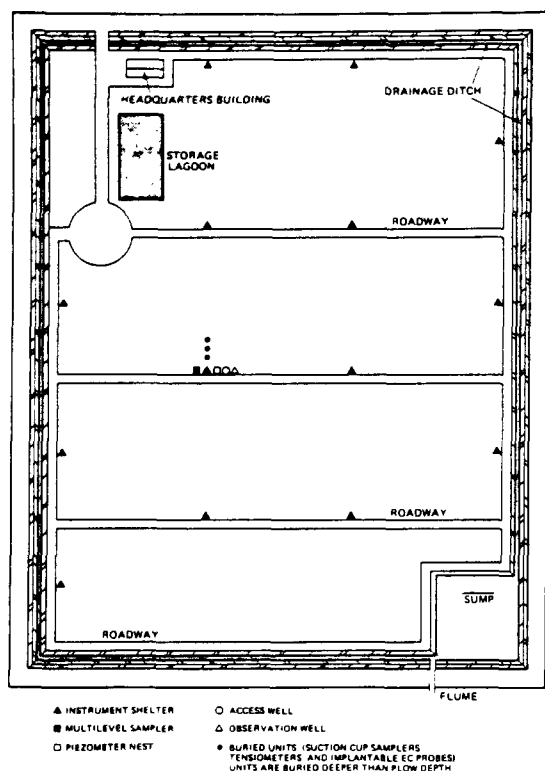


Figure 4.

Plan view of monitoring units for land treatment area

### Land Treatment Premonitoring

In general, the premonitoring activities relative to land treatment of hazardous wastes will be identical to those for site selection, e.g., characterization of wastes and vadose zone properties. Ideally, these activities should be staged as follows: (1) identify properties of wastes that will affect the mobility of pollutants in the vadose zone, (2) identify properties of vadose zone solids that will affect the mobility of waste pollutants, and (3) conduct tests to evaluate waste/soil interactions promoting pollutant attenuation in the vadose zone.

As indicated, the techniques specified by USEPA for vadose zone monitoring at land treatment sites includes soil core and soil-pore water monitoring. The monitoring plan requires that the owner/operator must specify details on the depth of monitoring, number of samples, the frequency of sampling, and the timing of sampling when using these techniques. The generic monitoring program presented here is based on the premise that the owner/operator has also chosen a mixture of nonsampling methods to assist in determining sampling depth, frequency, and timing of samples using the two basic techniques. In view of the great cost involved in analyzing for pollutants, this approach would be cost effective. In addition, it is assumed that the owner or operator is sufficiently environmentally conscious that he has elected to use alternative sampling methods to back up the suction cup samplers that are inoperative at soil-water pressures below -0.8 atmosphere.

### Nonsampling Methods

Nonsampling approaches to monitoring at an active land treatment area include: (1) conducting a water budget analysis, and

(2) installing nonsampling units. The water budget approach using soil moisture accounting is a simple, rapid method for estimating the volume of deep percolation below a selected soil depth. The method developed by two researchers<sup>24</sup> is used most often and a computer program designated WATBUG is available to simplify calculations.<sup>25</sup> Inflow components that must be measured include precipitation and waste water application. Outflow components requiring measurement include runoff and crop evapotranspiration. The change in storage equals water content change in the depth of interest. All terms are equated to deep percolation.

A generic assortment of monitoring units at a station at a land treatment area is shown in cross section in Fig. 5. Elements of the design include: (1) an access well for neutron moisture logging, (2) implantable electrical conductivity probes for detecting changes in salinity, (3) tensiometers for measuring matric potential down to -0.8 atm, and (4) thermal dissipation sensors for measuring matric potential below -0.8 atm. Technical descriptions, limitations, and field applications of these techniques have been described.<sup>16</sup>

To avoid interfering with field operations and to facilitate access, each station should be located on a beam extending across the field as shown in a plan view of the facility in Fig. 4.

Two access wells have been installed at the station, one shallow and one deep (Fig. 5). In practice, a large number of shallow (<10ft) access wells could be installed throughout the site to determine changes in water content during application and drying cycles. If it appears that all of the water content changes are occurring in the shallow depth, deeper units may not be required. However, if extensive deep percolation is occurring, deeper access wells will be needed, perhaps extending to the water table. This method is useful in determining site-specific water balances and soil water flux. Moisture logging only accounts for changes in water content, a capacity factor. However, water (and pollutants) may flow through specific zones without a change in water content being registered on moisture logs. Thus, backup facilities are required.

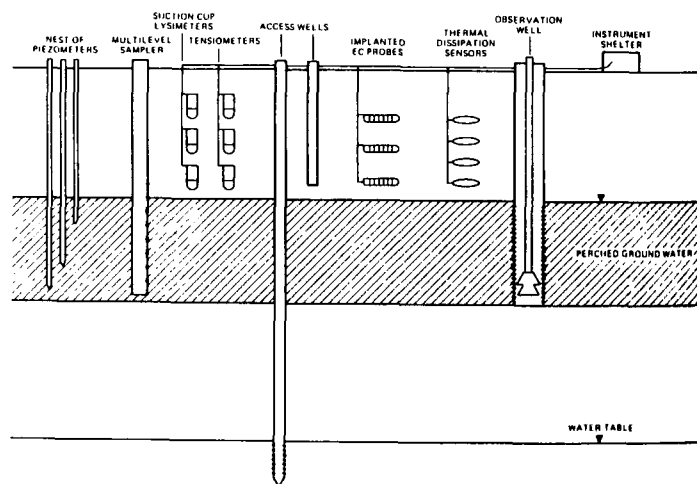


Figure 5.

Generic assortment of monitoring units at land treatment area

A depth-wise battery of implantable conductivity probes is included. These units are based on the four-probe Wenner array for detecting electrical resistivity in the field of measurement. Changes in resistivity indicate that conductive fluids are moving past the units. Alternative techniques that could have been used for detecting changes in salinity include salinity sensors, portable conductivity probes, and a portable four-electrode array.

Tensiometer units are included for sensing the soil water matric potential. Tensiometer readings are useful in determining the correct vacuum to be applied to suction cup samples (to avoid influencing the flow field). For soil-water pressure gradients that are

detectable by a battery of units where the gravitational component does not limit the matric potential readings, inexpensive hydraulic switches can be used to attach many tensiometers to a single pressure transducer.<sup>26</sup> Deeper units will require the use of integral pressure transducers. The latter units also have the advantage of rapid response time and no aboveground components, except lead wires running to a shelter.

Inasmuch as tensiometer units fail at negative pressures below -0.8 atm, the generic system also includes a battery of thermal dissipation sensors, operative in the dry range. Other units that could have been used to extend the range of tensiometers for detecting changes in matric potential include electrical resistance/capacitance blocks, thermocouple psychrometers/hydrometers, and osmotic tensiometers.<sup>26</sup>

An identical array of nonsampling methods to that shown in Fig. 5 could be installed at a new site. The principal difference would be that the installation depth at access wells, conductivity probes, tensiometers, and thermal dissipation sensors would be shallow, say within 10 feet of the land surface. This approach would minimize the cost of installation. However, if it becomes evident that fluids are moving beyond the sensing depths, installation of monitoring equipment at greater depths will be required.

### Sampling Methods

Sampling methods at an active site include soil sampling, pursuant to the requirements of USEPA,<sup>23</sup> and the generic methods depicted in Fig. 5. Soil sampling includes using hand augers and samplers such as the Veihmeyer tube. Deeper methods require the use of power equipment including flight augers and hollow stem augers with wire-line samplers.<sup>27</sup>

Generic methods depicted in Fig. 5 include: (1) suction cup samplers, (2) multilevel samplers in perched groundwater, (3) a depthwise array of piezometer units, (4) an observation well, and (5) a screened well point at the end of the access well.

Suction cup lysimeters are installed in a depth-wide battery to ensure detecting the vertical movement of pollutants. For shallow sampling depths, the simple vacuum-operated unit will be adequate.

Deeper unit will require vacuum pressure or high-pressure vacuum units. In lieu of suction cup units, filter-candle type samplers can be used.

Multilevel samplers are installed in a shallow body of perched groundwater. These units are useful for depth-wise sampling to determine the vertical extent of a plume. A horizontal transect of such units is useful in detecting the lateral dimensions of a plume. They are also used to measure hydraulic gradients. As shown in Fig. 5, some of the sampling points extend above the water table to facilitate sampling during a water table rise (useful for collecting pollutants "hung up" in the vadose zone). A battery of piezometer units shown in the figure could be used in place of or to supplement the multilevel samplers. Piezometers are useful for conducting the so-called piezometer tests for determining saturated hydraulic conductivity values.

A standard observation well is shown installed in a body of perched groundwater. Such wells permit extracting large volumes of perched groundwater for analysis. Results may be indicative of the integrated water quality flowing through the vadose zone. As such, these units may be more useful in estimating mass flux than point samplers, such as suction cup lysimeters. Pumps installed in the observation wells facilitate sampling. Pumps are also useful for conducting pumping tests when determining the hydraulic properties of the vadose zone.

Finally, the deep access well shown in the figure includes a well point for obtaining a water sample near the water table. A suitable batch is required for sampling these units. The representativeness of such a point sample is perhaps questionable. However, the results are useful in a qualitative sense.

The sampling methods shown in Fig. 5 are also applicable to a new facility. However, a staged approach should be taken for installing sampling units. In other words, deeper units should be in-

stalled when evidence from shallow sampling (and nonsampling) units shows that pollutants are moving deeper in the profile.

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# MITIGATION OF SUBSURFACE CONTAMINATION BY HYDROCARBONS

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## INTRODUCTION

Subsurface contamination by hydrocarbons is a recurring problem. Sources range from home-fuel tanks to terminals and trans-continental pipelines. Subsurface releases may go undetected for months or years. The technical literature from the United States and Europe contains numerous references regarding the fate of hydrocarbon in the subsurface.

Overviews of subsurface hydrocarbon contamination are presented by Schwillel and Dietz.<sup>2</sup> A theoretical description of hydrocarbon migration is given by J. Van Dam.<sup>3</sup> Duffy<sup>4</sup> and M. Van Der Waarden<sup>5</sup> present analytical procedures and the results of laboratory experiments dealing with percolation and leaching of hydrocarbons. Subsurface biodegradation of hydrocarbons is addressed by Vanlooche.<sup>6</sup> Case histories involving hydrocarbons in groundwater are presented by McKee,<sup>7</sup> Williams and Wilder,<sup>8</sup> Matis,<sup>9</sup> and Moein.<sup>10</sup>

An understanding of the various transport phenomena is beneficial in developing initial working hypotheses for a given site. Site-specific definition of the extent of contamination is ultimately necessary, however, for implementing cost-effective mitigative measures. In this paper, the authors describe two cases involving hydrocarbon leaks from terminals which have substantially different hydrogeological settings and consequently required different approaches for evaluation and mitigation.

## CASE STUDY—A

### Background

Case A involved the subsurface movement of hydrocarbons in a multiple-terminal area. The source of the hydrocarbon, a discolored and apparently old gasoline, was not obvious. The terminals are in a mixed industrial-residential setting where the hydrocarbon was first detected as petroleum vapors from a sewer line. Seepage of the hydrocarbon first appeared near a commercial operation, causing a partial interruption of business. The hydrocarbon subsequently entered a nearby stream.

"Terminal A" was held responsible for the clean up of the stream, determining the source of the leak, and resolving the problem. Terminal A is at a lower elevation than the other terminals which reportedly had some leaks in the past. The sewer line also entered the vicinity of Terminal A from these and other potential upgradient sources.

This problem occurred in an area which is characterized by rolling hills, numerous streams, and a thick sequence of relatively flat-lying sedimentary rocks. Exposed bedrock in the vicinity is chiefly limestone of Ordovician age. The regional dip of rock units in this area is generally to the northwest, but is locally modified by secondary folds. Flexing of the rocks during the formation of secondary folds has resulted in numerous joints and small-displacement faults.

## Methodology

The objectives of this project were to determine the potential source(s) of the contamination and to implement corrective action to control the hydrocarbons. The project evolved in the following sequential activities.

The initial activities at the site concentrated on recovery of the hydrocarbon from the streams. This cleanup operation was followed by the installation by the owner of approximately 40 observation wells in an unsuccessful attempt to determine the source of the contamination. Air percussion drilling techniques were used and the wells were of a simple construction.

Subsequently a geologic reconnaissance was conducted in the terminal area and a preliminary evaluation was made of the available data. Interviews were conducted with terminal personnel, sewer authorities, and the owners of the commercial property. The site was surveyed and a base map was prepared.

Test pits were excavated near some of the observation wells in which hydrocarbon was encountered to obtain a better understanding of the subsurface conditions. This activity was followed by a resistivity survey and the placement of supplemental observation wells and test pits in anomalous areas depicted by the survey. These data were incorporated into the final site evaluation and subsequent design of the mitigative measures.

In an area with well-lithified, fractured rock, the presence and orientation of fractures are significant with respect to the flow of fluids in the ground. Although fractures provide conduits for flow, they are very thin and therefore difficult to assess through conventional drilling. Geophysical methods which measure a total-field condition within a known volume of ground are more effective in locating such features. The electrical resistivity method was selected for the site to supplement the data provided by observation wells. Four resistivity profiles were aligned parallel to the southern property boundary. Six profiles were parallel to the eastern property boundary.

The test pits used for observation of hydrocarbon occurrence were excavated with a medium-sized backhoe. Because of the relatively thin limestone beds, it was possible to break the rock and rip up slabs of the limestone within the uppermost-weathered zone. Deeper excavations for the recovery trenches required pre-drilling on close spacings before excavation of rock could be accomplished.

## Findings

Subsurface material beneath the site consists of two rock units which are overlain by a thin layer of residual clayey soil and occasional fill material. The contact between the two rock units appears to exist in the vicinity of Terminal A.

The lower rock unit is predominant at the site and consists of blue-gray, medium-grained, moderately fossiliferous limestone. These rocks have beds from one to eight inches thick, with moderately well defined bedding planes. Thin layers of calcareous shale or shaley limestone are also present.

The overlying rock unit is finer grained and more thinly bedded than the lower rock unit with little or no fossil content. The beds, although generally planar, are very uneven. The rock material within the individual beds is very dense, but the bedding planes frequently contain thin layers of clay or shale.

The dip of observed joints in the rock units is nearly vertical. The orientation of the jointing is consistent with regional patterns. A zone of rock weakness was also observed in excavations oriented approximately parallel to the strike of the rock. This zone appeared to coincide with the contact of the rock units.

Overlying the consolidated rock is a layer of clayey soil which represents residual material from *in situ* chemical weathering of the underlying limestone. The soil ranges from less than two feet to more than ten feet in thickness. The boundary between the soil and the underlying rock is very distinct in areas where layers of dense limestone form the uppermost rock and is gradational in shaley zones.

Ground water beneath the site primarily occurs within bedding planes and joints in the limestone bedrock. There is also a limited amount of water within the clayey soil, mostly at the interface between the clay and the rock. The upper surface of the saturated zone is under water table conditions. In the bedrock beneath the site, the water flows through the more porous zones (bedding planes, or joints), and the exact flow path of individual water particles is influenced by the geometry of these discontinuities. Flow paths may therefore be more contorted than in a homogeneous material.

The configuration of the water table is similar to that of the ground surface at the site, with a general slope downward from the northeast toward the southwest (Fig. 1). Groundwater discharges into a nearby stream during periods of high groundwater levels.

The hydrocarbon has been observed in many of the wells and excavations in the southern and eastern portions of the site. In all locations where hydrocarbon could be observed it was flowing from the bedding planes within the rock. Its occurrence within the ground appeared to be limited vertically by the water table, upon which the thin layer of hydrocarbon was floating. The overall direction of contaminant movement was controlled by the configuration of the water table. The exact flow paths appeared to be influenced by the occurrence and orientation of discontinuities in the rock.

Apparent resistivity was calculated and plotted versus distance along the profiles. A strong anomaly (high apparent resistivity) was located in the southern profiles and suggested an alignment roughly perpendicular to the southern property boundary. A high apparent resistivity anomaly was also located on the profiles along the eastern side of the property. The locations of peak readings suggest a possible linear alignment trending almost perpendicular

to the eastern property boundary. These anomalies appear to be associated with structural geologic features and coincide with the occurrence of hydrocarbon.

Excavations were performed near the sewer line to determine if hydrocarbons existed adjacent to these structures. The sewer line consisted of a concrete pipe, buried at an approximate depth of 3ft below the road's upper surface. The line had apparently been placed in a trench which was backfilled with the natural soil materials. Some of the southern sections of the line had been excavated within bedrock.

Groundwater was observed in the sewer line backfill with no indication of hydrocarbon in the northern section of the line. Groundwater and hydrocarbons were observed in the soil backfill and in the adjacent walls of the rock trench along the southern section of the line. In plain view, the occurrence of hydrocarbon forms a "U"-shaped pattern, concave to the south and generally consistent with the directions of groundwater flow (Fig. 1). The pattern of hydrocarbon contamination can be explained by the presence of rock discontinuities (observed in excavations and indicated by geophysical methods) and by the presence of the sewer line. These subsurface features could provide a vertical and horizontal path with a higher permeability than the surrounding rock for contaminant flow.

The interpretation of the hydrocarbon occurrence indicates that an on-site loading area was the likely source area for the product. This interpretation does not preclude the possibility of other on or off-site sources under different conditions. Hydrocarbons originating from this area could potentially move southeast and southwest from a localized groundwater high, with preferential movement within the higher permeability zones.

### Solution

The installation of relatively shallow recovery trenches within the bedrock at two locations was the most feasible technique for preventing additional seepage exiting, or entering, Terminal A. The trenches were also the most feasible technique for recovering the existing petroleum products beneath Terminal A and the adjacent property to the southwest.

The recovery trenches were constructed in general accordance with the schematic drawing presented in Fig. 2. Variations in the subsurface conditions (geology, groundwater, and the occurrence of hydrocarbons) were anticipated at the site. These variations resulted in minor modifications of the corrective action plan. The final details of the recovery trenches were established during the field implementation to allow for on-site modifications. The implementation was supervised by a hydrogeologist who was familiar with the site conditions.

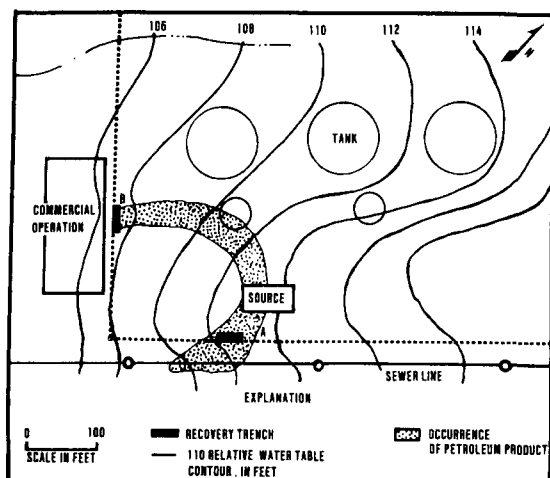


Figure 1.  
Layout of Case A

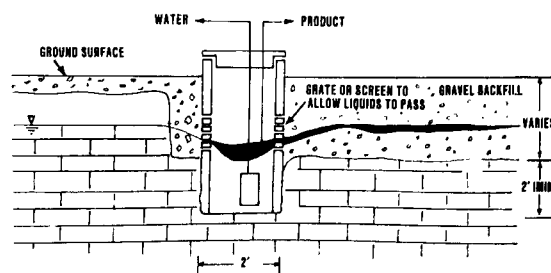


Figure 2.  
Schematic Drawing of Recovery Trench

Trench A was 20 to 30 ft long; its depth is from 6 to 8 ft with a central sump 2 ft deeper (Fig. 2). The primary purpose of this trench was to intercept hydrocarbons which were believed to exit the site along localized geologic discontinuities observed in the test pits. This trench location and orientation is also based upon the results of the resistivity anomaly encountered in this area of the site.

Trench B was 30 to 50 ft long and 12 to 14 ft deep. Its primary purpose was to help recover hydrocarbons moving down-gradient from the source area and from the adjacent commercial property. The water level in the center of the trench will remain at a specified elevation under pumping conditions to reverse the flow of groundwater beneath the northern portion of the adjacent property.

The overall effectiveness of the recovery trenches will be ascertained by routine measurements of water levels in existing wells and springs. Provisions for monitoring were also made for several of the original excavations by the installation of standpipes prior to backfilling.

## CASE STUDY—B

### Background

Case B involved the loss of hydrocarbons from a known source at "Terminal B." More than 200,000 gal of a primarily non-leaded gasoline entered the subsurface by an underground pipe line that was damaged during routine maintenance (Fig. 3). The contamination has not migrated from the owner's property.

The site is located in a belt of Pre-Cambrian age metamorphic rocks. The facility is underlain by deep residual soils that appear to be derived from the in-place weathering of a mica-quartz schist. The silty soils are relatively uniform and no structural features are apparent from the boring data.

### Methodology

The objectives of this project were to recover the usable hydrocarbons and to prevent off-site migration. In the first phase of study, nine observation wells were installed around the source area. The purpose of the wells was to allow a preliminary estimate of the areal extent and thickness of the contamination and to indicate fluid-flow directions.

The wells were constructed of 4 in diameter PVC using manufactured well screens with a slot size of 0.010 in. A sand pack was placed between the borehole wall and the well screen. A bentonite seal was placed above the sand pack and the remaining annular space filled with grout. The screen lengths varied from 5 to 25 ft, and well depths varied from 20 to 35 ft. Split-spoon samples and/or auger cuttings were obtained from the borings to determine subsurface soil conditions.

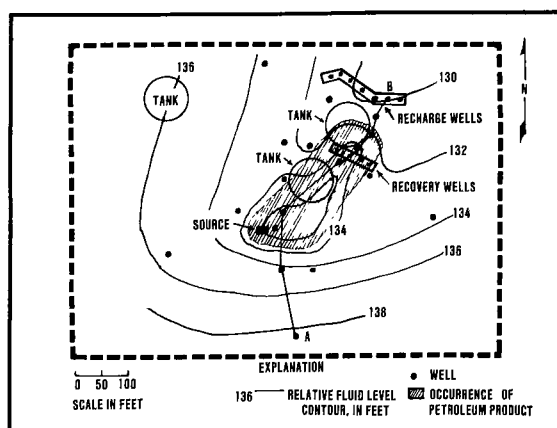


Figure 3.  
Layout of Case B

The wells were developed with a pump or bailer and allowed to return to static conditions before measuring the fluid levels in the wells. *In-situ* permeability tests were then performed in selected wells for preliminary estimates of contaminant migration rates. During this period of study the owner independently installed a 12 in diameter well immediately adjacent to the hydrocarbon source area to begin the recovery operation.

After completion of the first phase, it was determined that additional wells and aquifer testing would be required to more accurately determine hydrocarbon extent, flow direction and aquifer properties. A preliminary recommendation was to install a recovery system near the downgradient hydrocarbon front. The data to be obtained from the second phase would help determine the location and spacing of the recovery system.

In the second phase, six additional observation wells were installed closer to the suspected product limits. The wells were constructed in a manner similar to that described in the first phase. After analysis of the data obtained from the additional observation wells, a 6 in diameter well was installed just upgradient of the contaminant front. This well was installed as a prototype recovery well and used to perform an aquifer test in an area where the hydrocarbon had a considerable thickness. Prior to testing, static fluid levels were obtained in all the wells and a constant fluid-level recorder installed in the observation well closest to the pumped well.

The aquifer test was performed in several steps to obtain as much useful information as possible within the time constraints of the project. Eight observation wells were monitored at selected intervals throughout the testing. During the first 48 hr the test well was pumped at a constant rate of 0.25 gal/min. The well was then pumped at 0.33 gal/min for 8 hr while the response of the eight observation wells and the pumped well to the increased discharge rate was monitored. The pump was then turned off and a recovery test was performed over a period of 16 hr. After the recovery test the pump was raised and lowered in the test well and pumped at various rates to observe if any significant changes occurred in the hydrocarbon to water ratio.

### Findings

The subsurface at the site consists of residual soils that vary from red-brown to buff, micaceous fine sandy to clayey silts. The sand content is estimated to vary from 5 to 30% and the clay content is generally less than 10%. Unweathered rock was not encountered in any of the borings.

The fluid depths (hydrocarbon or groundwater) varied from 10 to 20 ft below land surface. The thickness of hydrocarbon varied from 15 ft near the source area to 12 ft in the well located 200 ft downgradient from the source area (Fig. 4).

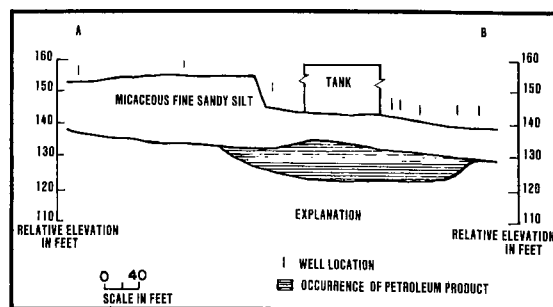


Figure 4.  
Profile of Subsurface Conditions

A potentiometric surface map was constructed from the observation well data. Contaminant flow is from the southern end of the site to the north-northeast. The shape of the hydrocarbon plume is elongate and orientated to the northeast. The shape and preferred orientation suggest that the physical properties of the soils are anisotropic, which is supported by analysis of the aquifer test data.

A sustained yield of slightly less than 0.25 gal/min could have been maintained in the pumped well. The specific capacity of the well was estimated to be less than 0.03 gal/min/ft. The transmissivity of the aquifer was estimated to average 350 gal/day/ft with a storage coefficient of 0.09. The fluid levels in observation wells within 25 ft of the pumped well were influenced during the test. The fluid level in a well 70 ft from the pumped well was only slightly affected. After the recovery test it was observed that intermittent pumping in the test well produced a significantly greater hydrocarbon to water ratio than by constant pumping.

### Solution

A recovery well system consisting of five 6 in diameter wells was installed in the vicinity of the test well. The test well was also utilized in the system. Recovery wells were spaced on centers 20 ft apart on the basis of the hydraulic properties obtained from the aquifer test, with an average depth of 30 ft. The wells will be pumped to approximately 15 ft below static level and allowed to recover within 10 ft of static before resumption of pumping. This will maintain a minimum drawdown of 10 ft and allow for intermittent pumping to obtain the optimum hydrocarbon to water ratio.

A recharge well system consisting of seven 4 in diameter wells was installed downgradient of the recovery wells. Two of the existing observation wells were utilized in the system. The wells are spaced on centers 20 ft apart with an average depth of 25 ft. The purpose of these wells is to form a hydraulic barrier by injecting water and thereby minimize downgradient migration of hydrocarbons.

The entire system will be observed for six months. Any modifications to the system or further corrective measures will be considered at that time.

### SUMMARY

The two cases of hydrocarbon contamination described in this paper, as well as those of previous publications, illustrate that several factors impact the approach to problem assessment and mitigative planning. These factors include: timing of leakage discovery, type and age of hydrocarbons, rate of contaminant migration, hydrogeological setting, general site layout, and proximity of adjacent utilities and structures to the contaminated area.

If the extent of hydrocarbon migration is such that the contaminant is an imminent threat to the environment, then the assessment is directed toward immediate mitigation (as illustrated by Case A). If product migration is slower there is often time for more

detailed evaluation and development of optimal mitigative measures (as in Case B).

The detailed *in-situ* testing utilized in Case B was not appropriate in Case A because of the shallow occurrence of the hydrocarbons in a heterogeneous setting. Also, the wells and excavations used in Case A were relatively inexpensive. Excavations to examine the occurrence of hydrocarbon were not practical for Case B. Likewise, the geophysical techniques utilized in Case A were not appropriate for Case B because of the extensive network of transfer pipes and electrical conduit in the area of interest.

The site conditions occasionally preclude the use of one or more mitigative measures. For example, in Case A the heterogeneity of the rock units and the necessity to minimize increases in groundwater levels did not permit the use of hydraulic barriers. The use of continuous trenches was unacceptable in Case B because of the depth and thickness of hydrocarbons, the presence of buried utilities, and the proximity of settlement-sensitive structures to the contaminated area.

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# AN APPROACH TO INVESTIGATING GROUNDWATER CONTAMINANT MOVEMENT IN BEDROCK AQUIFERS: CASE HISTORIES

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## INTRODUCTION

Many hydrogeologic investigations of hazardous waste sites have been focused on contamination in the unconsolidated materials above bedrock. A common investigative approach involves the installation of groundwater monitoring wells to a depth just below the water table. This approach has been utilized by investigators who accept the hypothesis that organic chemical contamination remains near the upper surface of an aquifer.

However, several studies have indicated that organic compounds readily migrate to the bottom of the overburden aquifer regardless of their specific gravity or solubility. Furthermore, shallow wells may be inappropriately located to take into account the configuration of the bedrock surface which may play an important role in channeling contamination.

With the discovery of thousands of hazardous waste sites across the United States, the need to assess bedrock aquifers and their effect on groundwater movement has taken on a new importance. In New England, where many drinking water wells are screened in bedrock, the bedrock aquifer cannot be ignored when investigating the impact of a hazardous waste site. When planning remedial measures for hazardous waste sites an adequate assessment of the bedrock aquifer is necessary to properly design a program that is capable of containing or removing contaminated groundwater.

Additionally, bedrock aquifers underlying proposed sites for hazardous waste treatment facilities or disposal areas should be properly assessed to determine the possible impact the site may have on groundwater resources. Therefore a thorough assessment of the entire groundwater regime is required when investigating hazardous waste sites or planning for future hazardous waste treatment or storage facilities.

This paper was written in response to the need to more adequately assess the relationships of bedrock aquifers to unconsolidated overburden aquifers. The approach presented here is based upon Ecology and Equipment, Inc.'s (E & E) field experience at more than 100 hazardous waste sites in England. This experience has shown that bedrock plays a significant role in the migration of contaminated groundwater.

The purpose of this paper is to illustrate the failure of some common approaches to investigating hazardous waste sites, to stress the importance of assessing the potential for bedrock contamination, to outline an approach for assessing the bedrock aquifer regime, and to present brief case histories which illustrate the successful employment of E & E's approach to investigating bedrock aquifer contamination.

## EVALUATION OF SOME COMMON APPROACHES TO GROUNDWATER MONITORING

Commonly, hydrogeologic investigations of hazardous waste sites have been conducted with little or no emphasis on assessing contaminant migration at depth and within bedrock or the hydraulic relationship between the bedrock and overburden aquifers. Monitoring wells are often screened at depths that are too shallow or

in unsuitable locations to detect contaminants within the lower portion of an aquifer system. Several reasons why wells are improperly installed or misplaced are discussed here.

In the past, monitoring well networks have been developed based on the theory that volatile organic compounds, some of which are less dense than water, remain at the top of the aquifer. However, E & E's field experience and analytical data, as well as those of other investigators,<sup>1</sup> indicate that contaminants are often forced lower into the aquifer as the contamination migrates from its source. Therefore shallow wells installed a distance from the source may not intersect a contaminant plume.

A common practice for installing wells has been to use driller's "refusal" as an approximation of the bedrock surface and the depth for the well. In glaciated terrain, refusal commonly represents till or boulders. Although till is frequently located at or near the bedrock surface, resistant tills can occur at any depth within the overburden aquifer. Boulders in excess of one meter in diameter are also common and may be mistaken for bedrock. Failure to identify the true bedrock surface may result in wells that are too shallow to monitor groundwater at the bedrock-overburden interface.

Wells are also installed at inadequate depths when the presence of till or a clay layer is assumed to act as an aquiclude that may inhibit the migration of contamination to underlying portions of the aquifer. Numerous studies<sup>1,2</sup> have shown that under the proper hydraulic conditions contamination can migrate through or around till and clay. Therefore deep or fully penetrating bedrock wells are needed when these geologic conditions exist in order to monitor contaminant movement at all levels of the aquifer.

Inadequate assessment of the bedrock surface configuration and structure (i.e., bedrock troughs or fractures that may channel contamination) has led to the installation of deep or bedrock wells in areas that are not in the proper location for detecting contamination. Finally the costs associated with the proper construction and placement of deep bedrock wells have often influenced investigators to install shallow overburden wells.

## APPROACH TO INVESTIGATING BEDROCK CONTAMINATION

Common approaches used in establishing a monitoring well network to investigate hazardous waste sites often do not accurately assess the hydrogeologic conditions that may influence contaminant behavior within or near the bedrock aquifer. For this reason, E & E has developed an approach which enables an assessment of characteristics of the bedrock and overburden aquifers which is cost-effective and allows a successful monitoring network to be developed and implemented.

Aspects of this approach that are discussed below involve the assessments of : 1) hydraulic relationships between the overburden and bedrock aquifers, 2) the hydraulic characteristics of the bedrock aquifer, 3) the structure and configuration of bedrock, 4) the natural groundwater quality in bedrock and 5) considerations for well installation designed to assess bedrock contamination.

### Hydraulic Relationship Between the Overburden and Bedrock Aquifers

In areas where an overburden aquifer overlies a bedrock aquifer, the hydraulic relationship between the two aquifer systems needs to be established. Three characteristics of the aquifer systems should be considered: 1) the hydraulic conductivity of the overburden aquifer mantling the bedrock, 2) the extent and thickness of the overburden aquifer and 3) groundwater flow directions between the bedrock and overburden aquifer systems.

The hydraulic conductivity of the overburden dictates the ease with which contaminants will migrate into bedrock. A deposit exhibiting low conductivity, such as glacial till or clays in contact with the bedrock surface, may impede or prohibit contaminant movement into bedrock.

The hydraulic conductivity(ies) of the deposit(s) at a site can be extrapolated from existing information or measured directly in the field. If the amount of hydrogeologic information available for a specific site is minimal, hydrogeologic data published by the USGS, state and local agencies can be reviewed prior to field work. Often these publications give general conductivity values, or values can be assigned from published figures for a particular deposit. Well logs of nearby existing wells or for wells installed to monitor a site can be reviewed to establish types of subsurface deposits. Approximate hydraulic conductivities can then be assigned to each deposit using published figures.

A more accurate determination of the hydraulic conductivity is made during field work by one or a combination of field permeability determinations, such as the slug test, the auger hole or piezometer method. If possible the conductivity of the formation that covers the bedrock should be determined. Conductivity values obtained from field measurements may be verified to some extent in the laboratory using permeability tests.

The lateral extent and thickness of the unconsolidated deposits covering the bedrock determine if contaminants in the unconsolidated aquifer are likely to move into the bedrock aquifer. Discontinuous or thin deposits will allow contaminants to reach bedrock, whereas deposits that are continuous and adequately thick throughout the area of groundwater contamination will likely prevent contaminant movement into bedrock.

The extent and relative thickness of deposits can be determined in many cases by a preliminary review of existing information concerning the study area, and then verified by field work. In the field, the extent and thickness of deposits are generally determined using geophysical methods such as seismic refraction and/or resistivity and direct methods such as soil borings/well installations.

Information generated from the preliminary literature review and field work is used to construct geologic cross-sections through the study area. The cross-sections can be used to predict the character and extent of the unconsolidated deposits.

Regardless of the hydraulic conductivity, and the extent and thickness of deposits lying on the bedrock, an interchange of contaminated groundwater between the unconsolidated and bedrock aquifers is not possible unless there is a net vertical downward component of groundwater flow between the two aquifer systems. Flow components are predicted prior to field work from a review of topographic maps and existing information.

### Hydraulic Characteristics of the Bedrock Aquifer

The hydraulic characteristics of the bedrock aquifer are determined to establish if the bedrock is water-bearing and capable of transmitting contaminants and also to predict the velocity with which contaminants will move through the bedrock. Hydraulic characteristics of the bedrock that need to be determined are the relative total porosity (primary, genetic and secondary) and hydraulic conductivity of the bedrock unit. Review of existing information will provide preliminary data and additional inferences concerning porosity and hydraulic conductivity values can be made by:

- Observing bedrock outcrops in the area of the site; noting bedrock type and frequency of fractures/faults in the bedrock

- Noting yields of bedrock wells in the vicinity of the study area
- Noting Rock Quality Designations (RQDs) measured during engineering studies in the vicinity of the study area

Values derived from such observations may at best be rough estimates since the rock types observed or those in which measurements were taken may not be continuous under the entire study area. More accurate assessments of bedrock porosity and hydraulic conductivity are determined in the field by measuring RQDs during well installation and performing permeability tests in monitoring wells installed and sealed in bedrock.

### Assessment of the Structure and Configuration of the Bedrock Aquifer

To insure the proper placement of bedrock monitoring wells, it is important to first access the bedrock surface configuration and structure. Bedrock wells which are placed without regard to these features may fail to intercept plume migration along fault zones or within bedrock troughs.

Both classical field techniques and more contemporary remote sensing techniques are used to assess bedrock structures and surface configuration. The methods include:

- A field observation and statistical evaluation of bedrock fractures, frequency and orientation in outcrops
- Fracture trace analysis and aerial photographic interpretation to determine predominant fault and fracture orientations
- Seismic refraction and electrical resistivity methods to determine depth and orientation of the bedrock overburden interface and the presence of clay or till layer within an overburden aquifer
- Ground penetrating radar to determine the presence or absence of boulders in the overburden at proposed well locations

### Assessment of Natural Groundwater Quality in Bedrock

Concentrations of naturally occurring inorganic compounds and metals within the overburden and bedrock aquifers must be assessed to understand what effect a hazardous waste site has had on the quality of the groundwater. Naturally-occurring organic compounds (other than methane) are rare except in areas where natural deposits of oil, gas or coal exist. The presence of organics in groundwater is therefore assumed to be derived from a source other than soil or bedrock in regions lacking fossil fuel deposits.

The primary source of inorganic compounds and metals is from bedrock. The amount of any given compound will depend on rock type, fault zones, ore deposits and degree of weathering. In New England, where many sulfide mineral deposits occur along major fault zones and in pegmatites, there may be naturally elevated concentrations of arsenic, antimony, cadmium, copper, lead and mercury in the groundwater. A preliminary literature search should provide information about an area's subsurface geology, faulting, existence of ore deposits and mineralogy of the rock types present.

Determination of the extent of faulting and fracturing (see Assessment of Bedrock Structure and Configuration) can give an indication of: 1) the extent to which groundwater may flow through the bedrock and thereby increase the weathering process, and 2) indicate those areas where enhanced heavy metal deposits may exist. The presence of these deposits can be assessed by field examination of bedrock outcrops and thin sectioning of rock samples from outcrops or well cores. Thin section analysis can also assist the investigator in determining the existence of major faulting if cataclasis is present.

Comparison of groundwater analyses from existing upgradient and downgradient off-site wells will provide data on the natural or background levels of inorganics and metals in a given area. When comparing analyses, it is important that the sampled wells be screened over the same depths and in the same rock types and geologic structures.

Analyses of groundwater from newly-installed monitoring wells must also be carefully evaluated. Recent E & E analyses of both new and old wells within similar rock types and geologic structures have shown higher concentrations (by 50 to 2000%) of the



trace elements and heavy metals in the newest wells. The increased levels in new wells may be attributed to the suspension of pulverized bedrock and overburden materials as a result of drilling. The use of hardened steel tools may have contributed to the increased concentration of such compounds as vanadium and iron.

### Well Installation for Assessing Bedrock Contamination

There is a wealth of information currently available on well installation procedures and techniques; therefore, an in-depth examination and review of existing procedures will not be discussed. The most critical aspects of well installations related to evaluating groundwater in bedrock will, however, be discussed here.

In designing a monitoring network that includes bedrock wells, the purpose of the bedrock wells will determine the type and method of construction of the well.

Various criteria for locating bedrock wells must be evaluated so that the objectives of the monitoring program can be met. These criteria should include, but not be limited to the following:

- The monitoring well network should insure detection of contaminants that may be migrating along the bedrock surface or in bedrock fractures. This can be accomplished by one or more wells installed within possible pathways such as bedrock troughs or fault zones. This requires prior knowledge of the bedrock surface configuration and structure to assess possible contaminant migration directions.
- The bedrock monitoring well network should allow the natural or background levels of inorganic compounds to be determined. A minimum of one well should be installed in the same rock type and geologic structure (i.e., fault zone) as where the contamination is.
- A minimum of one bedrock well, in conjunction with a co-located overburden well, is necessary to establish hydraulic head relationships between the bedrock and overburden aquifers, enabling vertical hydraulic gradients to be determined.
- Bedrock wells should be installed both within and out of major fracture zones to adequately assess the variability of bedrock hydraulic characteristics.

A variety of drilling methods can be employed when drilling to bedrock and subsequently into bedrock. Certain drilling considerations to take into account include:

- The utilization of driven casing rather than hollow stem augers enables the driller to telescope through boulders (after coring)
- A minimum of 10 ft of bedrock coring should be allowed to establish bedrock competency and rock type
- The drive casing should be advanced as far into bedrock as possible to prevent caving in of the cored borehole. A roller bit can be employed to assist in flushing out any bedrock materials that may have fallen into the hole.

Three types of bedrock wells or well systems are suggested (Fig. 1). Each well should incorporate the use of Schedule 80PVC well casing with threaded-flush joints to prevent bowing of the casing, to provide a smooth casing surface to alleviate problems when removing the drive casing and to eliminate the use of solvent joining compounds. Screens should have 0.010 in maximum slots to prevent silting and should be set at depths depicted in Fig. 1. Back-filling of the screen is accomplished by using Ottawa sand or a similar silica material with a grain size greater than 0.010 in. The annular space around the well casing should not be less than one in.

### CASE HISTORIES

The phased approach for assessing bedrock aquifer contamination has been successfully employed by E & E in their investigation of hazardous waste sites in New England. The extent to which the approach is utilized at any given site is determined by the quantity and quality of existing information and the complexity and size of the site.

Two case histories which illustrate E & E's overall approach and the effect of bedrock on contaminant migration are presented here. While each case history is purposefully brief, the discussions center on the use of E & E's approach, the lack of existing data to fully assess the problem and the effect of the bedrock aquifer in controlling contaminant migration.

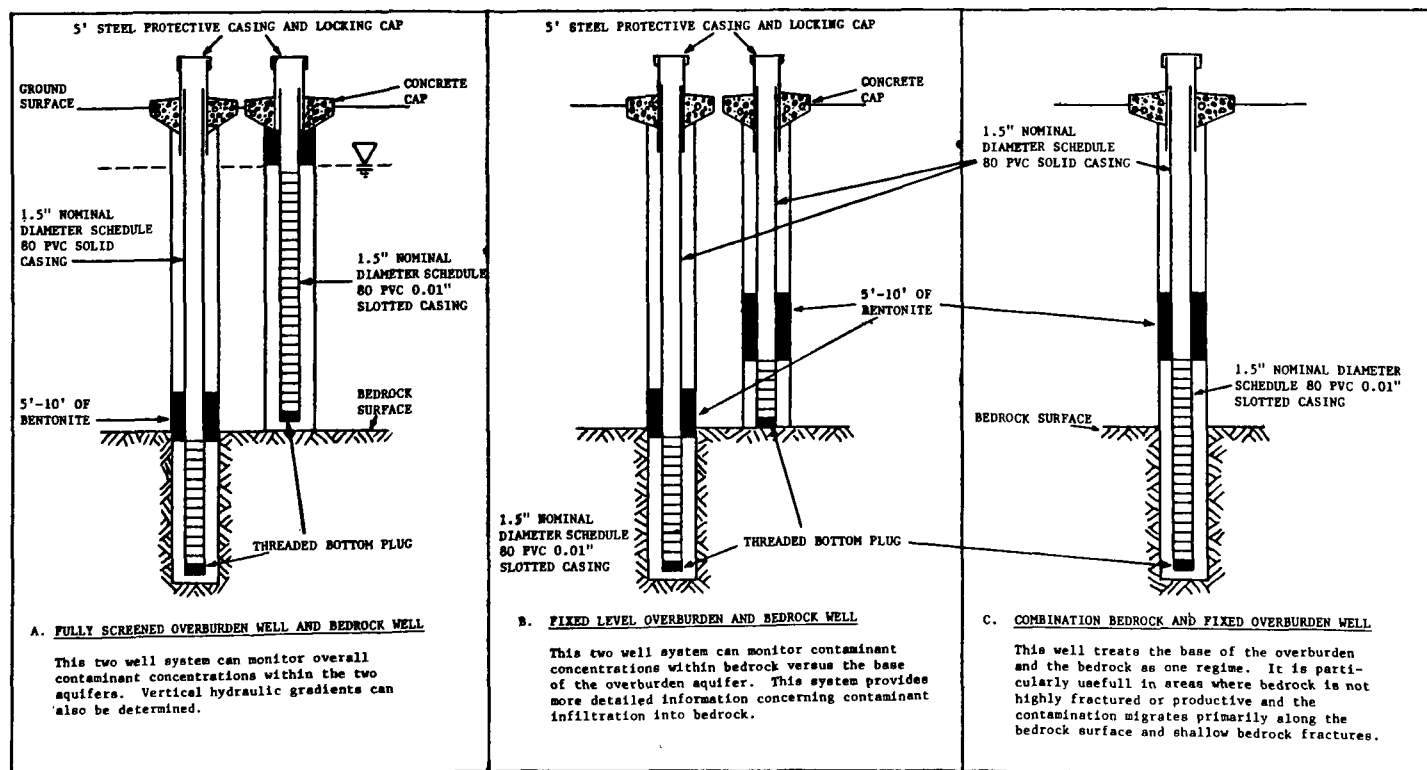


Figure 1.  
Monitoring Well Systems

## Case History I—Picillo Farm Site, Rhode Island

### Site History and Description

The Picillo Site, a former pig farm in Coventry, Rhode Island, operated as an illegal hazardous waste disposal site until 1977 when a fire resulted in the discovery of containers of various chemical wastes by the Rhode Island Department of Environmental Management.<sup>1</sup> Subsequent geophysical and excavation work revealed that approximately 10,000 containers of wastes were buried in four trenches on the site.

The disposal site consists of 7.5 acres of clear land surrounded by terrain that slopes to the north, west and south. A swamp located 1200 ft northwest of the disposal site is a major discharge area for surface and groundwater flowing from the site. Surface and groundwater flow from the swamp is toward the southwest. A stream which drains the swamp carries surface water to Whitford Pond which is an irrigation source for a cranberry bog one mile directly southwest of the disposal site (Fig. 2). Several miles to

the east of the site is the Quidnick Reservoir, which is not currently a source of drinking water. Private bedrock wells are located approximately one-half mile north of the site.

### Previous Investigation

Prior to E & E's involvement, the State of Rhode Island and USEPA, through several subcontractors, had installed a total of 30 groundwater monitoring wells on and around the disposal site. This initial work included well installation, bedrock coring, seismic refraction survey, field permeability tests, and sampling and analysis of soil, surface water and groundwater. The focus was upon areas immediately adjacent to the disposal site and as such did not address the impact the site might have on environmentally sensitive areas nearby. The locations and depths of monitoring wells installed during the initial work made it impossible to assess the extent of contaminant movement.

### Hydrogeologic Investigation

The major objective of E & E's investigation was to determine the possible existence of a hydraulic connection between the disposal site. Quidnick Reservoir, the cranberry irrigation pond and private wells. The approach included:

- Establishment of major plume directions using existing wells
- A preliminary evaluation of bedrock characteristics
- Field assessment of bedrock characteristics
- Installation of monitoring wells
- Sampling and analysis

Analytical data from existing monitoring wells were incomplete and an additional sampling program involving all existing wells was required. All samples were analyzed on a portable gas chromatograph and several key samples were analyzed for USEPA priority pollutants.

The analyses confirmed the presence of contamination in groundwater and defined the major contaminant plume directions, one of which was toward the swamp. A seismic study was then conducted to define the bedrock surface configuration and a fracture pattern analysis to determine the bedrock structure. From these data a bedrock surface map (Fig. 3) was prepared which in-

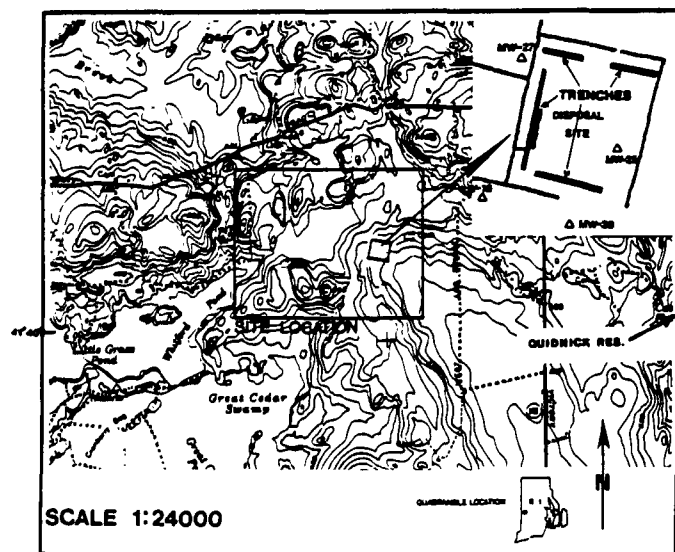


Figure 2.  
Location Map of the Picillo Site

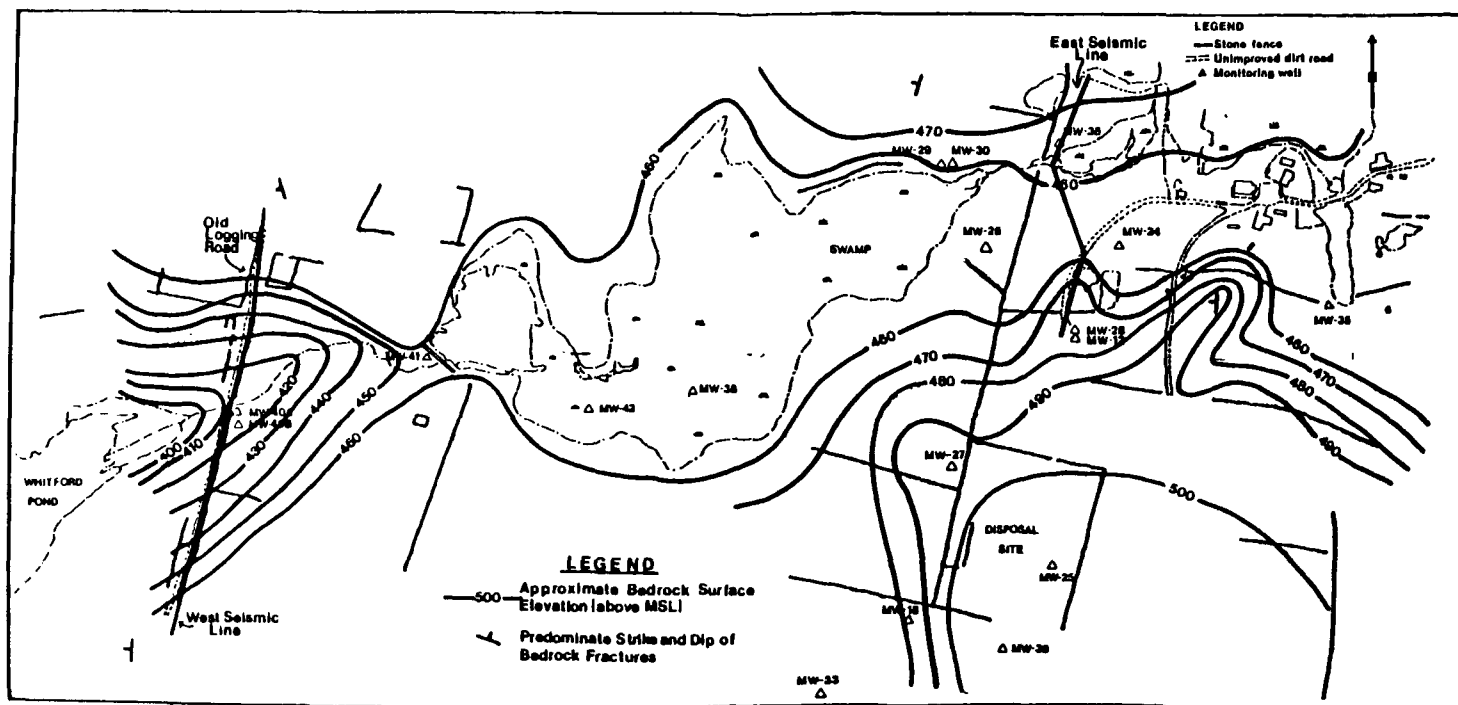


Figure 3.  
Bedrock Geology

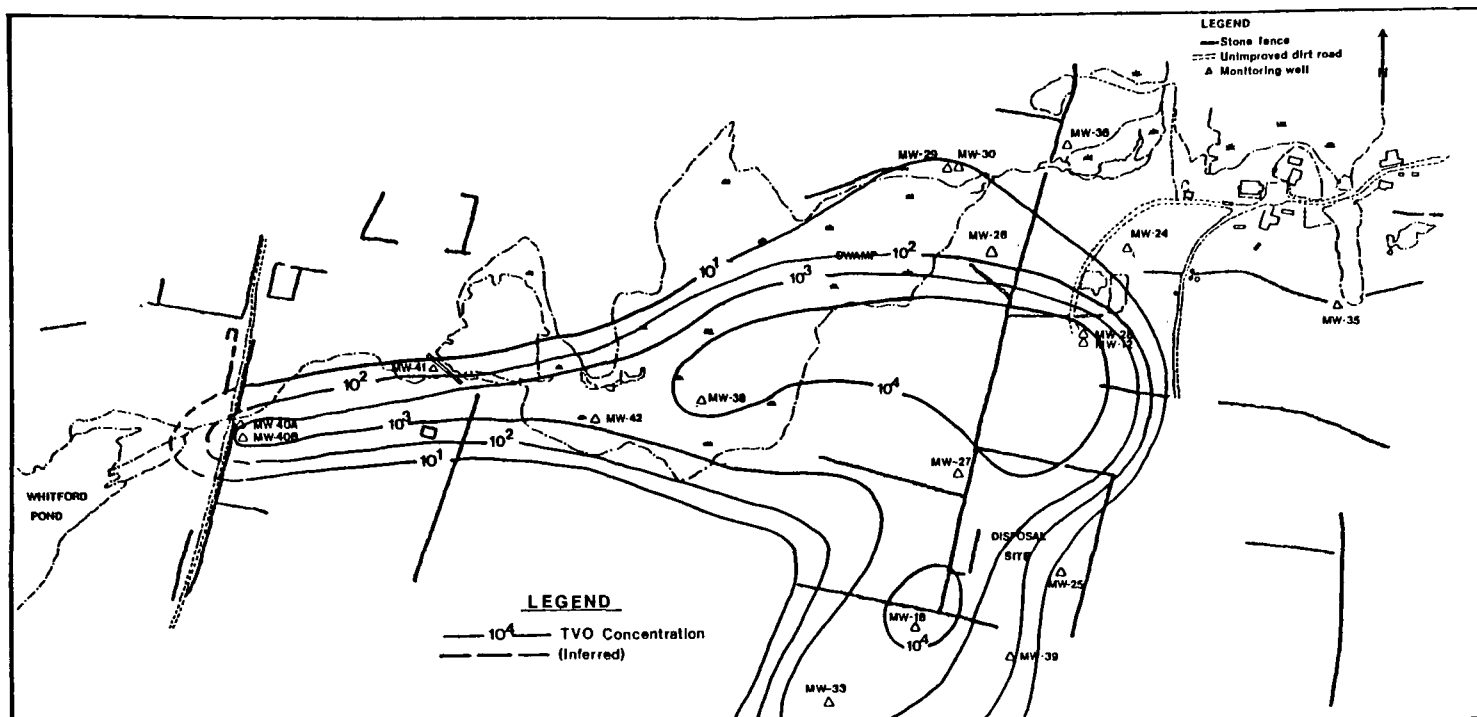


Figure 4.  
Concentration of Total Volatile Organics (ppb)

indicated that an east-west-trending bedrock trough existed beneath the swamp and that bedrock fractures strike north-south with a moderate dip toward the west.

Nine monitoring wells were then installed (Fig. 3) in overburden and bedrock to assess the full extent of contamination and possible migration through the bedrock trough and fractures. An additional sampling and analysis round was performed to include the newly-installed wells.

Hydrologic and analytical data indicated that major contaminant plumes originating from the disposal site were moving in two directions through the overburden aquifer. Contaminants from the disposal site migrated predominantly in a fan-shaped configuration northwestward toward the meadow and swamp (Fig. 4). A portion of the contamination discharged into the swamp, and the balance migrated westward in and under the swamp, toward Whitford Pond.

Hydrologic and analytical data generated from monitoring well installations, existing data, and groundwater sampling indicated a slight vertical downward component of groundwater flow from the overburden to the bedrock aquifer in recharge areas, and vice versa in discharge areas. However, vertical interflow between aquifers was believed to be minimal when compared with lateral flow, since lateral hydraulic gradients exceeded vertical gradients. Therefore, the lateral flow in the bedrock aquifer was found to be in the same general direction as flow in the overburden aquifer.

Based on bedrock data gathered during field studies and analytical data generated from the sampling efforts, E & E concluded that the major contaminant flow direction in the bedrock aquifer is from east to west and is controlled by bedrock structure (orientation of fractures and slope of bedrock trough).

As a result of the comprehensive assessment of the bedrock as well as the overburden aquifer performed during this investigation, E & E concluded that Whitford Pond and the cranberry bogs are in danger of being contaminated. Contamination was not detected nor is expected to reach Quindnick Reservoir and the residential bedrock wells in the vicinity of the disposal site.

#### Case History II—Woburn, Massachusetts Site

##### Site History

Potentially hazardous materials have been generated, stored

and disposed of in the City of Woburn, Massachusetts for over 120 years.<sup>4</sup> These activities have contaminated a large and productive aquifer that has supplied as many as 100 industrial, private and municipal wells.

In 1979 two of Woburn's municipal drinking water wells, located within this aquifer, were closed when significant amounts of chlorinated organic solvents were detected in the water. An investigation was required to assess the full extent of contamination and the sources of contamination so that an evaluation of the impact on human health and the environment could be made.

##### Site Description

The study area (Fig. 5), approximately 10 mi<sup>2</sup>, includes most of East and North Woburn and is centered within the Aberjona River Watershed. The Aberjona River, which flows toward the south, forms a moderate north-south topographic valley along the axis of the study area. The valley forms a productive aquifer where two of Woburn's drinking water wells were located. The water from these wells serviced as many as 20,000 residents.

The study area also incorporates several large industrial complexes and is the region in which many tanning and chemical manufacturing firms once existed. Presently high technology firms dominate the region in addition to food service, trucking, barrel cleaning, tanning and plastics manufacturing industries.

##### Previous Investigations

Several investigations have been performed within the study area concerning the hydrologic characteristics of the aquifer and the hazardous waste problems by the Commonwealth of Massachusetts, USGS and USEPA subcontractors. Emphasis was placed on surface deposits of heavy metals that typically do not migrate in groundwater and on surface water contamination where volatile organics for the most part will rapidly volatilize. Preliminary groundwater evaluations utilized water level readings from different types of wells taken during different seasons of different years.

The delineation of bedrock aquifers and overburden aquifers was never fully addressed. The lack of sufficient data to properly assess the contamination problem required further hydrogeologic investigations.

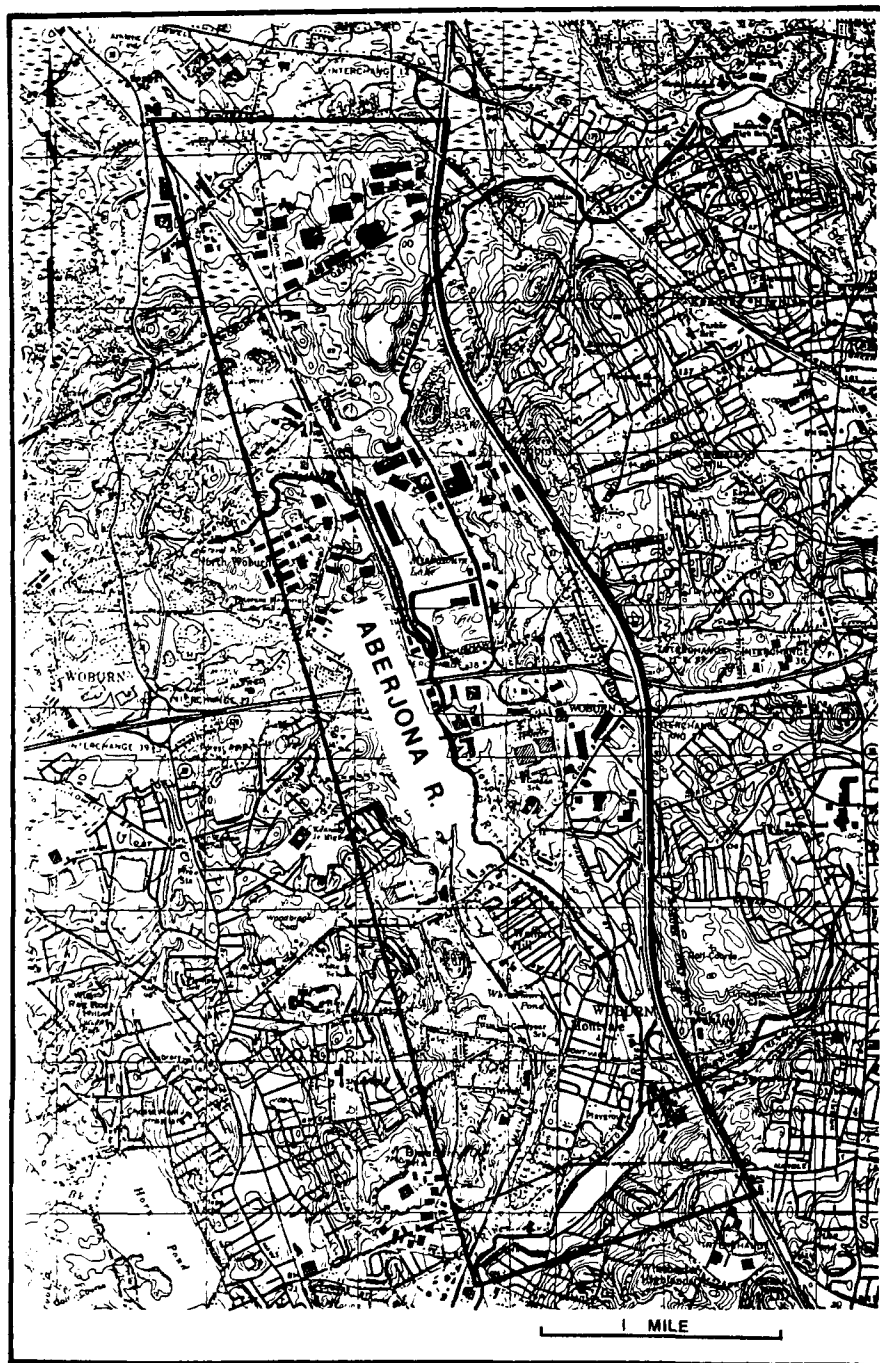


Figure 5.

Locus Map—North and East Woburn, Ma. Study Area Base Map from USGS Topographic Sheets—Wilmington, Reading, Lexington and Boston North Quadrangles

### Hydrogeologic Investigation

The presence of chlorinated organic solvents within well water from Woburn's municipal wells indicated that a contaminant plume existed within and was migrating through the aquifer. E & E followed the approach outlined below to determine the extent of that contamination, to identify possible sources and to provide data useful for evaluating remedial options:

- Review existing data
- Determine extent of contamination from existing wells
- Assess geologic materials of the aquifer including bedrock characteristics that may affect flow
- Install monitoring wells
- Sampling and Analysis

All available information regarding the geology and hydrology of the study area was reviewed including driller's logs for 123 wells. These data indicated that the Aberjona River Valley was underlain by a complex interstratified mixture of glacial deposits within a deep buried bedrock valley. In many places till or other suitable confining materials did not exist suggesting that a hydraulic connection between the overburden and bedrock aquifers may extend over wide areas.

Thirty-two accessible existing wells within the study area were sampled and analyzed for USEPA priority pollutants. There were over 60 present in the groundwater. Some of the wells screened in bedrock or near the bedrock surface were contaminated with chlorinated volatile organics indicating that the bedrock aquifer had been affected.

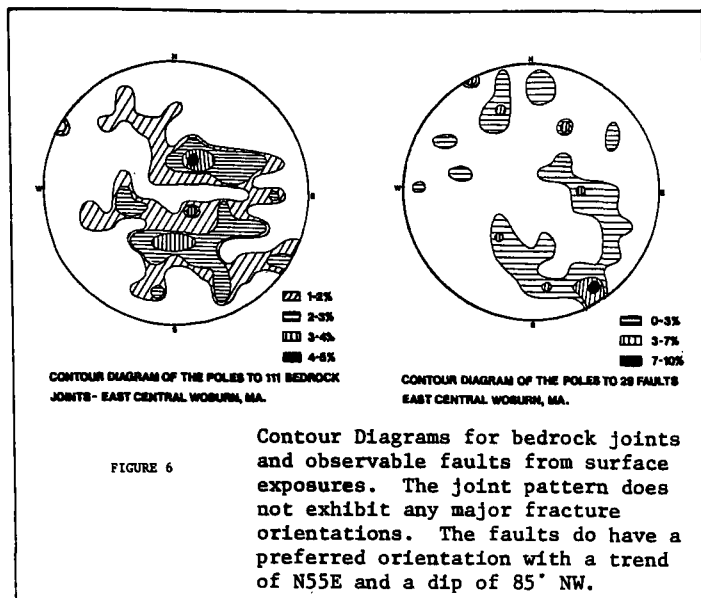


Figure 6.

Contour Diagrams for bedrock joints and observable faults from surface exposures. The joint pattern does not exhibit any major fracture orientations. The faults do have a preferred orientation with a trend of N55E and a dip of 85° NW.

Because contamination existed within bedrock an accurate map of the bedrock surface topography and its structure was required to evaluate contamination migration. A seismic survey was performed to gather the necessary depth to bedrock data, and defined regions within the bedrock that exhibited extensive fracturing. Field analysis of bedrock outcrops including fracture pattern analysis of faults and joints indicated preferred directions of these fractures (Fig. 6).

Using the available bedrock and contamination data 22 monitoring wells were installed and fully screened both in overburden and bedrock. Bedrock cores examined for fracture frequency and petrographically for evidence of faulting confirmed the existence of several fault zones and minor offsetting faults. Soil sampling during drilling also indicated that most of the volatile organic contamination existed near the bottom of the overburden aquifer, even for compounds that are less dense than water.

A second round of sampling and analysis on groundwater from both newly installed wells and existing wells provided a more accurate extent of contamination. When the data for total volatile organics was plotted as an isoconcentration map, a pattern of contamination emerged that is consistent with the hydrogeologic data

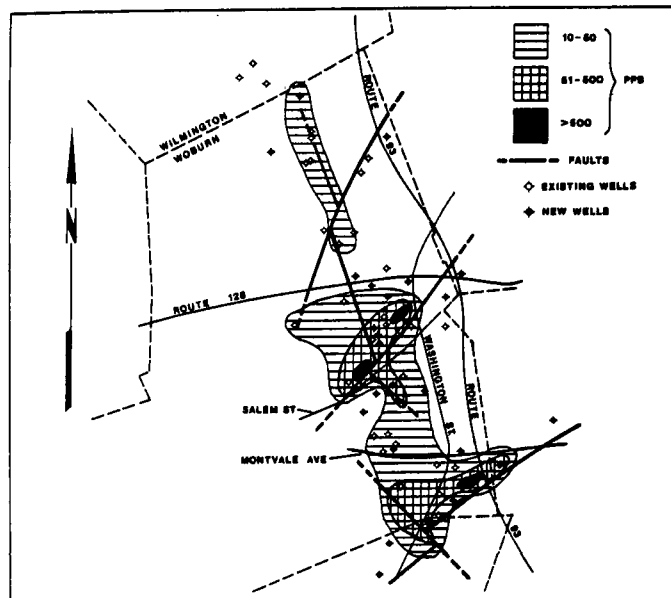


Figure 7.

Areal Distribution of Trichloroethylene in Woburn

(Fig. 7). In fact, many of the known and suspected faults of the region closely follow the pattern of contaminant migration. This indicates that the faulted bedrock can play a significant role in controlling the movement of contamination. The presence of most of the contamination near the base of the aquifer shows that migration will probably be along bedrock troughs developed by faults and/or that migration may be through the bedrock fractures themselves.

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# EVALUATION OF REMEDIAL ACTION ALTERNATIVES— DEMONSTRATION/APPLICATION OF GROUNDWATER MODELING TECHNOLOGY

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## INTRODUCTION

The LaBounty landfill was an active chemical waste disposal site from 1953 to 1977. During this period, it is estimated that over 181,000 m<sup>3</sup> of chemical waste were disposed in this 4.86 ha site located in the flood plain of the Cedar River in Charles City, Iowa. Compounds that are known to have been dumped in significant quantities include arsenic, orthonitroaniline (ONA), 1,1,2-Trichloroethane (TCE), phenols, and nitrobenzene. Disposal ceased in December 1977 following the discovery that wastes from the site were entering the river. Since that discovery, the LaBounty landfill has been under intensive investigation.

One aspect of these investigations was the groundwater modeling effort described in this paper. The overall objective of this modeling effort was to demonstrate the use of modeling technology for evaluating the effectiveness of existing and proposed remedial action alternatives at the site. The primary emphasis of the project was on technology demonstration which included:

- Modeling of the groundwater system and prediction of the movement of contaminants
- Development of criteria to determine which water sources impacted by the site would require remedial action and the level of action necessary to insure risks are at acceptable risk levels
- The evaluation of the costs and effectiveness of various remedial action alternatives

## DESCRIPTION OF THE STUDY AREA

The LaBounty landfill site is located on the floodplain of the Cedar River just south of Charles City, Iowa. Charles City is in Floyd County situated in northeastern Iowa. The site sits on alluvial sand and gravel overlying a bedrock formation (Cedar Valley formation). Glacial tills have been found along the west side of the site above the Cedar Valley formation. The Cedar Valley formation can be divided into upper and lower units separated by a shale layer which acts as a confining layer at the site.<sup>1,2</sup>

The hydrology of the LaBounty site is somewhat complex in that regional potential contours for the upper Cedar Valley aquifer and the shallow alluvial groundwater system indicate that the river acts as the major discharge area. In order to accurately represent the site with a model it is necessary to simulate this vertical movement.

## MODEL DEVELOPMENT

Two computer codes were used to model the LaBounty landfill study area: FE3DGW<sup>3</sup> and CFEST.<sup>4</sup> The FE3DGW code is a three-dimensional, finite-element, groundwater flow code that can be used to predict ground water potentials, water flow paths and travel times. The CFEST (Coupled Flow, Energy, and Solute Transport) code is an extension of FE3DGW that predicts the movement of contaminants with the convective dispersion equation for contaminant transport.

In order to better characterize the groundwater system at the LaBounty site, a two-stage modeling approach was used. The first stage consisted of developing a coarse grid regional hydrologic flow

model, and the second stage consisted of developing a flow and contaminant transport model for the immediate vicinity of the LaBounty site. The purpose of the regional model was to establish hydrologic boundary conditions for the local model.

## Regional Flow Model Implementation

The coarse grid regional model covers an area of 6.3 km by 4.8 km. The regional boundaries were chosen so that the equal potential contours could be assumed nearly vertical with depth, or at a distance far enough away that errors in the assigned potentials did not influence local model boundary conditions.

The finite element grid pattern used to represent the large region is shown in Fig. 1. The local model finite element grid boundaries superimpose onto the regional element pattern at the site.

Five different material types (layers) were simulated in the regional model. The lower layers, upper and lower bedrock and shale, are present over the entire model region. The alluvial layer exists along the Cedar River from a point north of Charles City southeast to the model boundary (Fig. 1). A combined fill and till layer was simulated in the area of the LaBounty Site. The structural top and ground-water potential for the layers were taken from data reported by Munter's paper.<sup>2</sup> Hydraulic conductivities ( $K$ ) of the layers were initially set at average values obtained from several sources<sup>1,2,5,6,7</sup> and the vertical to horizontal permeability ratio ( $K_z/K_{xy}$ ) was set at 0.1.

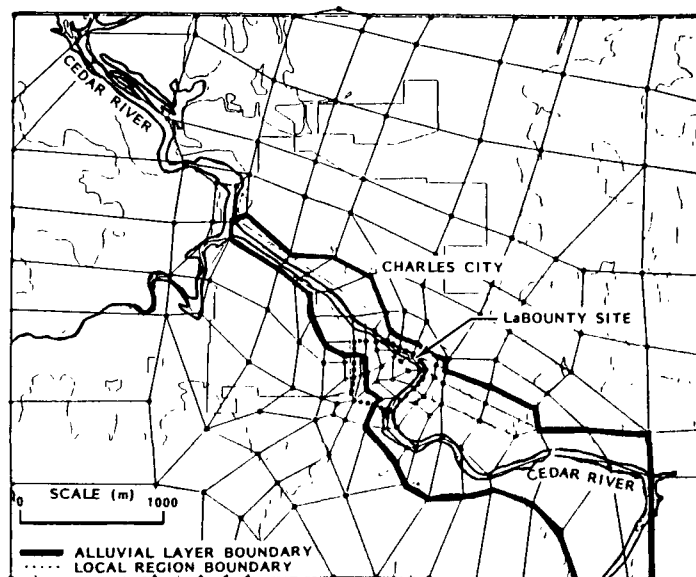


Figure 1.  
Large Region Model Finite Element Grid

Initially it was assumed that 10% of the total precipitation of 900 mm<sup>a</sup> recharged the groundwater system. This was the only source of recharge considered.

### Local Flow Model Implementation

The local model covers the area just in the immediate vicinity of the LaBounty site (Fig. 2) and is 685 m on a side. The Cedar River forms the boundary to the north, east, and south while the western boundary was arbitrarily set to the west of the fill material.

The finite element grid pattern used to represent the small region is also shown in Fig. 2. The same materials simulated in the large region were simulated in the small region except that the fill and till were modeled separately.

The structural top and bottom and potentiometric surfaces for the shale and bedrock layers were defined the same as in the regional model. More detailed structure and potential surfaces were prepared for the local model alluvium, fill and till layers from data obtained by Munter.<sup>2</sup>

Stage data for the Cedar River were extrapolated to obtain held river elevations along the model boundary. The same permeabilities and recharge rate used in the regional model were initially used in the local model.

### Local Contaminant Transport Model Implementation

The CFEST code was used to simulate the movement of arsenic from the landfill to the Cedar River in the local model region and to test the effectiveness of the proposed remedial action alternatives in controlling the arsenic plume. Since the groundwater flow portion of CFEST is identical to FE3DGW, the final calibrated FE3DGW data set was used directly in CFEST to predict groundwater flow. The additional inputs required by the CFEST code to simulate contaminant transport were longitudinal ( $D_L$ ) and transverse ( $D_T$ ) dispersivity and initial contaminant concentration levels. Initially  $D_L$  and  $D_T$  were set at 30.0 m and 0.5 m, respectively. Arsenic was chosen for use in the calibration and remedial action simulations because it has been extensively monitored and its source is fairly uniformly distributed over the area of the fill material.

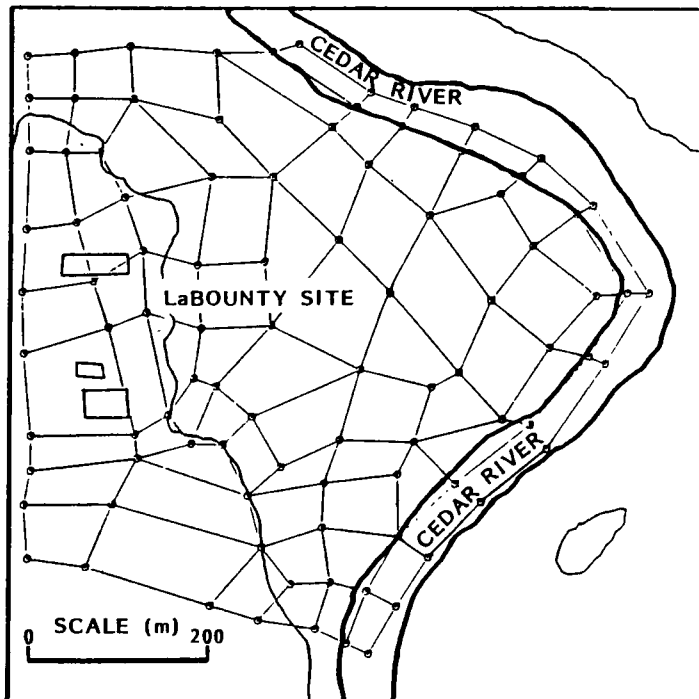


Figure 2.  
Local Groundwater Flow Model Finite Element Grid

Arsenic probably enters the groundwater flow system from two sources: 1) precipitation infiltrating through the fill material, and 2) leaching due to fill material being below the water table. The location of the saturated portion of the bill was determined from the literature<sup>2,6</sup> to be in two places (Fig. 3). For modeling purposes these two sources were simulated by holding the downgradient surface nodes of the saturated fill layer at an arsenic concentration of 500 mg/l. The 500 mg/l concentration is based on the estimates of the arsenic solubility. Water infiltrating through the cap was also assigned an arsenic concentration of 500 mg/l.

### MODEL CALIBRATION

The flow model calibration process consisted of matching observed potentials with model predicted potentials for both the regional and local models. Calibration was accomplished by first calibrating the regional model and then testing the local model with a consistent set of data. This alternating process was carried out until a satisfactory agreement between measured and model-predicted heads was achieved in both models.

The final input parameters obtained for the local model were then used in the contaminant transport model. These parameters were not changed in the contaminant transport calibration process. Parameters related to contaminant transport were adjusted to obtain a reasonable match between field-measured and model-predicted contaminant concentrations.

### Flow Model Calibration

The parameters adjusted in the flow model calibration process were the hydraulic conductivities ( $K$ ), the ratio of vertical to horizontal hydraulic conductivities ( $K_z/K_x$ ), the specific storage, and the rate of recharge. After several calibration runs, a good match was achieved between measured and model-predicted potentials for both the regional and local models. The final calibrated hydraulic conductivities and storages used in the flow models are listed in Table 1. More detailed recharge calculations estimated that about 14% of the precipitation (126 mm/yr) reached the ground water.

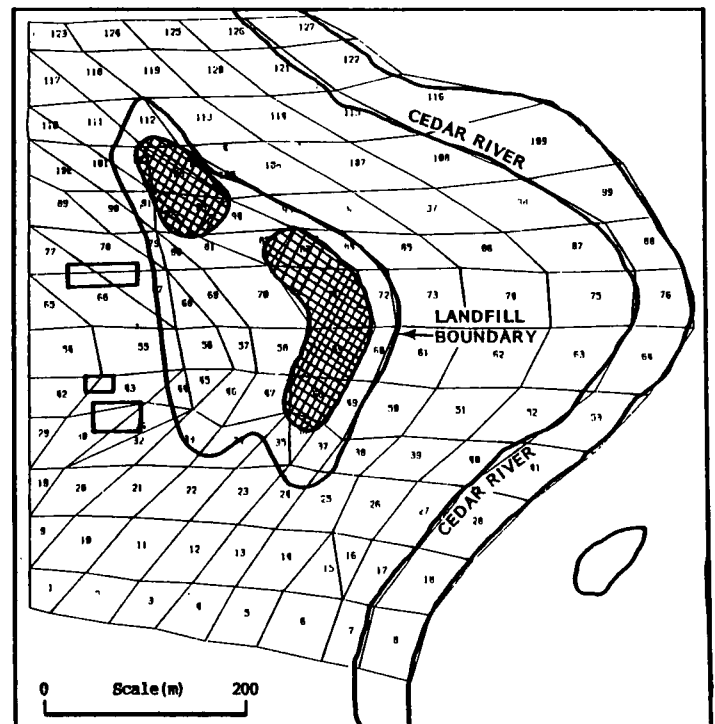


Figure 3.  
Contaminant Transport Model Finite Element Grid. Cross-hatched area indicates area determined to be below the water table



**Table 1.**  
**Input Values Used in the Final Calibrated Flow Models**

Layer (Small)	Material	K* (m/day)	Specific Storage (1/m)	K <sub>y</sub> /K <sub>x</sub> Ratio
1*	Fill	0.5	0.0025	0.1
2	Aluvium	10 and 2	0.01	0.1
3†	Till	$5 \times 10^{-4}$	0.0025	0.1
4	Upper Cedar Valley	2.0 and 4.0	$10^{-4}$	0.1
5	Shale	2.0 and $5 \times 10^{-3}$	$10^{-4}$	0.1
6	Lower Cedar Valley	2.0	$10^{-4}$	0.1

\*Where the two values of K are given, the first number listed covered the largest percentage of the total area covered by that material.

†The fill and till layers were combined into one layer in the regional model with a K of  $10^{-3}$  m/day.

### Contaminant Transport Model Calibration

One of the first changes made was to change the node and element grid to allow for a more accurate description of the location of the arsenic source and better represent the spread of the resulting arsenic plume. The finite element grid used in all subsequent calibration runs and in the remedial action cases is shown in Fig. 3.

Different values of longitudinal and transverse dispersivity were tested in order to match model-predicted with measured arsenic concentration levels. The results of these test runs indicated that longitudinal and transverse dispersivities of 5.0 m and 0.5 m, respectively, gave the best results. The initial concentration level for arsenic of 500 mg/l was not changed in the calibration process.

The last step in the calibration process was to determine the location of the arsenic source.<sup>3</sup> Arsenic could enter the flow system from either infiltration alone, or a combination of infiltration and groundwater leaching where fill material is thought to be below the water table. Both cases were tested by comparing model-predicted arsenic concentrations and river loading quantities against field-measured levels.

After running both cases for 6000 days (16.4 yrs), it became apparent that the case of infiltration alone would never achieve the arsenic levels that have been measured at the site. The results indicate that part of the fill material must indeed be below the water table and that the majority of the contaminant transport is originating in the saturated groundwater system and not in the unsaturated flow system as a result of infiltration.

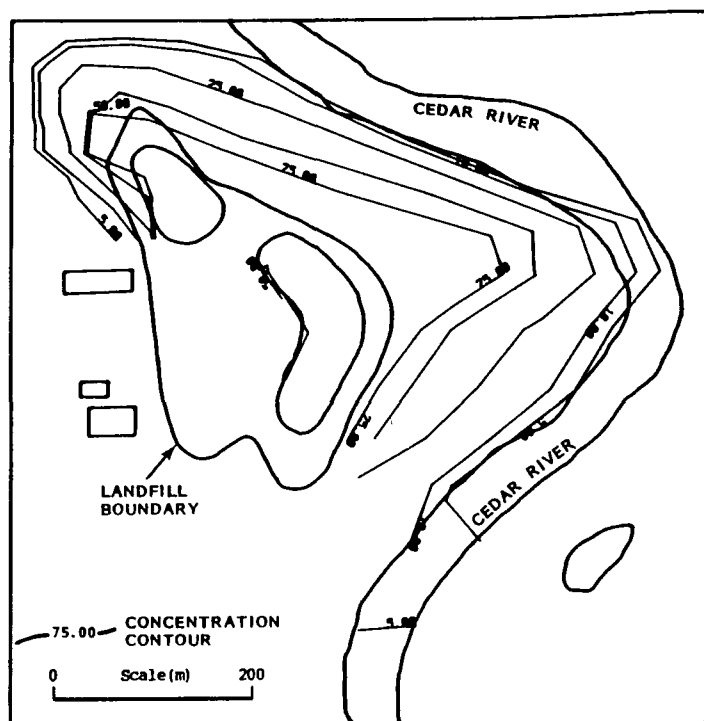
Based on these findings, the final calibrated model, hereafter referred to as the base case, included both sources of arsenic, infiltration and groundwater leaching. A contour map of the base case arsenic concentrations after 6000 days (near equilibrium) is shown in Fig. 4. This final calibrated contaminant transport model base case became the initial condition from which all the remedial action cases were initiated.

The final calibrated transport model predicted arsenic mass outflow rate to the river was 25.2 kg/day. The average mass outflow rate as measured by the monitoring system at the site is 22.7 kg/day.

### ASSESSMENT OF REMEDIAL ACTION ALTERNATIVES

Seven remedial action alternatives were identified for potential application to the LaBounty landfill site and were modeled with the CFEST model; clay cap, upgradient cut-off wall, downgradient cut off wall, limited excavation, limited bottom lining, stabilization, and pump and treat. The clay cap alternative has already been implemented at the site.

Contaminant transport model parameters were adjusted to simulate arsenic migration to the river for each alternative. The alternatives were assessed by first quantifying their effectiveness on reducing contaminant concentrations and Cedar River loading rates.



**Figure 4.**  
**Arsenic Concentrations (mg/l) at the Top of the Alluvium for the Base Case of Combined Infiltration and Disposal Below the Water Table**

These results were compared with the results for the clay cap alternative to obtain a measure of effectiveness.

The next step was to estimate the capital and annual operating and maintenance costs associated with each alternative. Given the effectiveness and cost, the final step was to make a cost-effectiveness comparison of the alternatives.

The base case, as discussed earlier, was run for 6000 days. Each remedial action case was run for an additional 4500 days beginning at the end of the 6000-day period.

#### Clay Cap

The clay cap alternative was modeled by reducing the infiltration rate by a factor of 100 in the area of the cap. The magnitude of the decrease was estimated using a simple compartmental model and a permeability for clay of  $3 \times 10^{-5}$  m/day. The rate of arsenic injection from infiltration was also reduced by a factor of 100 to 0.08 kg/day.

The results of this run indicated a continued but slight rise in predicted arsenic loading of the Cedar River to 27.5 kg/day after 4500 days, again illustrating that the portion of the waste disposed below the water table is the major source of the contamination problem at LaBounty. The clay cap was assumed to be in place for simulation of the remaining six remedial action alternatives.

#### Upgradient Cut-Off Wall

The objective of the upgradient cut-off wall is to reroute incoming ground water such that it bypasses waste contaminated soil. This can only work if the wall extends downward to an impermeable layer or incorporates some means of transport to carry off water mounded behind the wall. Since the dolomite base rock at Charles City is transmissive, the latter would be required. For the purposes of this evaluation, it was assumed that a subsurface drain is constructed upgradient from the cut-off wall to carry uncontaminated water away from the site.

The effectiveness of the upgradient cut-off wall was simulated by introducing a line of elements with low permeability upgradient of the landfill (Fig. 5). The upstream set of surface nodes along the low permeability cut-off wall were treated as held potential boundary nodes to simulate the upgradient drain. The flux to these held nodes was calculated to determine the required capacity of the subsurface drain associated with this alternative.

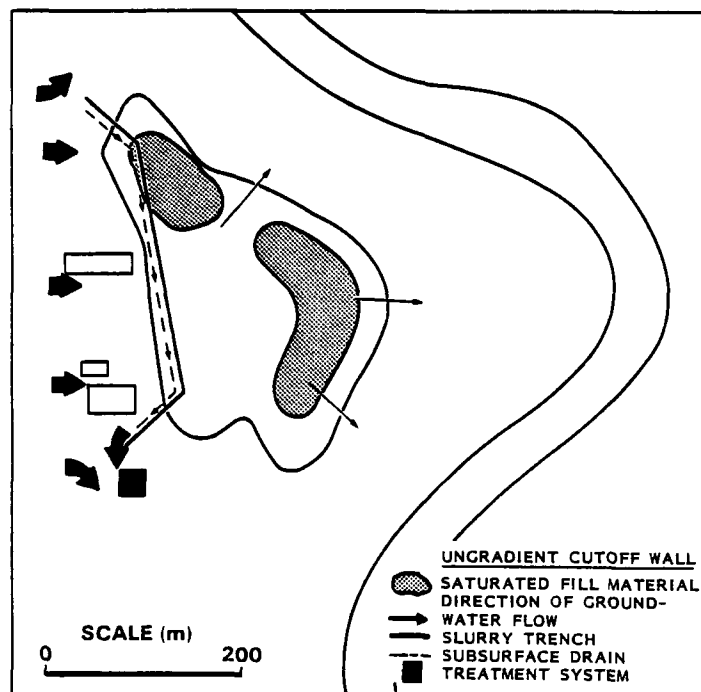


Figure 5.  
Upgradient Cut-Off Wall Remedial Action Alternative

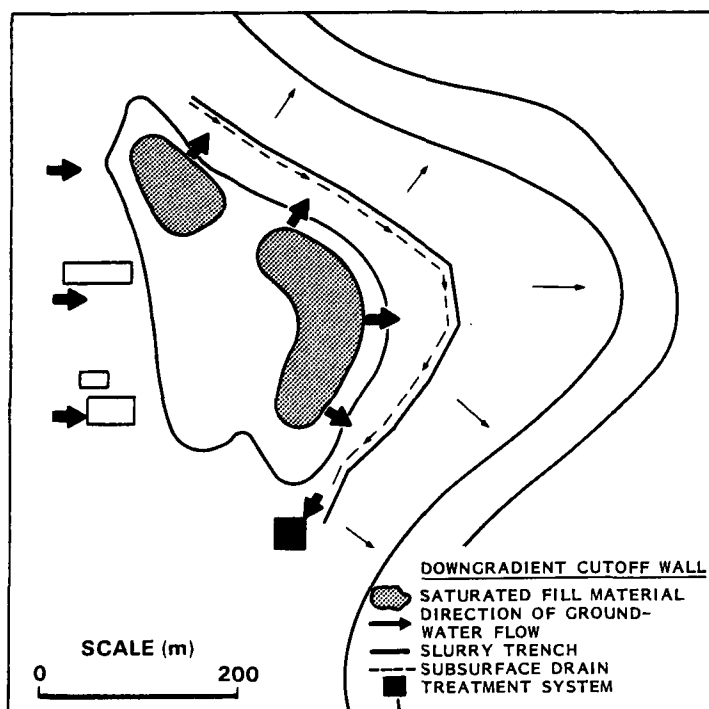


Figure 6.  
Downgradient Cut-Off Wall Remedial Action Alternative

The results of this analysis indicate that new equilibrium is reached in about 5 years with Cedar River loading rate reduced to 14.9 kg/day after 4500 days.

#### Downgradient Cut-Off Wall

The downgradient cut-off wall is intended to intercept contaminated groundwater and then route it via drains for treatment. The effectiveness of the downgradient cut-off wall was simulated in the model with a line of impermeable elements downgradient from the site (Fig. 6). The upstream set of surface nodes formed the simulated drain and were treated as a held potential outflow boundary. The flux to these nodes and arsenic concentration levels were predicted to determine the capacity of the subsurface drain and the treatment facility.

Results of this simulation indicate that new equilibrium river loading rates were achieved after approximately 3 years, 2 years faster than for the upgradient case. The new Cedar River loading rate predicted at the end of 4500 days was 7.66 kg/day.

#### Limited Excavation

The intent of the limited excavation approach is to remove those portions of the waste below the water table and to backfill with clean material.

Simulation of the limited excavation case with the model involved removing the source term associated with wastes disposed below the water table and changing the permeability in the area where the fill material was removed to that of the alluvium. The approximate size of the areas below the water table is shown in Fig. 3.

Results of this simulation indicate that this alternative provides a more delayed response in terms of river loading rates but that with time, much lower arrival rates could possibly be achieved. Model results indicated that after 4500 days predicted Cedar River loading has decreased to 8.0 kg/day.

#### Limited Bottom Lining and Stabilization

These two approaches are very similar in that they are both isolation techniques, either through the use of a liner or fixation method. Only those portions of the waste below the water table would be lined or stabilized. Presumably, this would reduce water flux and hence minimize further contributions from these portions of the landfill to the overall contaminant plume. Stabilization presents a challenge to current technology since *in situ* fixation has not been perfected and may not be technically feasible at the La-Bounty landfill. Both of these alternatives were modeled in an identical manner.

The total source mass of waste remained the same as the base case but the leach rate was reduced. This was simulated in the model by changing the permeability in the saturated fill area to that of a clay ( $10^{-5}$  m/day).

The results for these alternatives are very similar to those of the limited excavation alternative. As with limited excavation, the reduction in Cedar River loading is more gradual but it has the possibility of eventually reaching much lower river loading rates. After 4500 days a Cedar River loading of 8.14 kg/day was predicted.

#### Pump and Treat

In this isolation method, removal is accomplished through use of a series of withdrawal wells (Fig. 7). The water is subsequently treated to eliminate contaminants and either discharged back to the river or reinjected to assist in directing the contaminated plume toward the wells.

Pumping rates were estimated at 1806 m<sup>3</sup>/day. As with the downgradient cut-off wall, predicted concentrations for treatment during the first year are higher (71 mg/l) but soon levels off at about 34 mg/l. Predicted Cedar River loading rates have pretty much equilibrated after 5 years and were predicted to reach 10.12 kg/day after 4500 days.

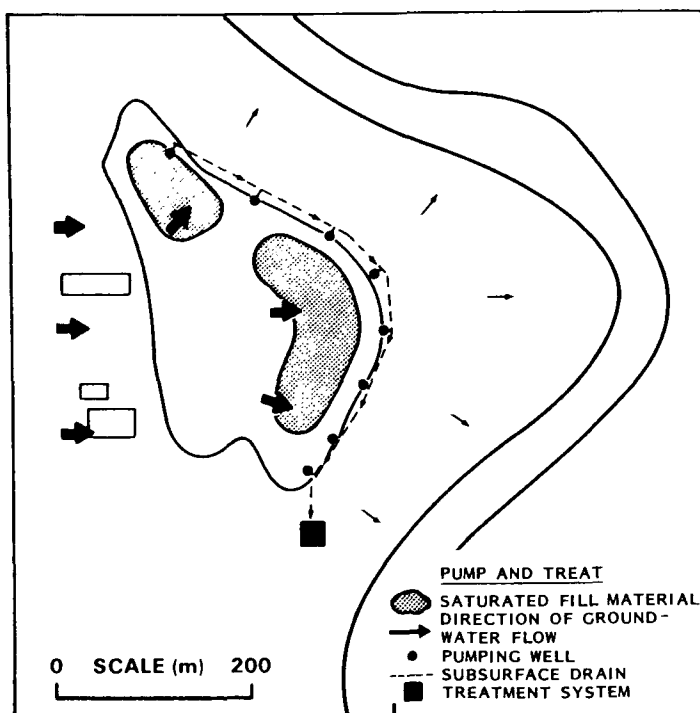


Figure 7.

Pump and Treat Remedial Action Alternative

The capital cost and annual operating cost for all the alternatives are given in Table 2. For all cases, these costs should be considered only as rough estimates, since they are based on preliminary conceptual designs for each alternative and they do not reflect local cost differences.

## DISCUSSION

A comparison of arsenic mass outflow rates to the river for the base case and the seven remedial action alternatives as predicted by the model is shown in Fig. 8. The contaminant transport model very clearly indicated that the major source of groundwater con-

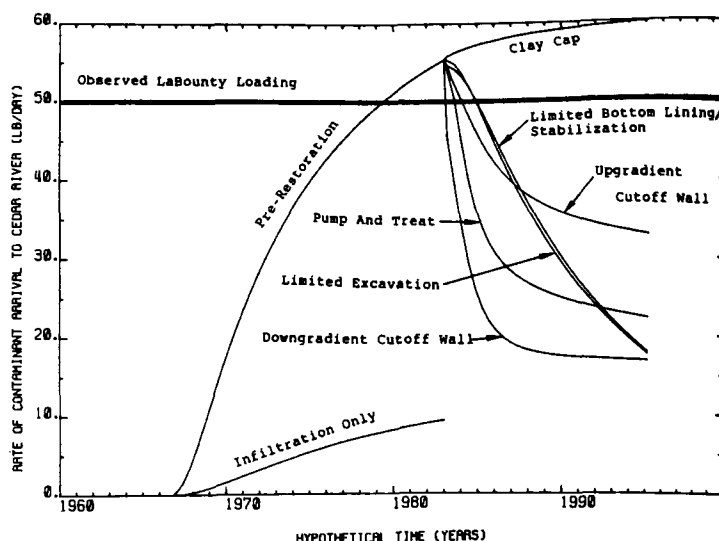


Figure 8.

Predicted Effective of the Various Remediation Alternatives in Reducing the Arsenic Loading of the Cedar River

tamination arises from that portion of the arsenical sludge buried below the water table.

Model results indicate that only the clay cap and the upgradient cut-off wall would probably fail to bring river concentrations (under low flow conditions) below drinking water standards. The upgradient cut-off wall, however, could probably be significantly improved through optimization studies with the transport model. Optimization studies were not performed for any of the alternatives.

The remaining five alternatives all lowered river concentrations to less than drinking water standards for Cedar River low flow conditions; however, the selection of the best alternative is still subjective. The downgradient cut-off wall and pump and treat alternatives show a quick response in reducing contamination levels but they approach a higher Cedar River loading limit. On the other hand, the bottom lining, excavation, and stabilization alternatives do not respond as quickly but have the potential to achieve much lower Cedar River loading rates and aquifer contamination levels.

Cost effectiveness of the various remediation alternatives is an important part of any decision making process. As indicated in Table 2, limited excavation (on site reburial) and bottom lining are the least cost alternatives (excluding the upgradient cut-off wall which failed to meet the level of contamination criteria). When comparing costs per unit reduction after 4500 days in predicted Cedar River arsenic concentrations (low river flow conditions) or the cost per unit reduction in arsenic contaminant mass in the saturated aquifer system, the limited excavation (on site reburial) is most cost-effective, followed by limited bottom lining and pump and treat. In both cases, stabilization is the most expensive alternative, followed by limited excavation (offsite reburial) and the downgradient cut-off wall.

## CONCLUSIONS

A hydrologic flow and transport model of the Charles City LaBounty landfill was developed, calibrated and used to evaluate seven remedial action alternatives for the LaBounty site. This modeling study has reaffirmed the importance of considering the regional hydrologic system when modeling the hydrology and transport for a more local system like LaBounty, and illustrates the value of groundwater modeling in developing an understanding of a complex flow and transport system.

In the process of modeling the LaBounty site, it was demonstrated that boundary conditions for the local model cannot be

**Table 2.**  
Estimated Cost for Each of the Seven Remediation Alternatives  
(1982 dollars)

Remediation Alternative	Capital Cost (\$)	Annual Operating Cost (\$)
Upgradient cut-off wall* and treatment	835,000	99,000
Limited excavation** (on site reburial)	1,000,000	35,000
Limited bottom lining	1,348,000	67,000
Pump and treatment	1,431,000	168,000
Downgradient cut-off wall and treatment	2,569,000	114,000
Limited excavation (off site reburial)	16,000,000	35,000
Stabilization	16,787,000	35,000

\*If optimized for additional contaminant removed, costs for this alternative are likely to be higher since diversion of more water will most likely be required.

\*\*Assumes made here is that waste removed from below the water table would be reburied on site above the water table and capped with clay

arbitrarily set and still obtain reasonable estimates for travel time and river discharge rates. The contaminant transport model developed for the LaBounty site, while not a perfect indicator of observed contamination movement, is certainly an adequate indicator for the purpose of general understanding and for the evaluation of the effectiveness of various remedial action alternatives.

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# REMEDIAL ACTION MASTER PLANS

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## INTRODUCTION

The Remedial Action Program has been developed to respond to releases of hazardous substances from the 400 sites comprising the National Priorities List under the commonly known Superfund Program. These sites may require long-term cleanup actions to provide adequate protection of public health, welfare and the environment.

The specifics of the Remedial Action Program are described in Phase VI, Section 300.68 of the National Contingency Plan (NCP), published in *Federal Register*, Vol. 47, No. 137, July 16, 1982, pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The Remedial Action Program is complex even with the limited number of sites currently being addressed.

The Interim Priority List, which identified 115 sites eligible for remedial funding, was published on Oct. 23, 1981. This list was expanded to 160 sites on July 23, 1982. As the program expands and the National Priorities List of 400 sites is published, an effective long-range planning mechanism becomes essential.

An effective technical and financial planning document which has been developed to assist with the long-range planning needs of the USEPA is the Remedial Action Master Plan or RAMP. In this paper, the authors discuss the development of the RAMP and its current and future uses as a planning tool for conducting remedial activities at uncontrolled hazardous waste sites, and outlines the basic structure and contents of the RAMP with the use of an illustrative example.

## BACKGROUND

The conduct of work in the Remedial Action Program is governed by certain provisions of the NCP and CERCLA. Engineering, economic and environmental factors must be considered in developing the "cost-effective" remedy for a hazardous waste site. A brief description of the remedial action process and the key provisions of the NCP and CERCLA that affect the financial aspects of the program are highlighted below.

The NCP identifies sequences of activities that must be undertaken prior to remedial action implementation. These phases are: a remedial investigation, a feasibility study to select the cost-effective action, and design of the selected remedy. The eventual remedial action selected may be one of the three types: initial remedial, source control and off-site measures. Certain sites will undergo combinations of these measures, depending on the need for that particular site.

Several provisions of CERCLA affect the financial aspects of the Remedial Action Program. The first is the State cost share requirements, which are 10% for privately owned sites and at least 50% if the State or one of its political subdivisions owned the site at the time of disposal. The second is the need to balance the funding requirements of a site against the amount of money available in the CERCLA Trust Fund to respond to other sites which present or may present a threat to public health, welfare or the environment. The third is the potential for responsible parties

to provide funds or undertake the activities themselves for all or part of the necessary response actions.

The primary purpose of the RAMP is to assess available data for a site and identify the type, scope, sequence and schedule of remedial projects which may be appropriate. Budget level cost estimates are prepared for the first projected phase of activity, along with a detailed statement of work. Brief project descriptions and order of magnitude cost estimates for future projects are also included. Other key components of the RAMP are the evaluation of existing data and any limitations associated with the data such as sampling/analysis protocols and chain of custody requirements; assessment of the need for additional data to evaluate remedial alternatives; community relations requirements; and a discussion of administrative and procedural requirements including any special problems that may be encountered during project implementation.

## Ramp Development

The concept of the RAMP is not new to the remedial program. Upon the passage of CERCLA, remedial action plans were developed for several sites to establish a priority for funding under a special Resource Conservation and Recovery Act (RCRA) appropriation which was authorized to conduct remedial planning activities at hazardous waste sites. The sites selected comprise what is known as "the initial 20 list". Remedial action plans were prepared on short notice and were primarily limited in scope and content, but were useful for initiating work at these sites. It was decided to expand this concept into the Remedial Action Master Plan and develop a document that would assist with the long-range planning needs in the Superfund program.

The starting point was defining what a RAMP should include and what the desired products should be. With the assistance of USEPA Region II, Region X and URS Company, Inc. (a subcontractor to Booz-Allen and Hamilton, Inc.), several sites were selected to have RAMPs prepared under a trial project. The objective was to determine the timing and level of effort to complete a RAMP. This trial project was completed in March 1982 and provided a basis for preparing RAMPs at other sites. The current estimate for the completion of an average RAMP is about 300 work hours of effort over a duration of three months. These numbers should decline as the procedures for completing RAMPs become more refined. The responsibility for preparing RAMPs rests with each USEPA Regional Office, in close consultation with the States. There are currently 68 RAMPs completed or under development at this time excluding sites where remedial activities have already been initiated.

## RAMP SUPPORT FUNCTIONS

The major planning and administrative tools of the RAMP are the site master schedules, the project cost estimates and the detailed statements of work. These tools are of use for technical and financial planning purposes, the necessary ingredients of a cost-effective remedial action program.

## Technical Support

Remedial activities will be conducted by any one of the following methods: (1) the responsible party through voluntary or judiciary actions, (2) the State through a cooperative agreement with USEPA, or (3) USEPA in accordance with a State Superfund contract. The RAMP provides a technical guide for conducting remedial activities at a hazardous waste site following the procedures in the NCP, eventually leading to the recommendation of the cost-effective remedial action for the site. These activities should be followed regardless of who performs them, thereby ensuring compliance with the intent of the NCP and CERCLA.

Once a decision is made to use Superfund monies to clean up a site, the work schedules, cost estimates and statement of work are used to prepare the cooperative agreement or State Superfund contract. For State lead projects, the statement of work provides ample information for the development of a Request for Proposals for the State to procure engineering services. For USEPA lead projects, the statement of work would be formulated into either a work assignment for a USEPA contractor or an interagency agreement with the U.S. Army Corps of Engineers. The RAMP will also provide the USEPA Regions with a guide for overseeing activities conducted by other parties.

The RAMP will be updated when events cause significant changes in the scoping of remedial activities at the site. By keeping the RAMPs up-to-date with the current technical and financial requirements of sites, USEPA and the States can periodically reassess their priorities and make changes as necessary.

## Financial Planning

The Superfund program is almost two years old and has been operational (i.e., funded by Congressional appropriations) for one and one-half years. The RAMP has demonstrated its short-term capabilities for scoping out remedial activities and providing a basis for the development of cooperative agreements and State Superfund contracts. The long-term financial planning capabilities of the RAMP are yet to be tested.

### State Financial Planning Requirements

States are required to contribute 10% of the remedial costs or at least 50% of the costs if the State or one of its political subdivisions owned the site at the time of disposal of hazardous substances. States are also required to assume all future maintenance of remedial actions. Some states have already passed their own minisuperfunds, appropriations, and bond issues to cover the costs for their share of remedial activities under the Superfund program.

The project schedules and cost estimates of the RAMP can be used to develop the overall financial needs of the program as well as cash flow projections for both USEPA and the States. This is important for establishing and managing any program, not just Superfund. States can use the RAMPs developed for their sites to establish their own priorities. The information will assist the States in identifying State financial requirements and it can be used to justify and obtain funds from State legislatures to cover the cost share requirements.

### USEPA Financial Planning Requirements

USEPA has the responsibility of administering the Trust Fund for the entire Superfund program including emergency response actions, site discovery and investigation efforts, other Federal agency programs, research and development efforts, and remedial response activities. The key aspects of CERCLA that affect the Remedial Action Program are the cost sharing provisions, the development of cost effective remedial actions, and the need to balance Trust Fund monies at the facility under consideration with the ability to respond to other sites.

Remedial activities at sites are beginning to pick up at a rapid pace. Until now, emphasis has been on initial project startups. However, with the expected release of the 400 list and the expected completion of many feasibility studies recommending large expenditures for remedial implementation projects, emphasis is shifting

toward the planning and phasing of projects at sites.

The RAMP will be a useful tool for this purpose because it contains project costs which are based upon actual conditions at the site. Current practice is to use an average unit cost to conduct a remedial investigation, feasibility study, design or implementation project until more definitive costs are developed on a site by site basis. The cost estimates in the RAMP, either the budget level for the first phase of activity or the order of magnitude estimates for future projects, will be more accurate for the purpose of developing long-range plans.

## RAMP STRUCTURE

The basic structure of a RAMP includes an executive summary and three major sections: (1) compilation and evaluation of existing data, (2) remedial activities, and (3) appendices.

### Compilation and Evaluation of Existing Data

The compilation and evaluation of existing data is a necessary first step in approaching site remediation. Probably one of the most difficult questions to answer is what additional information is necessary to be able to identify and evaluate remedial alternatives for a hazardous waste site without "studying the site to death." This problem became apparent as USEPA and the States began to work on the initial 20 Superfund sites. Some of these sites had an extensive array of reports available, while others had little if any information about them. Much of the data was compiled years ago, raising several important questions such as: how good are these data today; can an engineering solution be properly developed and designed; and will the data be defensible in court?

The first step of a RAMP is to collect, analyze and evaluate available data and identify any data gaps or other limitations. This is not intended to be a detailed assessment of all existing data, which could, in some situations, be very costly and time consuming. For instance, there is one particular site about which more than 100 reports have been written, all of which contain potentially useful information for evaluating remedial alternatives. The brief review of data for the RAMP is designed to prevent the costly duplication of previous efforts and to ensure that the information from which decisions are made is technically and legally sound.

To minimize costs, RAMPs are prepared exclusively from existing information. The site data base is likely to include assessments and site inspections performed by USEPA, studies performed by the State, county or municipality, and records contained in regulatory and licensing agency files. The actual volume and quality of data will vary considerably from site to site and, therefore, influence the level of detail contained in the RAMP. The review of existing data focuses on the quality assurance/quality control procedures, chain of custody procedures, and sampling and analytical protocols.

A preliminary determination is then made on the adequacy of the information, to support the development and evaluation of remedial alternatives, as well as support cost recovery actions. The available data serve as a baseline to be used in assessing the site situation and provides a mechanism for determining data limitations and the need for obtaining additional data. Appropriate techniques on how to best collect the required information are discussed in the remedial activities section of the RAMP.

The first section also includes a description of the location and history of the site, the environmental setting, previous community relations efforts, enforcement actions and other pertinent information. The previous uses of the site are summarized as a means of providing a general understanding of the current site situation. This description outlines previous waste disposal practices or site operations which have led to the contamination of the site.

Although a complete chronological description of all past site activities is seldom possible, the site historical description outlines major actions at the site. The description provides a chronological listing of site owner(s), the operations which have taken place at the site, and the periods during which these operations have taken place. Of particular importance are the types of operations and the

types of raw and waste materials used or processed at the site. Any permits issued or regulatory actions taken against the site or its previous owners are also identified and briefly described. The environmental setting is often a key to identifying potential pathways of exposure to the hazards posed by a particular site. In most situations, a site visit is conducted to verify the information gathered and to note significant changes at the site.

### Remedial Activities

The remedial activities section is the key section of the RAMP. In this section, the sequence, timing, estimated cost and correlations of projects needed to clean up the site are outlined.

The major element of this section is a preliminary "scoping decision" which establishes a basis for conducting all future remedial activities at the site. The preliminary scoping decision is based upon the existing data and identifies the potential for initial remedial measures and the need to evaluate source control and/or off-site measures. Such initial measures might involve the removal of drums and/or visibly contaminated soils. Options could also include drainage controls, lagoon stabilization, temporary potable water supplies and temporary capping. In this way, appropriate actions can be taken based on available information while simultaneously collecting additional information and evaluating alternatives for source control or off-site measures. Parallel activities are practical at most sites where imminent hazards are taken care of as an initial remedial measure while more extensive source control and off-site actions are evaluated.

With the necessary scoping decision made, the engineer is able to prepare a detailed statement of work, project work schedule and cost estimate to complete the next phase of remedial activity. Future remedial activities are also identified and are displayed on a site master schedule. Order of magnitude cost estimates are provided, as appropriate, to assist with the financial planning requirements of the Superfund program.

In order to illustrate "scoping" more clearly, a typical RAMP is described below. The RAMP is for an actual site but the site name and location are withheld as the contents and concept of the RAMP are the primary concern. The particular site is selected because it portrays the potential for "fast tracking" an initial remedial action and scopes out the full remedial investigation and feasibility study to evaluate source control and off-site remedial alternatives.

### Site Description

The site has been inactive for several years. There are several thousand drums of various waste stored on the site. The drums have deteriorated over the years and, as a result, the contents of the drums have leaked. Since there is evidence of the area being regraded, one would expect the presence of buried wastes. Previous aerial surveillance of the site also supports this assumption. There are no surface drainage controls present at the site, and off-site migration by run-off is evident from stressed vegetation. Water samples from a nearby creek and groundwater samples from monitoring wells show high levels of several priority pollutants. The ability to identify buried wastes is hindered by the cramped conditions in the regraded area caused by drums stored on the surface.

### RAMP Recommendations

Through the compilation and evaluation of existing site data, the recommendations in the RAMP include a limited remedial investigation and feasibility study, and the design and implementation for a fast track initial remedial action to remove surface drums and visibly contaminated soils. The RAMP also proposes a more detailed remedial investigation and feasibility study to evaluate source control and off-site control measures. The comprehensive work schedule covers 40 months to conduct the remedial activities. The first 24 months of the site activity are shown in Fig. 1.

The State in which this site is located has elected to enter into a cooperative agreement with the USEPA. The State will, therefore, have the lead in the projects and conduct the remedial activities through State contractors. The time sequence of the schedule begins with the signing of the cooperative agreement with the State. The normal sequence of activities (bottom track) can be initiated at almost any time. This is annotated by the dashed line as "float time" in the schedules.

The separate site activities continue on parallel schedules (Fig. 1). The limited remedial investigation and feasibility study provides the information necessary to prepare contract bid documents and to determine the cost-effective disposal alternatives for the various wastes present at the site. Various reviews and decision points are also scheduled. For this particular site, most of the remedial investigation activities (bottom track) will have to wait due to worker safety considerations and the difficulty with determining the extent of buried materials until the surficial cleanup is completed.

The cost estimates for all phases of work at the site as well as the

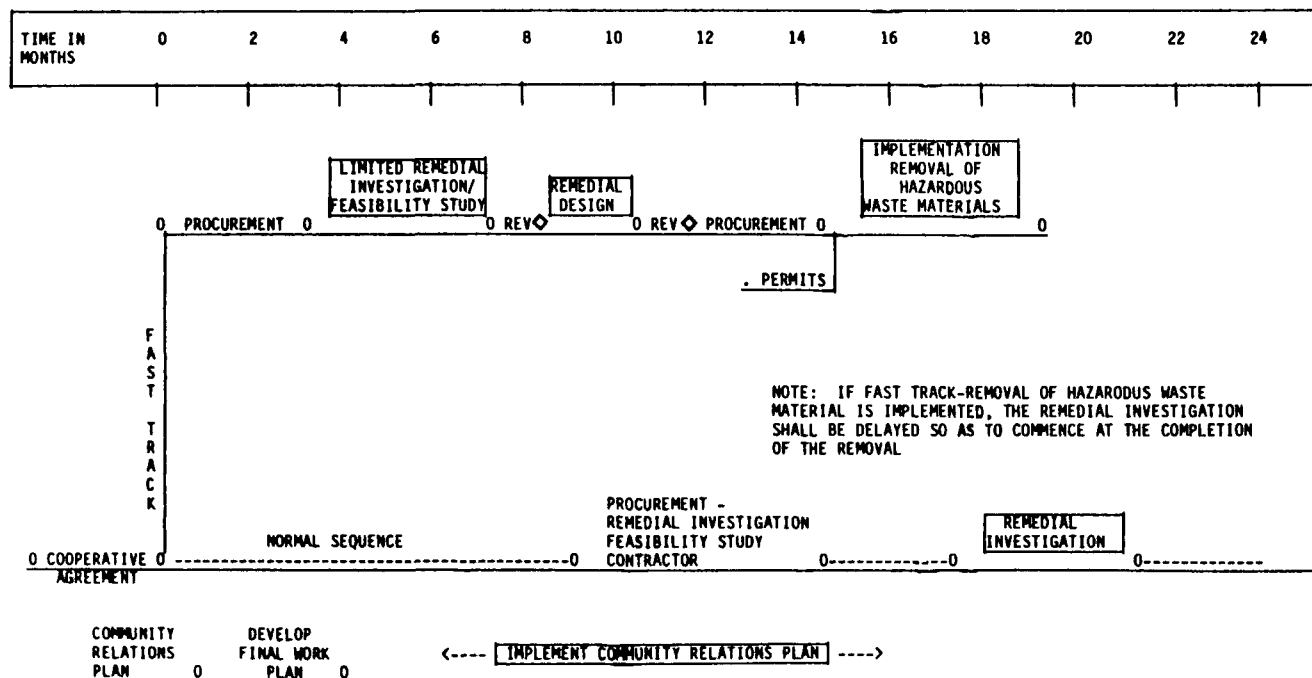


Figure 1.  
Master Site Schedule



estimated work schedule in calendar days are summarized in Table 1. Cost ranges are provided to account for any unknown site conditions that may be encountered during the limited remedial investigation stage. The cost estimates, work schedules, and a detailed work statement (prepared as part of the third section of the RAMP) provide the basis for an allocation of Superfund monies to conduct the work at the site.

**Table 1.**  
**Summary of Remedial Projects**  
**Schedules and Cost Estimates**

Project	Schedule (Cal. Days)	Estimated Cost	
		Low	High
Community Relations Plan	As Needed	Lead Agency	Lead Agency
*Limited Remedial Investigation/Feasibility Study	90	\$ 30,900	\$ 44,600
*Remedial Design	90	\$ 25,800	\$ 39,000
*Implementation: Removal of Hazardous Waste Materials	180	\$1,800,000	\$2,428,000
Remedial Investigation	120	\$ 122,000	\$ 161,400
Feasibility Study	120	\$ 116,800	\$ 163,700
Remedial Design	---	---	---
Implementation of Source Control and/or Off-Site Measures	---	---	---
Post-Closure Monitoring	---	---	---
*Fast Track			

In this case, the State and USEPA have used the RAMP information to develop a cooperative agreement and the State is now preparing to conduct the limited remedial investigation and feasibility study at the site. The cost estimates developed in the RAMP established the amount of the funding request and helped to identify the direct project management costs of the State.

### Appendices

The final section of the RAMP includes the appendices. The most important appendix is the detailed statement of work for the first phase of activity that needs to be completed according to the procedures established in the NCP. The statement of work outlines the major activities of the remedial investigation, feasibility study, initial remedial measure or any phase of activity which can be properly scoped with the use of available data. In the example previously illustrated, the statement of work provided the basis for the work plan of the cooperative agreement with the State.

Other appendices may include summaries of sampling and analytical data, references, draft community relations plan, a detailed site chronology and other pertinent information.

### CONCLUSIONS

The RAMP has been developed as a management tool to assist with the technical and financial responsibilities of the remedial action program. The simplistic structure facilitates quick revision as site conditions change and as more definitive objectives for each site are established. States will be conducting remedial activities at some sites and USEPA at others. Since the State and Federal resources to conduct these activities are limited, these resources must be used in a prudent and consistent manner at sites across the country. The RAMP is one vehicle to meet these objectives.

# THE DEPARTMENT OF DEFENSE'S INSTALLATION RESTORATION PROGRAM

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## BACKGROUND

The Department of Defense (DoD) began its Installation Restoration (IR) program in 1975 before the passage of CERCLA. The IR program is a comprehensive program to identify and evaluate past DoD hazardous waste disposal sites on DoD installations, and to control the migration of contamination resulting from such operations. The IR program also is applicable to property that is excess to DoD requirements and which might be made available for other public or private use.

DoD initiated the IR program prior to any public outcry or legislative mandate because of its concern for the public health and welfare and environmental quality. The agency is proud of the program and the leadership it has demonstrated to federal, state, and local governments and to the private sector.

On Aug. 14, 1981, in Executive Order 12316, the President delegated certain authority specified in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to the Secretary of Defense. The Secretary of Defense was given responsibility for:

- Response actions (i.e., removal and remedial actions)
- Investigation, monitoring, survey, and testing
- Such planning, legal, fiscal, economic, engineering, architectural, and any other studies or investigations as necessary for response actions, cost recovery, and to enforce the provisions of CERCLA, for DoD facilities and vessels

The National Contingency Plan goes on to further recognize DoD on-scene coordinators for DoD facilities and vessels.

Within DoD, the Secretary of Defense's authority in Executive Order 12316 has been re-delegated to the Secretaries of the Army, Navy, and Air Force. The Assistant Secretary of Defense for Manpower, Reserve Affairs and Logistics on Nov. 20, 1981, formally identified DoD's functioning IR program as the DoD Superfund program.

The objectives of the DoD restoration program are these:

- To identify and evaluate past hazardous material disposal sites on DoD facilities, to control contamination migration, and hazards to health or welfare
- To review and decontaminate as necessary land and facilities excess to DoD's mission

These objectives go beyond the Superfund mandate.

DoD has required that the military departments and the Defense Logistics Agency establish and operate installation restoration programs, and complete records searches at every installation listed on their priority lists by the end of FY 1985. They have also been required to develop and maintain a priority list of contaminated installations and facilities requiring remedial action. In the IR program, priority is given to control of migrating contamination that may pose a threat to the public health and welfare of surrounding communities or to on-post personnel.

Other considerations in establishing the priority lists are:

- The installation's mission
- Suspected or known contamination hazard
- Possible land excessing action
- Environmental sensitivity of area
- Known disposal sites
- Public interest and any other factors considered appropriate by each DoD component—Army, Navy, Air Force, and the Defense Logistics Agency.

Each of the military departments has assigned a principal role to in-house environmental organizations to coordinate or accomplish installation restoration program actions (Fig. 1). The Army's Toxic and Hazardous Materials Agency is located at the Edgewood area of Aberdeen Proving Ground, Maryland. The Navy's Energy and Environmental Support Activity is located at Port Hueneme, California, and is responsible for the Navy and Marine Corps program. The Air Force's Engineering and Services Center is located at Tyndall Air Force Base, Florida, and is responsible for the installation assessment phase of the Air Force program. The Occupational and Environmental Health Laboratory is located at Brooks AFB, Texas, and is responsible for the confirmation, or field survey, phase of the Air Force program.

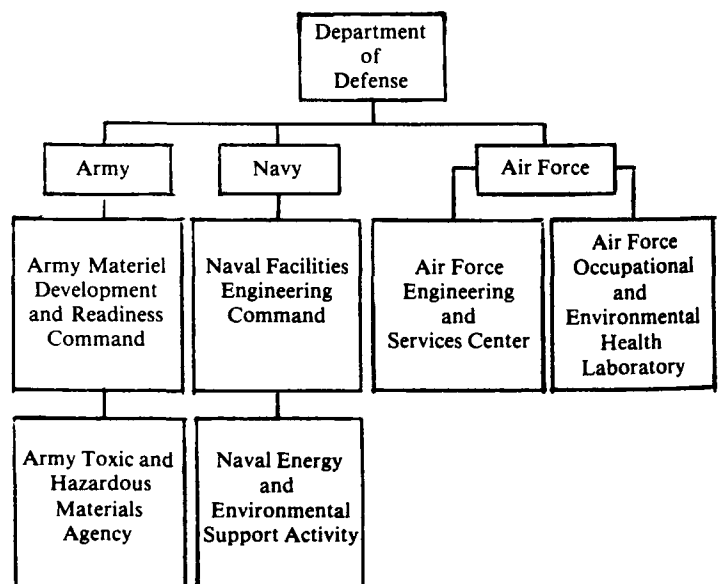


Figure 1.  
DoD Installation Restoration (Superfund) Organization

## THE IR PROGRAM: IN CONCEPT

### Installation Assessment Phase

The first phase in the IR program (Table 1) is an installation assessment. In this phase, installation files are examined, current employees and key retirees are interviewed, and the terrain and facilities are examined. Additionally, all available information on past mission, current operations, waste generation, disposal, and geohydrology of the area are collected. Limited soil and water sampling may also be conducted to determine if contaminants are present.

A preliminary survey may be conducted to produce field data which will either confirm or rule out the presence and/or migration of contaminants, and assess the degree of risk associated with the identified condition. If contamination exceeding safe levels is found, interim containment of the migration is accomplished as soon as possible. If not, no further action is required.

### Confirmation Phase

The second phase in the IR program is referred to as the confirmation phase. In this phase, a comprehensive survey is conducted to fully define the problem through environmental sampling and analyses. Data are developed to fill identified information gaps revealed during the installation assessment phase, and survey data from all technical areas is interpreted and interrelated. The survey will normally be sufficiently detailed to determine the locations of contaminant sources, quantify the contamination present, and define the extent of contaminant migration and the contaminant boundaries.

Depending on the nature of contamination being investigated, an ecological survey may be used to collect baseline data on plant, animal, and aquatic species to determine the presence of target contaminants throughout the ecosystem.

### Technology Base Development

In the third phase, referred to as Technology Base Development, control technology is matched with specific contamination problems at a given site to determine the most economical solution. If control technologies do not exist, they are developed in this phase. Technical specifications and corrective project programming documents may also be developed. Additional groundwater monitoring wells and sampling could be required to address specific technology application considerations and fill in remaining data gaps. Technology development may also support further project planning to control migration, or to support actual restoration efforts on contaminated properties.

A DoD IR Technology Coordinating Committee, chaired by the Army, has been established recently to facilitate the exchange of technical information among the military departments and to review control technology or other criteria that may be useful.

Also, in this phase decontamination criteria are identified, or developed if they do not exist. Criteria development defines the

contamination levels judged acceptable for protection of the public health and welfare, based on best available information, in the absence of federal or state standards. Criteria development efforts will generally include: (1) problem definition studies, (2) chemistry studies, and (3) toxicological studies.

Problem definition studies provide baseline information for data development through literature searches. Problem definition studies also identify the research necessary for an objective assessment of adverse effects. When the contaminant situation is unique to the DoD (i.e., a DoD-unique pollutant), the need for conducting chemistry and toxicology studies will be evaluated to decide whether to assess the risk associated with various concentration levels by controlled laboratory experiments on various animals or plant species.

Since the criteria to be developed are intended for widespread use, extensive coordination of presumptive criteria, research protocols, and results is accomplished. The results of these toxicological and chemistry studies are made available for peer review. The National Academy of Science may be requested to review presumptive criteria, research protocols and results. Additionally, experts from the Environmental Protection Agency, Department of Health and Human Services, Department of Agriculture, Department of the Interior, and other concerned agencies may be asked to comment when appropriate. Criteria developed by the Navy and Air Force are provided to the Army for incorporation into a DoD data base.

After collecting data on standards, contaminant control technology, ecological effects, and current environmental levels of contamination, DoD evaluates the costs and benefits of applying available control technologies to reduce the hazard from contaminants. The options considered would normally include a no-action alternative. This option is of particular interest when property is to be excessed to non-DoD ownership for a like-usage, and low-levels of contaminants are present, and not migrating.

### Operational Phase

The final phase of the IR program, when required, is what DoD refers to as the operations phase. This phase includes design, construction, and operation of pollution abatement facilities, and the completion of remedial actions. This phase could include the construction of containment facilities or decontamination processes, and associated monitoring systems. Also included are completed project phase-out, data storage, and publication of a final project report.

A project plan describes the survey results, analyzes feasible control options, and presents a proposed approach for controlling the contamination. An estimate of resources, research requirements (if any) associated with the proposed solution, and a planning schedule for design, construction, and operations are also included.

A survey will be conducted prior to, and following, the operations phase to ensure that target standards or criteria are achieved.

## IR PROGRAM ACCOMPLISHMENTS

DoD's goal is to complete records searches at every installation currently identified on Army, Navy, Air Force, and the Defense Logistics Agency's priority lists by the end of FY 1985. The Deputy Assistant Secretary of Defense for Installations monitors semi-annually the progress of the military departments toward this goal. The IR program results to date are impressive (Table 2).

As of June 30, 1982, 210 Army installations have been identified which require a records search, 156 installations have been, or are being assessed largely by contract effort. 104 records searches have been completed and published at an approximate cost of \$50,000 per installation. Of these 104, 49 surveys are required, 35 surveys are underway and 14 have been completed. Typical costs of the surveys, which are done by contract, is around \$300,000 per installation.

To date, eight installations have been determined to require remedial action. They are: Rocky Mountain Arsenal, Colorado, Redstone Arsenal, Alabama, Alabama Army Ammunition Plant, Ala-

**Table 1.**  
**DoD IR Program Concept**

- I. Installation Assessment
  1. Records Search
  2. Preliminary Survey
- II. Confirmation
  1. Comprehensive Survey
  2. Ecology Survey
- III. Technology Base Development
  1. Containment/Decontamination Technology Development
  2. Criteria Development
  3. Cost/Benefit Analysis
- IV. Operations
  1. Project Plan
  2. Survey

**Table 2.**  
**DoD Installation Restoration (Superfund)**  
**Program Accomplishments**

	<b>Army (+ DLA)</b>	<b>Navy</b>	<b>Air Force</b>
<b>Records Search</b>			
Required (Total)	210	80	82
Completed	104	1	26
<b>Survey</b>			
Required (Total)	49	0	26
Completed	14	0	4
<b>Operation</b>			
Required (Total)	8	0	2
Completed	2	0	0

bama, Milan Army Ammunition Plant, Alabama, Anniston Army Depot, Alabama, and Savannah Army Depot, Illinois. Work at two installations has been completed. Pine Bluff Arsenal, Arkansas; and Frankford Arsenal, Pennsylvania. Costs associated for this phase are site specific and vary considerably, ranging to date from \$1.6 to \$44 million.

Eighty Navy installations require records searches. Twenty-eight have been initiated to date, and one final report has been published. The Navy is currently evaluating their preliminary results to determine how many surveys are required. To date, two installations have been determined to require remedial action. These are the Jacksonville Naval Air Station, Florida, and a site at Pearl Harbor, Hawaii.

Eighty-two Air Force installations require a records search. As of June 30, 1982, 26 records searches have been completed and published. All 26 installations require surveys, and 4 are in progress. Two installations have remedial actions underway. They are

Wurtsmith Air Force Base, Michigan, and Air Force Plant 44, Arizona.

Probably the most widely reported DoD installation restoration project is the Army's effort at Rocky Mountain Arsenal, Colorado. Rocky Mountain Arsenal is adjacent to the City of Denver, with Stapleton International Airport lying directly south of the Arsenal. The Arsenal complex, some 17,000 acres, has groundwater contaminated as a result of the military production of chemical warfare agents and Shell Chemical production of commercial pesticides. The Army's project at Rocky Mountain Arsenal has been active since 1976. To date, over \$44 million has been spent to define contaminant migration and provide remedial actions at the Arsenal, with the end not yet in sight.

The data collection and analytical effort at the Arsenal has been extensive. Over 1500 wells have been drilled on the 25 square mile site. 4,000 to 6,000 analyses are completed every month, with over 270,000 data points on record, and over 900 technical reports published. Since this project has been discussed extensively elsewhere, suffice it to say, though, that the Army has demonstrated at Rocky Mountain Arsenal the commitment of the Defense Department to aggressively pursue its installation restoration program.

## CONCLUSION

DoD has developed substantial expertise in the identification, characterization, and control of environmental contamination. DoD will continue to actively pursue its Installation Restoration program over the next several years.

However, the IR program is only one important part of the DoD environmental quality programs. DoD has demonstrated significant initiatives and accomplishments in other important areas of concern. DoD believes, though, that its Installation Restoration program has demonstrated significant leadership, and serves as a model for other agency Superfund programs. Hazardous waste disposal site problems will remain a major area of emphasis within DoD for the 1980s.

# **SURVEY AND CASE STUDY INVESTIGATION OF REMEDIAL ACTIONS AT UNCONTROLLED HAZARDOUS WASTE SITES**

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## **INTRODUCTION**

With the passage of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) and the release of the National Contingency Plan, the USEPA has developed a systematic methodology for assigning liability and conducting remedial actions at uncontrolled hazardous waste management facilities. Prior to the passage of Superfund, USEPA relied on two laws for providing assistance for remedial actions at uncontrolled hazardous waste sites, the Clean Water Act (Section 311) and the Resource Conservation and Recovery Act.

It is clear from past experiences such as Love Canal that short term and long term environmental and health related hazards exist when inadequate technologies are used during the handling and disposal of hazardous materials. Presently the Solid and Hazardous Waste Research Division USEPA (Cincinnati, OH) and the Oil and Hazardous Spills Branch USEPA (Edison, NJ) are involved in the research and development of existing and novel technologies for use in the remediation of hazardous materials released to the environment.

Because new remediation techniques are continually evolving and known technologies are constantly being retrofitted and adapted for remedial actions use, the alternatives available for cleanup are continuing to expand. In order to assess the effectiveness and limitations of these remedial actions techniques, USEPA is conducting case study examinations of these technologies which have been employed in field situations.

## **PROJECT DESCRIPTION**

JRB, under contract with the USEPA, is in the process of conducting a nationwide survey of uncontrolled hazardous waste sites to identify and examine the various types of remedial action technologies which have been implemented or which are in progress or are proposed as cleanup techniques. At selected sites, detailed case studies will be performed to document the specific reasons for the success or failure of applied remediations technologies and to determine the limitations and applicability of these technologies in other restoration activities or situations.

The results of the case study investigation will be used to provide a transfer of information between those who have experienced the implementation of a remedial action and those contemplating or presently assessing or pursuing some form of site cleanup. The anticipated audience to be assisted by the survey findings and case study reports includes members of industry and commerce, State Agencies, Local Authorities, and the USEPA.

Case Study reports will be structured so that they will provide detailed data on the remediation techniques employed, the circumstances and conditions in which they were implemented, their apparent effectiveness in correcting or controlling the problem, and their potential uses in other natural environments and remedial action situations. Ultimately the survey and case study results will quantify the number and type of reported uncontrolled releases of hazardous substances that have undergone a certain degree of

remediation, will provide a standard for comparison when assessing or deciding on a plan for remediation, will identify cleanup technologies which may warrant further research, and most importantly will provide a forum in which others can learn from past miscalculations and successes.

## **Survey Method**

The initial task was to compile an updated list of uncontrolled hazardous waste sites which included both ongoing and completed remedial actions. The sources of information used to compile this list included: in-house literature review of selected documents, data from USEPA on present and past remedial action programs and site studies, including work at Superfund sites, Department of Defense contacts with knowledge of restoration work at military bases, State environmental and health agencies involved in site remedial actions, and industrial and pertinent trade association contacts involved in spill responses or hazardous substances cleanups.

The first step in conducting the survey began by conducting a review and updating data on the 199 sites identified by SCS Engineers' and the data contained within the list of 114 Top Priority Superfund Sites released Oct. 23, 1981. Simultaneously, an internal review was conducted of in-house files and publications, including the Groundwater Newsletter, Hazardous Waste Reporter, and Hazardous Materials Report, to identify any sites not contained in the SCS Report or Superfund list.

Once the data review was completed, USEPA Regional, State and Local parties identified as being knowledgeable about hazardous site remediation activities were contacted to supplement information collected from the internal survey and to expand the site data base. Knowledgeable parties contacted included USEPA Regional Emergency Response Coordinators, Regional Land Disposal Branch personnel, Regional On-Scene Coordinators, State On-Scene Coordinators, consulting contractors, site manager and operators, Department of Defense, and State and Local officials.

Cooperation was requested from trade associations representing industries which may have been involved in hazardous waste management, generation or transportation. Contact was also made with the firms involved with the design and implementation of remedial actions at hazardous materials spills sites and waste management facilities.

Approximately 300 sites were identified. Data collected on the sites included the name and location of the site, the remedial actions implemented or planned, the type of waste management practices used at the facility, the waste types/contaminants present, the availability of engineering cost data, and the ease of access for case study. A clear majority of the sites surveyed were obtained from two data sources, the SCS Report and the 114 top-priority Superfund sites. Contacts made during discussion with responsible parties involved in remediation activities at the Superfund sites and SCS sites often led to discovery of sites not previously listed.

The results of the DOD survey effort indicate that remediation activities within the armed forces are in the initial stages. DOD has established a phased approach for conducting site restoration activities within all branches of the Armed Forces. Presently, each branch of DOD is proceeding at individual rates relative to the phase program, and in most cases have conducted initial site assessments but have not initiated any site restoration activities.

Contacts with several cleanup firms, consultants specializing in remedial alternative design, and trade associations led to the discovery of several sites. However, in most cases client confidentiality agreements hindered full cooperation in identifying sites. It is reasonable to assume the many private sector cleanups are completed and not reported and therefore are not identifiable and are not included in this population of surveyed sites.

Once the site survey activities were completed a series of criteria were used to select candidate sites for detailed case study analysis. These criteria included:

- Availability for field survey activities
- Availability, accessibility, and completeness of remedial action cost and engineering data
- Type of remedial action technology implemented, so that a range of remedial action techniques were investigated
- Type of waste management practice, so that a wide range of technologies common to hazardous waste management were studied
- Types of waste and contaminants present at the facility to ensure that a variety of waste streams and pollutants were included
- Hydrogeologic setting, so that a variety of settings were represented
- Geographic location to provide a nationwide distribution of sites

Approximately 20 sites have been identified for case study analysis and field surveys for these sites are presently being performed.

#### Survey Results

Three hundred and sixteen sites have been identified as being associated with some form of completed, ongoing or planned remediation activity relative to the uncontrolled releases of hazardous substances to the environment (Table 1). This is a substantial increase in the number of sites identified in a similar survey conducted in 1980. Two key factors can be attributed to the increased number of identified sites:

- The data base used in the 1982 survey was an expanded version of the 1980 data base, including contact with the Department of Defense, pertinent trade associations, industrial contacts, and cleanup contractors
- Additional data relative to hazardous waste sites have been made available through the USEPA Field Investigation Team activities over the past two years and there has been increased awareness by state and local officials relative to site discovery and identification

Even though the general population of identified sites has increased by 147, the percentage of sites located in the individual states has not changed. Also, a majority of sites identified are concentrated in the heavily industrialized regions of the country. This corresponds well with the economics and convenience of disposing of waste materials near the generating source.

A compilation of the various types of disposal methods employed at the sites identified during the survey is found in Table 2. The data collected from approximately 30 of the sites surveyed have not been accumulated in sufficient detail to enable an accurate assessment of the disposal method used. Therefore, these sites were eliminated from consideration when constructing Table 2.

Waste management practices and contamination releases identified during the survey included land disposal, drum and tank storage, incineration and treatment, subsurface injection, spills and illegal dumps. Seventy eight percent of the facilities where remedial actions were either completed, ongoing, or planned can be associated with three waste management technologies: landfilling,

**Table 1.**  
**State Location of Remedial Action Sites in 1980 and 1982<sup>1</sup>**

State	No. of Sites '80	% of Total*	No. of Sites '82	% of Total*
Alabama	2	1.2	2	0.6
Alaska	0	0.0	0	0.0
Arizona	3	1.8	6	1.9
Arkansas	2	1.2	4	1.3
California	3	1.8	9	2.8
Colorado	3	1.2	5	1.6
Connecticut	4	2.4	11	3.5
Delaware	2	1.2	4	1.3
Florida	7	4.1	26	8.2
Georgia	4	2.4	5	1.6
Hawaii	0	0.0	0	0.0
Idaho	0	0.0	0	0.0
Illinois	8	4.7	14	4.4
Indiana	3	1.8	4	1.3
Iowa	1	0.5	2	0.6
Kansas	2	1.2	3	1.0
Kentucky	5	3.0	6	1.9
Louisiana	3	1.8	9	2.8
Maine	2	1.2	3	1.0
Maryland	1	0.5	3	1.0
Massachusetts	5	3.0	11	3.5
Michigan	11	6.5	13	4.1
Minnesota	3	1.8	8	2.5
Mississippi	0	0.0	3	1.0
Missouri	4	2.4	10	3.2
Montana	5	3.0	5	1.6
Nebraska	0	0.0	0	0.0
Nevada	0	0.0	1	0.3
New Hampshire	1	0.5	6	1.9
New Jersey	10	5.9	17	5.3
New Mexico	0	0.0	3	1.0
New York	14	8.3	29	9.2
North Carolina	7	4.1	8	2.5
North Dakota	6	3.6	6	1.9
Ohio	4	2.4	5	1.6
Oklahoma	0	0.0	3	1.0
Oregon	0	0.0	0	0.0
Pennsylvania	16	9.5	23	7.2
Rhode Island	4	2.4	5	1.6
South Carolina	3	1.8	5	1.6
South Dakota	0	0.0	2	0.6
Tennessee	10	5.9	10	3.2
Texas	3	1.8	7	2.2
Utah	1	0.5	2	0.6
Vermont	0	0.0	1	0.3
Virginia	2	1.2	4	1.3
Washington	0	0.0	5	1.6
West Virginia	1	0.5	2	0.6
Wisconsin	3	1.8	5	1.6
Wyoming	1	0.5	1	0.3
Total 50 States	169		316	

\*Percent of total identified nationwide.

**Table 2.**  
**Types of Disposal Methods**

Disposal Methods	No. of Sites	Percent of Total
Landfill	121	32
Drum Storage	67	18
Surface Impoundment	104	28
Spills	25	7
Incinerator	10	3
Injection Wells	7	2
Illegal Dumps	39	10
Total	373	100%

In some cases, more than one disposal method has been used at an individual site.

drum storage, or surface impounding. This association is to be expected based on the fact that these technologies have been the most common methods over the years for managing and disposing of hazardous substances.

The relatively low percentage of incinerators and injection wells identified in the survey can be attributed to the limited applicability of these technologies for treating and disposing of a wide spectrum of hazardous materials, and to their limitations for use in broad geographic and environmental regions. The low percentages of illegal dumps identified can be associated with the expected unavailability of data necessary to sufficiently characterize these facilities.

The remedial technologies used at the surveyed sites included a variety of methods such as capping and grading, removal and off-site burial, groundwater pumping, chemical and biological treatment, and containment and encapsulation (Table 3). However, 76% of the remediation efforts identified involved only four

**Table 3.**  
**Types of Remedial Action Employed**

Remedial Action	No. of Sites	Percent of Total
Capping/Grading	59	19
Drum Removal	56	18
Contaminant Removal	70	23
Groundwater Pumping	22	7
Groundwater Containment	23	8
Contaminant Treatment	48	16
Encapsulation	8	3
Dredging	5	2
Gas Control	3	1
Incineration	3	1
Lining	7	2
Total	304	100%

In some cases, more than one remedial action technique has been used at an individual site.

techniques, capping/grading, drum removal, contaminant removal or treatment. In most instances, these techniques correlate well with the high percentage of facilities identified as practicing land-filling, drum storage, or surface impounding as a waste management method. This correlation is based on the following factors:

- Most remedial actions to date have been directed at controlling the immediate threat, i.e. removal of the waste material by land-fill and contaminated soil removal, surface impoundment pumping and removal, or drum removal.
- Technologies such as grading/capping, contaminant removal, and drum removal are in most cases relatively unsophisticated and economic remedial activities when compared with other remedial options.
- In the natural order of implementing remedial actions, removal of the contaminant source is the most likely initial step in performing a staged facility cleanup.
- Complete removal of the source of contamination is the most effective and direct method of reducing or eliminating continued releases of contaminants to the environment.

Less often used methods of site remediation include encapsulation, dredging, incineration, groundwater containment or pumping, and subsurface gas control. Several reasons exist for the restricted use of these methods as remediation techniques, these include:

- Constraints based on site specific conditions such as waste type, area of contamination, and media contaminated
- Present level of technological development relative to proven field use and successful application in real world situation
- Effects of economic and institutional factors which limit the availability of funds, or requirements for specific approaches to

be used in resolving the cleanup problem (i.e., emergency cleanup vs. long term cleanup)

Based on the information gathered on the restoration activities of relatively new sites, it can be said that there has been a shift in the approach historically used to conceptualize and implement remedial actions. In more recent times, an emphasis has been placed on thoroughly understanding the dynamics of the contamination and then developing and implementing the remedial action program. The shift to more systematic approaches in planning remedial actions can be attributed to more comprehensive regulations relative to hazardous waste management and the assignment of strict site cleanup liabilities and responsibilities (i.e., Superfund and the Resource Conservation and Recovery Act), and also to lessons learned from successful and unsuccessful cleanup methods and techniques employed in the past.

## CASE STUDIES

Once JRB had selected the case study sites, field activities were conducted to collect additional information to ensure the development of accurate and complete case history reports. Field visits included trips to the sites as well as meetings with the appropriate Federal, State, and private parties involved in the site remediation. Presently, JRB is in the process of completing case study investigations and a companion report on these investigations. The following is a brief synopsis of three case study investigations.

### Trammel Crow Site—Dallas, Texas

The first case study was a former Texaco oil refinery which operated in Dallas, TX from 1915-1945. When the refinery ceased operation, it was sold to a metal recycling firm which reclaimed any valuable scrap metal on site. The property was left vacant for 20 years after the scrapping operation until it was sold in 1980 to the Trammell Crow Corporation for industrial development.

At the time of purchase, five waste sludge pits with over five million gallons of still bottoms and other petroleum refinery wastes were located on the site. The five ponds were not all the same size and did not contain the same materials. One pond, the largest, contained approximately 3.5 (16,600 yd<sup>3</sup>) million gal. of crude oil tank bottoms consisting of 50% carbonaceous material, 35% water, and 15% ash. The carbonaceous portion of the sludge was made up of equal portions of asphaltene and paraffins. A second contained approximately 10,000 yd<sup>3</sup> of hard-coke/slag material believed to be coke cinders from the petroleum refinery cracking process. The remaining three ponds contained approximately 1.5 million gals of sedimentation or oxidation pond oily residues.

The waste ponds were located above a Trinity Clay soil which extends to a depth of 20 to 45 ft below the ground surface. The Trinity Clay is a moderately alkaline soil of low permeability. This in turn, overlies in Eagle Ford shale which extends to a depth of approximately 400 ft below the surface. The Trinity Clay and Eagle Ford shale formations form an impermeable barrier between the surface and the underlying aquifer, therefore posing little threat of groundwater contamination.

The wastes were tested for toxicity using the USEPA required extraction procedure test as defined by the Resource Conservation Recovery Act (RCRA). The sludges were not found to be RCRA hazardous waste, however, the sludges in the ponds had to be treated, removed or both before development could take place. Although the waste oil was not RCRA hazardous waste, it was classified under Texas Law as a Class II industrial waste and could not be put into a municipal landfill. The costs of transporting the sludge to the closest industrial waste landfill were much greater than the alternative devised, which was to solidify and dispose of the sludge in a site with the approval of the Texas Department of Water Resources. Although the remedial approach was used for a non-hazardous waste oil, it is apparent that the same approach could be applied to similar sites where oily waste sludges are also defined as hazardous wastes.

The technology chosen was a sludge solidification process using cement kiln dust available locally. Instead of using only fresh kiln



dust (which is limited in supply because of outstanding contracts for the material) to mix and solidify with the sludge, a stale kiln dust was also used. The stale dust, which contains 38% moisture, is usually stockpiled in large quantities, is less expensive, and is a very effective solidifying agent.

The solidification procedure began with the three smaller ponds using stale cement kiln dust. A landfill was excavated next to the three ponds. Stale cement kiln dust was delivered to the bottom of the landfill and leveled by bulldozer into a 6 to 12 in. layer. A backhoe lifted the sludge out of the pits and on top of the kiln dust in the landfill. The bulldozer then mixed the dust and the sludge into one foot layers 3:1 and 2:1 dust to sludge ratios. A pulverizing mixer was then driven over the layer to completely homogenize the mixture. Each layer was air dried for approximately one day and then compacted and field tested to ensure proper compaction. This procedure continued until the contents of all three ponds were solidified in the landfill.

The largest pond solidification was somewhat different because the sludge was more liquid and the pond itself was several thousand feet from the landfill. Because of its more liquid nature, the sludge was solidified using both fresh and stale kiln dust. The procedure for solidifying the sludge incorporated the same layering process used for the three smaller ponds, however, the sludge was treated prior to placement in the on-site landfill.

Fresh cement kiln dust was blown into the sludge pond using a ratio of 1.5:1 dust to sludge. A backhoe mixed the dust into the sludge which semi-solidified the sludge. The semi-solidified sludge was loaded, transported to the on-site landfill, and unloaded onto a bed of stale kiln dust and mixed as previously described. As each side of the pond was excavated it was backfilled with clean dirt until all of the sludge had been removed and solidified in the on-site landfill. The coke/slag material was also removed from the remaining pond and mixed in with the sludge in the on-site landfill.

This entire process took approximately 75 working days using approximately 41,000 tons of kiln dust. This was much less than originally anticipated because the stale kiln dust solidified with the sludge better in the field than in the laboratory. The projected cost of \$500,000 had been based on an estimated use of 75,000 tons of kiln dust, however, the project cost only \$377,528. This was much less than the alternative of off-site disposal which was estimated to cost \$1,500,000.

Presently, the site is completely solidified, graded over, and covered with vegetation. It is awaiting sale for future development.

#### **Goose Farm Site—Plumsted Township, New Jersey**

The Goose Farm site is an abandoned hazardous waste drum burial site that was partially cleaned up in about a one year period from Aug. 1980 to Nov. 1981. The drum burial site is located in Plumsted Township, Ocean County, NJ in a region known as the Pinelands, a unique ecological area characterized by acidic sandy soils and low lying forests of pitch pine and oak.

From about 1945 to in the mid 1970s, Thiokol Corporation (a manufacturer of ammunition, rocket fuel, plastics, and organic fibers) dumped bulk and containerized hazardous wastes into a pit about 300 ft long by 50 ft wide by 15 ft deep, under contract with the site owner. In January 1980, township officials informed the New Jersey Department of Environmental Protection (DEP) of the existence of hazardous wastes at the Goose Farm site. Shortly thereafter, DEP conducted a preliminary investigation of the site, which revealed the discharge of contaminated groundwater as a surface seep to a nearby stream. During the next six months, site activities included sampling of the stream and groundwater from 17 monitoring wells, and reviewing regional geological data and well driller logs.

A report assessing the situation at Goose Farm was submitted in June 1980, which described a contaminated groundwater plume about 200 ft wide originating from the drum burial area and moving into the stream where it was discharging. The plume was also believed to be moving downward because of the geology in the area. Preliminary testing was inconclusive, but suggested potential

contamination of up to 60 ft in depth beneath the site, with the majority of contamination occurring within a depth of 40 ft.

Monitoring of the upper groundwater and surface seepage indicated that a large variety of inorganic and organic chemicals had been dumped, including chlorinated compounds, solvents, and pesticides. Levels of contaminants were highest for methylene chloride, benzene, and toluene, in the 100 mg/l range. Total organic carbon (TOC) concentration ranged from 1,600 to 17,000 mg/l. The report also indicated that the plume was not an immediate danger to any drinking water wells in the area, but if uncorrected could cause widespread contamination of the lower strata, a moderately used aquifer.

The state established the following objectives and hired an oil and hazardous waste cleanup contractor to carry out the following tasks:

- Obtain data to confirm contamination of the surface water by the Goose Farm site and to better define the extent of groundwater contamination
- Contain the discharge to the stream by pumping and treating the groundwater
- Remove the source of pollution, i.e. buried wastes and contaminated soil
- Further groundwater removal and treatment near the source area

Temporary containment measures such as the installation of an open or gravel filled cut-off trench were suggested but were not implemented.

The contractor proceeded with cleanup efforts, consisting of constructing a well-point treatment system to prevent the contaminant plume from discharging into the stream, and excavating, segregating, and treating the buried waste materials in the disposal area. The well-point system was located between the disposal area and the stream and was oriented in such a way as to intercept the contaminant plume. The well-point system consisted of about 400 ft of 6 in. aluminum header pipe with 100 well-points spaced about every 7.5 ft. The well-points were installed to a depth of 22 ft by water jetting. The system was pumped at a rate of about 50,000 to 75,000 gal/day to contain migration of the contaminants.

The collected groundwater was routed to a treatment system consisting of the following:

- A vacuum receiver which volatilized about 20% of the TOC in the stream
- Activated carbon adsorbers to treat the gaseous stream of the vacuum receiver
- A clarifier which reduced suspended solids and removed about 10% of TOC in the stream
- Multi-stage activated carbon adsorbers which removed about 70% of the initial TOC.
- After treatment, the effluent was spray irrigated

The final effluent from treatment had a TOC concentration of approximately 54 mg/l, a reduction of 96.6% to 99.7%.

Concurrently, waste removal operations were carried out in the pit area. During a 45 day period, over 4,880 drums and containers were excavated, analyzed, secured, and segregated. A backhoe and two specially designed drum grapples were used to complete removal operations. Salvagable drums were overpacked and stored on-site. Badly degraded drums were tested for acid-base compatibility and emptied into concrete holding tanks prior to disposal. In addition, about 3,500 tons of contaminated soil were excavated and temporarily stored, awaiting disposal.

After the drum pit area had been excavated, a second well-point system was installed in the pit area. Groundwater was pumped to the treatment system and the effluent was injected into the pit area via well points to flush contaminants from the underlying soils. The extraction well-points were first installed in the unsaturated zone to a depth of 7 to 13 ft and later lowered into the water table to collect groundwater contamination.

The groundwater treatment system was shut down in March 1981 before treatment was complete because of operating expenses.

Secured drums, bulked liquids, and contaminated earth were stored on site from March 1981 to Nov. 1981, awaiting funding for final disposal operations. In Nov. 1981, 4,400 tons of waste were transported in 200 truck loads to an approved waste disposal site. In addition, 12 drums of PCBs were transported to an approved hazardous waste incinerator.

#### Stroudsburg Site—Stroudsburg, Pennsylvania

The Stroudsburg site is located in the Borough of Stroudsburg, Monroe County, Pennsylvania, along the shores of Broadhead Creek at the site of a historical coal gasification plant once operated by Stroudsburg Gas Co. From the late 1800s to the early 1900s, one of the disposal methods practiced on site for the disposal of coal tar residuals was to inject the waste material into the ground through an injection well, located in the northwestern quadrant of the plant property. The well was constructed such that the waste products were injected into the gravel alluvium that underlies the plant area, approximately 20 ft below the surface.

In 1947, Pennsylvania Power and Light Company (PP&L) purchased several parcels of land from Stroudsburg Gas Co., most of which were located along the shores of Broadhead Creek. In Oct. 1980, during maintenance construction of the flood control levees along the western shore of Broadhead Creek, a black, odorous material was observed seeping from the base of the dike at several locations along the side of the stream.

The incident was reported to the Pennsylvania Department of Environmental Resources (DER), Bureau of Water Quality and investigations commenced to determine the nature and extent of the contamination. A preliminary assessment of the situation was made in March 1981 and at this time the DER requested the assistance of the USEPA in the further investigation of the problem. The investigative field studies that followed were conducted by DER, USEPA and the Pennsylvania Fish Commission (PFC) and involved the following areas:

- The hydrogeology of the site area
- The impact of the coal tar on stream quality and its biological community, and
- The erosional behavior of the stream

The remedial actions that were taken at the Stroudsburg site involved several technologies. The initial remedial response to the problem was conducted by USEPA in April 1981 under section 311 of the Clean Water Act (Public Law 92-500) and involved the installation of filter fences, sorbent booms and inverted dams. These installations were temporary structures constructed to prevent direct and immediate coal tar seepage into Broadhead Creek.

As field investigations continued, it was decided that actions permissible under section 311 (i.e., emergency, oil spill response actions) would not sufficiently remedy the pollution problem at the Stroudsburg site. A more reliable and permanent remedial system was necessary. In Nov. 1981, funds were appropriated under Superfund, establishing Stroudsburg as the first site to receive Superfund monies.

Also in Nov. 1981, PP&L began installation of a recovery well system to remove the coal tar from the stratigraphic depression. An estimated 35,000 gal of coal tar had accumulated in the depression. The project, completed in late spring of 1982, consists of four well clusters each containing four wells.

Presently, only one central well of one of the clusters is in operation and the recovery rate is less than had been anticipated. The original recovery rate predicted was approximately 100 gal/day. The present rate is between 20-25 gal/day. This situation was primarily caused by an over calculation of the quantity of concentrated coal tar present. Much of what exists is actually a mixture of coal tar and water, which was not realized until the wells had already been installed. Approximately 7,500 gal of pure coal tar (95% have been recovered to date). The recovered residue is sold to Allied Chemical in Detroit, MI, where it is used as fuel.

Concurrent with PP&L's project, USEPA constructed a cement-bentonite slurry trench cut-off wall along the west bank levee. The containment wall is 700 ft long, one foot wide and 17 ft deep. The downstream end of the barrier is horizontally keyed into an impermeable curtain formed by pressure grouting. The upstream end is keyed into the sheet piling wall that exists below the concrete flood wall. The slurry wall extends over the area of observed seepage and passes vertically through the gravel layer that bears the contaminant and is keyed two feet into the underlying sand stratum. A total of eight monitoring wells were installed for monitoring slurry wall performance and sampling groundwater in the area. Four wells are located on either side of the wall.

In Jan. 1982, following slurry wall construction and the installation of the monitoring well system, the contaminated material in the back water channel was excavated, drummed and disposed of at a secure landfill. Throughout all the activities undertaken at the Stroudsburg site, materials meant for disposal were packed in drums and stored on-site until appropriate disposal sites were located.

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# CONCEPTUAL DESIGNS AND COST SENSITIVITIES OF FLUID RECOVERY SYSTEMS FOR CONTAINMENT OF PLUMES OF CONTAMINATED GROUNDWATER

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## INTRODUCTION

At least one nationwide study<sup>7</sup> has shown that removal and treatment of contaminated fluids from wells or drains is the most commonly used method for controlling the movement of a plume of contaminated groundwater. Other methods, such as fluid encapsulation within subsurface physical barriers and *in-situ* treatment or fixation, are being researched and applied, but those involving fluid removal probably will continue to be the most popular on the basis of their cost and reliability.

The purpose of the authors in writing this paper is: (1) to describe simple hydraulic models for making conceptual designs and cost estimates for recovery-well systems, and (2) to examine the general sensitivities of recovery system costs to selected plume and aquifer characteristics. The costs presented are for simplified scenarios of contamination, which represent a foundation upon which more complex models can be built. Although the more complex models are increasingly being applied in the detailed design and evaluation of systems of recovery wells, there is and will continue to be a place for simpler mathematical models that can provide rough estimates of system discharge and number/size of recovery wells.

The costs apply only to engineered structures and related services for a containment system, with other cost elements such as source removal, land purchase, legal services, etc., not included. Also, the paper is concerned not only with containment and treatment of contaminated groundwater, but also with total cleanup of the site and the aquifer. The findings are derived from background work performed for Sobotka & Company, Inc., in conjunction with the Economics and Policy Analysis Branch Office of the Office of Solid Waste, USEPA. The contents do not necessarily reflect the views and policies of the USEPA.

## Fundamental Concepts of Containment

"Plume containment" is defined in this paper as stopping further migration of a plume of contaminated groundwater by removing the contaminated water through wells located inside the plume boundaries. Complete hydrodynamic containment can be achieved only when limiting flowlines or groundwater divides are maintained outside the plume boundary.

An idealized elliptical-shaped plume occupying part of a groundwater flow field is shown in Fig. 1A) and how a discharging well located at the downgradient end of the plume creates limiting flowlines around the plume is shown in Fig. 1B. All contaminated water within the plume is thereby induced to move toward the well. Depending upon the hydraulic properties of the aquifer and the dimensions and depths of a plume, more than one well may be needed to achieve total containment.

The approach illustrated is feasible only when the plume is moving in essentially one direction in response to the local hydraulic gradient. In more complex situations where, for example, a plume originating from a source of contamination is spreading radially, the need is to create a groundwater divide outside the plume

boundary by operating multiple recovery wells properly located inside the plume.

## Factors Affecting Design and Cost

The interrelationships of the technical factors or elements that can significantly affect the design and costs of a recovery-well system are shown in Fig. 2. These factors are grouped, as indicated, under three major categories pertaining: (1) to the plume itself, (2) the aquifer in which the plume is moving, and (3) the engineering aspects of the well system. The factors in the lowest tier of the diagram are the ones to be quantified in order to make an overall evaluation of the design and costs.

The analysis is restricted to the major driving variables relating to the dimensions and flux of the plume and to the hydraulic properties of the aquifer. All other factors along the lowest tier were held constant except for well discharge which was computed with a hydraulic model for each cost scenario.

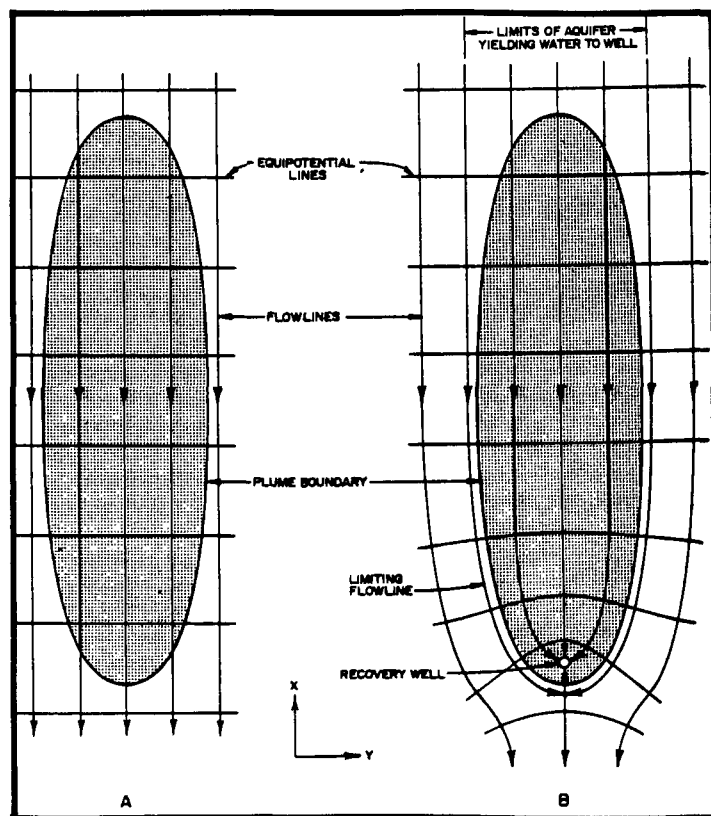


Figure 1.  
Control of plume movement with a single recovery well

## MODEL ASSUMPTIONS

The strategy illustrated in Fig. 1 is applicable to all aquifer and plume conditions regardless of their complexity. For this study, however, aquifers are assumed to be single layers of homogeneous and isotropic porous media, and are considered to be infinite in areal extent and underlain by impermeable rocks. No distinction is made between confined and unconfined aquifers, and flow is assumed to be essentially steady and horizontal.

Plumes are assumed to be single-phase homogeneous mixtures of groundwater and leachate, with an elliptical shape in plan view. In the vertical dimension, plumes are assumed to occupy the full aquifer thickness. Contaminant concentrations are assumed to be diluted in order to apply hydraulic models for fluids having a density equal to that of water. Finally, contaminant transport mechanisms that involve mechanical dispersion and chemical diffusion are ignored.

As shown on Fig. 3, an optimum solution is determined with successive approximations. Total discharge,  $Q$ , is initially calculated with Eq. 1,\* and is assigned to a single hypothetical recovery well.<sup>1</sup> The hypothetical well is located inside the downgradient limit of the plume at a distance,  $x_0$ , from the stagnation point downgradient of the well, as determined with Eq. 2 which is based on the work of Forchheimer.<sup>2</sup> A two-dimensional Cartesian coordinate system is established with the recovery well at the origin. The plume boundary can be mapped and the limiting flowlines can be plotted with Eq. 3 from Forchheimer.<sup>2</sup> Discharge from the well is increased in small increments until the flowlines bound the plume up to the widest point, beyond which the plume is narrower and remains within the limiting flowlines.

\*For all equations, see Fig. 3.

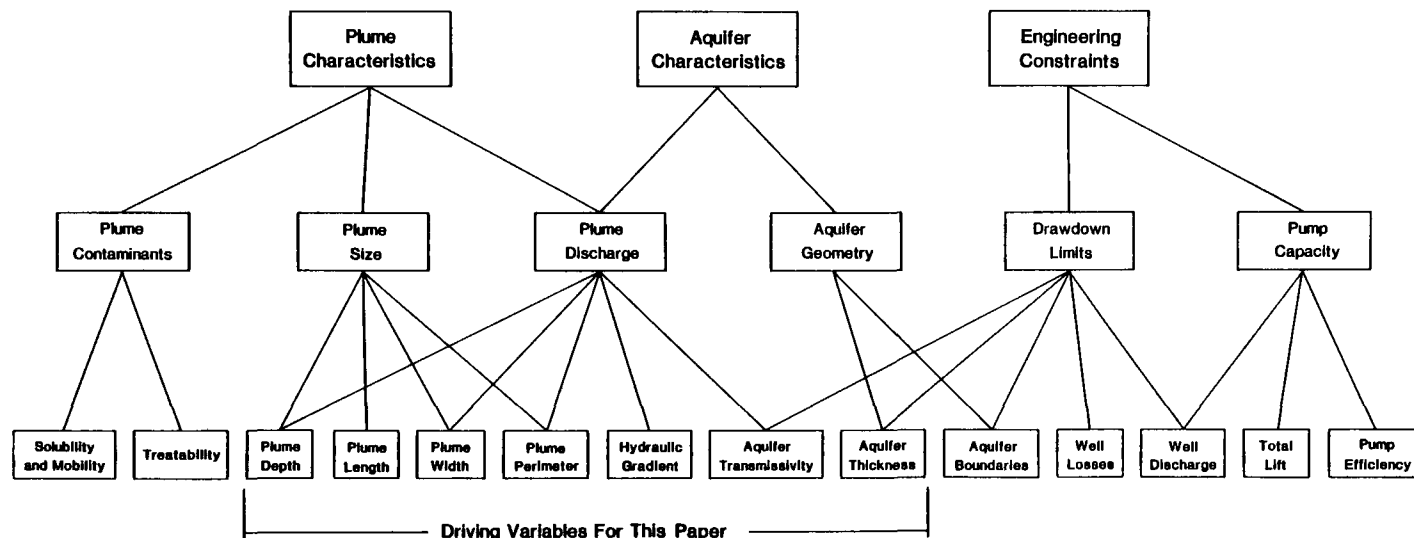


Figure 2.  
Factors that affect hydrodynamic containment, design requirements and costs

## CONTAINMENT STRATEGY AND HYDRAULIC MODELS

The containment strategy illustrated in Fig. 1 translates into an algorithm that uses hydraulic models for determining the location, number, and discharge of wells to contain a simple plume within limiting flowlines. The algorithm is shown as a generalized flowchart in Fig. 3 with a sequence of equations that simulate conditions at various steps. Variables used in the equations are defined in the Appendix to this paper. Data needed for the application of the strategy include plume dimensions (width, length, and general shape), the hydraulic gradient across the plume, and the transmissivity of the contaminated aquifer.

A feasible solution to the containment strategy must satisfy three constraints:

- The recovery system is located near enough to the downgradient plume boundary to reverse the hydraulic gradient at that boundary
- Total discharge is large enough to create limiting flowlines that bound the plume up to its widest part upgradient of the well system
- Drawdowns of water levels resulting from withdrawals from the system do not exceed limits that are a function of aquifer saturated thickness

An "optimum" feasible solution is defined as the minimum number of wells pumping the smallest discharge that meets the above constraints. These data may be modified by engineering safety factors to become the "design requirements" of the well system.

Having calculated the total discharge for a single-well system, the system discharge is apportioned among several wells in order to accommodate a practical limit on water-level drawdowns in the wells. In an array of wells, the drawdown will be greatest at the most central well, owing to well interference. Eq. 5 is one of several analytical solutions to the groundwater flow equation that can be used to compute drawdowns.<sup>9</sup> Wells are added on Fig. 1 along the y-axis of the coordinate system, in a line orthogonal to the hydraulic gradient. As more wells are added, the calculated discharge per well decreases and eventually the drawdown constraint is satisfied. In some cases, as in formations of very low transmissivity, the number of hypothetical wells becomes so large that the most practical design solution becomes a drain. When more than one recovery well is required, the shape of the limiting flowlines is altered slightly, however, this has a negligible effect on conceptual designs and costs of the recovery system.

## COST SENSITIVITIES

The sensitivity of recovery-well system costs to varying aquifer and plume conditions is qualitatively determined with selected cost scenarios. Non-complex conditions were assumed for the site, the aquifer, and the contaminant plume. As mentioned previously, other factors such as complex waste streams, conflicting property boundaries, litigation requirements and public opposition are not considered. These situations, however, can result in order-of-magnitude increases in total containment costs. In some instances, legal fees and public relations costs alone can be in the millions of dollars. Thus, the ranges presented are selected to demonstrate

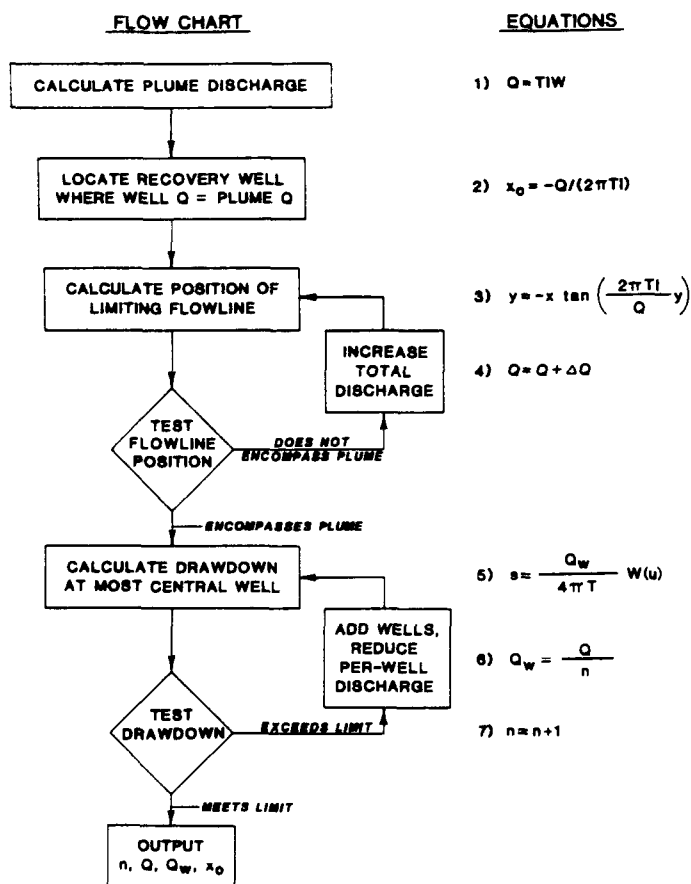


Figure 3.

Flow chart and equations for basic containment strategy

technical cost sensitivities and not to indicate total costs of remediation.

### Cost Components

The principal capital (K) cost components of fluid recovery systems include: plume delineation, system design, wells/drains, additions to surface infrastructure, and water-treatment facilities. Both capital and operation and maintenance (O&M) cost elements for each component are listed in Table 1.

Plume delineation includes determination of the areal and vertical extent of the plume, and the rate and direction of local groundwater flow. System design includes hydraulic modeling and the specification of the number, location, and yield of the wells. Pump capacity, well design, and completion method are also specified. Additions to the surface infrastructure include access roads, power transmission lines, and fluid handling (pipes) capabilities, which must be provided and integrated with the water-treatment facility. The recovered water is assumed to contain levels of less than 100 µg/l of a single organic contaminant such as TCE (Trichloroethylene). This frequently occurring contaminant is assumed to be treatable by filtration through activated carbon.

Associated with these K-cost components are annual operating and maintenance costs for the well/pump system, the treatment system, and to a lesser extent surface piping, power, and access roads. Monitoring costs will also be incurred for verification of plume containment through water-level measurements and analysis of water samples.

Plume delineation, system design, well system installation, and monitoring costs are based on several published sources,<sup>3,4,7,10</sup> manufacturer's catalogues, quotes from distributors, and professional experience. Infrastructure costs were based on recent work performed by SCS Engineers,<sup>4</sup> whereas treatment costs are based on data from Gumerman, Culp, and Hansen.<sup>5</sup>

**Table 1.**  
Overview of system components

Cost Component (K, O&M)	Cost Elements	Principal Factors Affecting Cost
Plume Delineation (K)	Soil borings Monitor wells Data analysis Laboratory analysis Reporting	Plume area & depth Complexity of hydrogeology
System Design (K)	Consulting fees Computer time	Complexity of hydrogeology Size of containment system
Well System (K)	Construction engineering Well construction Materials	Plume size Aquifer flux Transmissivity
Surface Infrastructure (K)	Access roads Power transmission Piping	Plume size Configuration of wells
Treatment Facility (K)	Construction engineering Treatment system	System discharge Composition/concentration of recovered water
Well System (O&M)	Pump operation (power) System maintenance	Aquifer flux/pumping depth Fluid corrosivity
Treatment Facility (O&M)	Chemicals Labor Power	System discharge Composition/concentration of recovered water
Monitoring	Sampling Analysis Reporting	Complexity of system
Plume Delineation (K)	Soil borings Monitor wells Data analysis Laboratory analysis Reporting	Plume area & depth Complexity of hydrogeology
System Design (K)	Consulting fees Computer time	Complexity of hydrogeology Size of containment system
Well System (K)	Construction engineering Well construction Materials	Plume size Aquifer flux Transmissivity
Surface Infrastructure (K)	Access roads Power transmission Piping	Plume size Configuration of wells
Treatment Facility (K)	Construction engineering Treatment system	System discharge Composition/concentration of recovered water
Well System (O&M)	Pump operation (power) System maintenance	Aquifer flux/pumping depth Fluid corrosivity
Treatment Facility (O&M)	Chemicals Labor Power	System discharge Composition/concentration of recovered water
Monitoring	Sampling Analysis Reporting	Complexity of system

### Cost Scenarios

To show the relative importance of well-system costs to other cost elements of the system, eight hypothetical scenarios have been evaluated. In these scenarios, plumes are assumed to be elliptical in plan view with the following range of dimensions:

- 250 to 2500 ft wide
- 500 to 5000 ft long
- 25 to 250 ft deep

Plumes are assumed to be moving in unidirectional flow fields representing low to high aquifer flux (0.05 to 1.0 mgd/mile). A relatively small transmissivity (5,000 gal/day/ft) is assigned to four high-flux scenarios and a large transmissivity (100,000 gal/day/ft) is assigned to four low-flux scenarios. Outputs of the analysis concerning numbers of wells and pumping rates are summarized in Table 2 while the costs of each element in the analysis are given in Table 3.

### Discussion of Sensitivities

How the cost components are effected by order-of-magnitude changes in plume size and aquifer flux is shown in Table 3. Plume delineation costs tend to be the largest cost component for all scenarios, but are only influenced by size variables. Delineation costs and both K- and O&M-costs of wells are moderately sensitive to depth. System discharge is directly proportional to plume flux and hence increases directly with plume width as indicated by Eq. 1. Although the data in Table 2 indicate that system discharge varies by a factor of 200 (from 2 to 400 gal/min), corresponding

**Table 2.**  
**Summary of design parameters**

Flux = 0.05 mgd/mile width Transmissivity = 100,000 gal/day/ft	Number of Wells	Well Discharge Discharge (gal/min)
250 x 500 x 25	2	2
250 x 500 x 250	2	2
2500 x 5000 x 25	2	20
2400 x 5000 x 250	2	20
Flux = 1.0 mgd/mile width Transmissivity = 5,000 gal/day/ft		
250 x 500 x 25	4	40
250 x 500 x 250	4	40
2500 x 5000 x 25	a	400
2500 x 5000 x 250	4	400

<sup>a</sup>Drawdown constraint forces use of drain instead of well.

total K- and O&M-costs vary by factors of less than 5. The plume delineation costs and the assumption of a non-complex waste stream for treatment together prevent system discharge from having a more significant influence on total costs.

Capital costs of well systems range from about 7 to 30% of the total capital costs, while corresponding O&M-costs for wells range from 37 to 57% of the total O&M-costs. Although well system costs are relatively small, discharge from the system influences infrastructure and treatment costs. In a few scenarios these two elements may become significant and can account for up to 40% of K-costs and up to 67% of O&M-costs.

The principal design parameters for each plume in the low-flux case indicate minimal variability in the number of wells and the discharge needed to contain both the smaller and larger plumes. Total capital costs vary from \$180,000 to a high of \$750,000. Operating and maintenance costs vary from about \$30,000 to \$35,000 per annum.

In the low-flux scenarios, delineation and modifications to surface infrastructure represent the dominant difference in cost among plume sizes. Changes in delineation costs are attributed to the larger number and increased depth of monitor wells required for delineation of a larger and deeper plume. Surface infrastructure costs increase in proportion to the surface area of the plume and to system discharge.

The high-flux scenarios (Table 2) require a greater number of wells to handle larger plume fluxes; this is the result of combining the higher flux with the lower transmissivity. Also, a hydraulic drain is required for the high flux scenario involving a large plume in a relatively shallow aquifer, in order to meet the limit on drawdown, which is set at 50% of saturated thickness. Due to greater depth of aquifer, and hence greater available drawdown, no additional wells are needed in the deeper large plume.

In the high-flux scenarios, the well system and treatment costs become more significant compared with costs of delineation, due to the larger volumes of recovered water. Annual operation and maintenance costs are still minimal compared with the capital cost components.

## CONCLUSIONS

In this paper the authors have presented a method for determining the conceptual design and cost of a fluid recovery system needed to provide hydrodynamic containment of a plume of contaminated groundwater. The method utilizes existing hydraulic models and is applicable to elliptical plumes moving in response to unidirectional gradients within an aquifer.

Cost scenarios developed for this paper indicate that recovery well systems represent a relatively small part of total capital costs but as much as 57% of total O&M costs. Discharge from the recovery system affects infrastructure and treatment costs and, in rounded figures, can control as much as 60% of capital costs and 90% of O&M costs. For more complex waste streams than that assumed for the cost scenarios, system discharge will have an even greater influence on costs.

After delineation costs have been incurred at a site, recovery sys-

**Table 3.**  
**Summary of Eight Recovery System Cost Scenarios**

AQUIFER AND PLUME CHARACTERISTICS	DELINEATION (K)	DESIGN (K)	WELLS / DRAINS (K)	SURFACE INFRASTRUCTURE (K)	TREATMENT FACILITY (K)	WELLS / DRAINS (O&M)	TREATMENT (O&M)	MONITORING (O&M)	TOTAL K	TOTAL O&M
<u>Low Flux, High Transmissivity</u> (plume width x length x depth, ft)										
(250 x 500 x 25)	75 <sup>a</sup>	25-100	15	35	30	15	<5	10	180-255	30
(250 x 500 x 250)	150	25-100	50	35	30	20	<5	10	290-365	35
(2500 x 5000 x 25)	200	25-100	15	150	40	15	5	10	430-505	30
(2500 x 5000 x 250)	400	25-100	60	150	40	20	5	10	675-750	35
<u>High Flux, Low Transmissivity</u>										
(250 x 500 x 25)	75	25-100	30	35	50	15	15	10	215-290	40
(250 x 500 x 250)	150	25-100	110	35	50	20	15	10	370-445	45
(2500 x 5000 x 25)	200	25-100	45	150	110	15	50	10	530-605	75
(2500 x 5000 x 250)	400	25-100	130	150	110	45	50	10	815-890	105

<sup>a</sup> Cost in thousands of dollars

tem discharge is the most critical design criterion needed for estimating costs of remedial options that involve hydrodynamic containment of a plume. System discharge is related to aquifer transmissivity, hydraulic gradient, and plume width. A recovery system must intercept the plume discharge; however, when wells are located inside the plume boundaries, modeling of the limiting flowlines shows that recovery system discharge is generally larger than plume discharge. The increase over plume discharge is controlled by plume shape, and varies with the ratio of plume width to length. Plume depth and changes in the aquifer saturated thickness were treated as having no effect on discharge. Rather, modeling showed that they greatly influence the depth, number, and spacings of recovery wells.

For the idealized scenarios tested, total capital costs range from \$180,000 to \$890,000 and annual operating and maintenance costs range from \$30,000 to \$105,000. Because of the common occurrence of complex hydrogeologic and/or contaminant-quality conditions, it is felt that the costs represent the low end of costs typically encountered in the field. These parameters, plus factors such as public and legal pressures, could easily increase total capital costs an order of magnitude higher than the basic costs quoted in this paper. Continued cost estimation work for more complex site conditions will result in an improved methodology for estimating costs for a wider variety of scenarios.

#### APPENDIX—DEFINITION OF VARIABLES

I	—Hydraulic gradient across plume	[dimensionless]
n	—Number of recovery wells	[dimensionless]
Q	—Volumetric discharge through a part of an aquifer that encompasses the plume	[L <sup>3</sup> /T]
ΔQ	—Incremental change in discharge from the recovery system	[L <sup>3</sup> /T]
Q <sub>w</sub>	—Discharge of an average well in a multiple-well recovery system	[L <sup>3</sup> /T]
S	—Drawdown caused by pumpage from recovery well(s)	[L]

T	—Aquifer transmissivity	[L <sup>2</sup> /T]
W	—Maximum width of plume measured at right angles to gradient	[L]
W(u)	—Well function of u	[dimensionless]
x, y	—Cartesian coordinates	[L]
x <sub>0</sub>	—Distance from stagnation point to single recovery well creating limiting flowline	[L]

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# PLANNING SUPERFUND REMEDIAL ACTIONS

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## INTRODUCTION

The remedial action program is a key part of the Superfund mandate to clean up uncontrolled hazardous waste sites across the nation. The USEPA has developed a remedial planning process embodied in the National Contingency Plan (NCP) that ensures rapid, consistent, and rational decision-making on the appropriate extent of remedy at priority hazardous waste sites. The process will be applied to individual sites to ensure that projects focus on remedial action in an effective manner. A flow diagram illustrating the major steps in the remedial action process is shown in Fig. 1.

In this paper, the authors review five elements of the remedial planning process: (1) the remedial action master plan, (2) remedial investigations, (3) feasibility studies, (4) selection of a remedial alternative, and (5) remedial design. For each of these activities, the authors discuss both the technical considerations and the procedural requirements for conducting and submitting a complete product. The emphasis in this paper is on remedial investigations and feasibility studies, which form the basis for determining the appropriate extent of remedy and the cost-effective remedial alternative at an uncontrolled hazardous waste site.

## REMEDIAL ACTION MASTER PLAN

A remedial action master plan (RAMP) is generally prepared for sites that have been ranked as a priority on the national Priorities List (or Interim List) and selected for remedial action. The RAMP acts as both a general planning document and an effective site management tool. It contains the information necessary for planning a coherent strategy and for assisting in the selection of an appropriate course of action.

The preparation of the RAMP is the responsibility of the Regional EPA office working closely with the State. The RAMP contains available site information, such as site inspection sampling data, maps and topographical information, previous corrective actions, and available cost estimates, indicates where data gaps exist, and presents and justifies the scoping decision on which type or types of remedial action should be initiated or studied.

The scoping decision is a preliminary determination of the general category of remedial action needed, based on the complexity, imminence, and extent of the hazard at the site. Three types of remedial action are identified in the NCP: (1) initial remedial measures, (2) source control remedial actions, and (3) off-site remedial actions. The scoping decision selects which of these three actions or combinations of actions may be appropriate for the site, either for rapid implementation (initial remedial measures) or for further study and design (source control and/or off-site remedial actions).

### Initial Remedial Measures

Initial remedial measures may be appropriate when straightforward solutions are available for relatively simple problems. These measures must be able to limit either actual or potential exposure to a significant health or environmental problem. Examples include construction of fences, stabilization of dikes or waste impoundments, temporary provision of alternative water supplies, and removal of drums stored above ground.

### Source Control Measures

Source control remedial actions may be appropriate if a substantial concentration of hazardous substances remains at or near

## REMEDIAL ACTION PROCESS

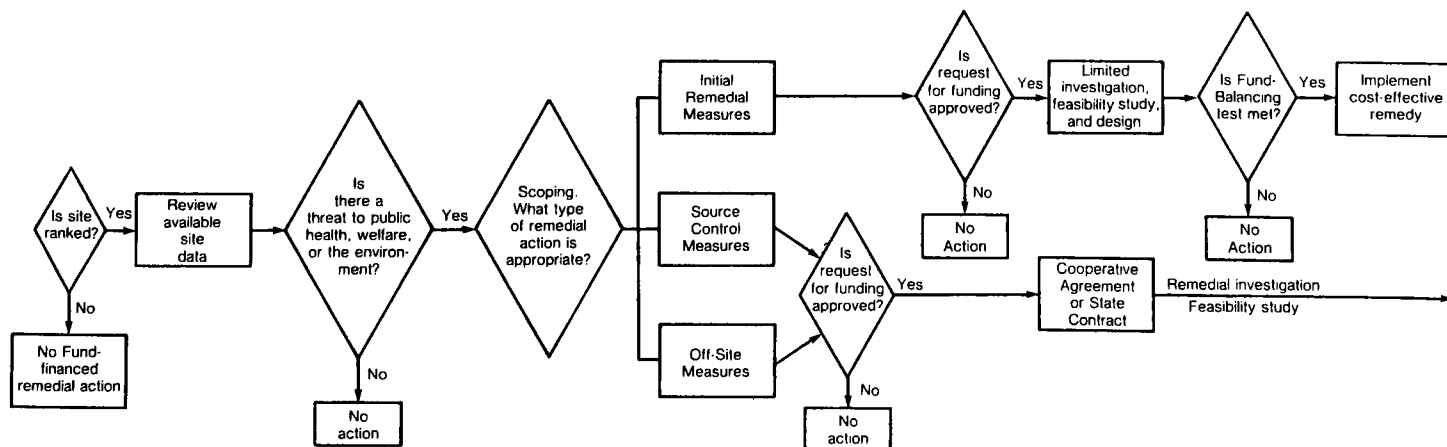
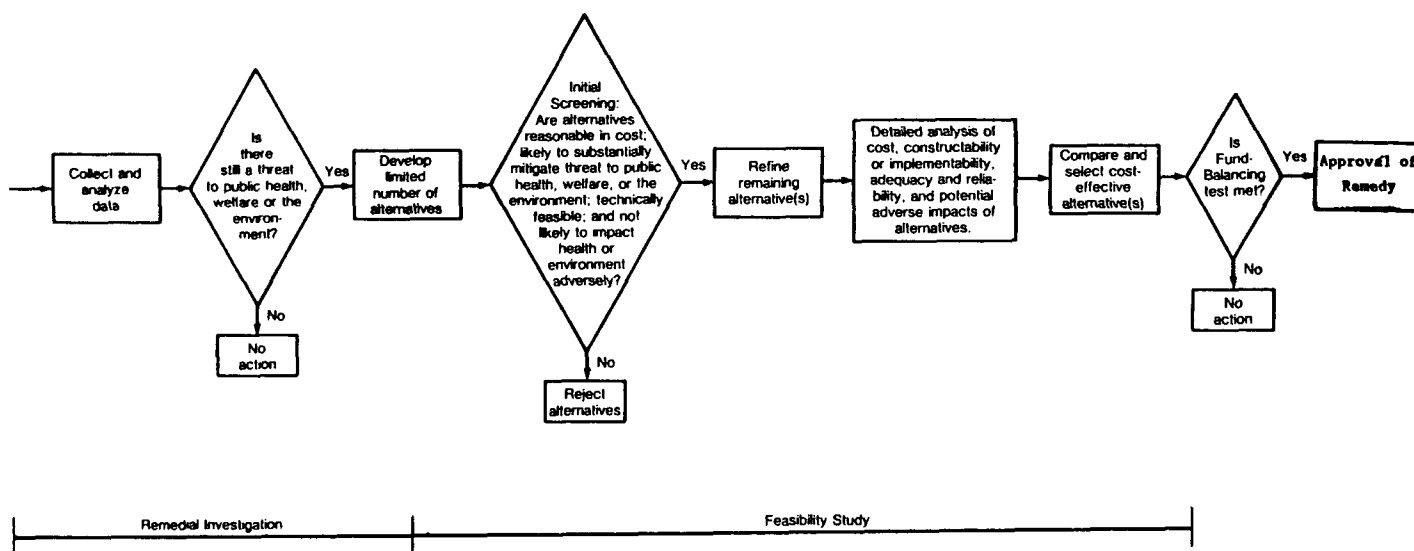


Figure 1.  
Remedial Action Process

## Remedial Action Process (continued) Remedial Investigation/Feasibility Study Phases



the area where they originally were located and the substances are inadequately contained from migration into the environment. Examples of source control actions include installation of grout curtains, trenches and drains, closure of surface impoundments, placement of caps over contaminated areas, leachate collection and treatment systems, and excavation and off-site disposal of contaminated soil or buried drums.

#### Off-Site Measures

Off-site remedial actions may be appropriate in some situations to minimize and mitigate the migration of hazardous substance and the effects of such migration. Off-site remedial actions may, for example, include provision of permanent water supplies, control of a contaminated aquifer, treatment of a contaminated drinking water source, dredging of contaminated river sediments, or relocation of affected population.

If the scoping decision indicates that initial remedial measures are called for, based on the criteria listed in the NCP, then a "fast-track" implementation is possible. Planning for Fund-financed initial remedial measures will generally not run longer than six months; and in many cases can be much shorter. Planning will include: (1) negotiation of a state cooperative agreement or contract, (2) a remedial investigation focused on the initial measures, (3) a limited analysis of alternatives which demonstrates the cost-effectiveness of the measures proposed, and (4) a limited remedial design to prepare contract documents needed for competitive bidding.

In essence, the process for implementing initial remedial measures is a limited and expedited version of source control and off-site remedial actions. Because of their limited nature, initial remedial measures can be implemented while planning for source control or off-site actions is underway. However, the determination must be made that an initial remedial measure is cost-effective, or will be a necessary part of any possible cost-effective source control or off-site remedy. More detailed and extensive remedial investigations and feasibility studies are needed for most source control and off-site actions because of their increased complexity and cost.

Following development of the RAMP, a request for funding an initial remedial measure or a remedial investigation/feasibility study for source control or off-site actions is submitted. Usually, the remedial investigation and feasibility study are conducted as one project, although they are discussed separately below. These studies begin after the negotiation and signing of a state contract or cooperative agreement between the State and USEPA, which outlines the responsibilities of the Federal and state governments with

respect to management of the remedial action at a particular site.

#### REMEDIAL INVESTIGATION

The remedial investigation is conducted to assess the problem at a site and collect data necessary for its resolution. Investigation activities must be carefully planned to obtain essential information while minimizing costs. During the investigation phase, activities are continually assessed to determine whether all the planned investigation activities are actually needed in light of new information as it is obtained. The output resulting from the remedial investigation is a data base adequate to justify the need for site remedial action, and to support the selection and analysis of alternatives in the feasibility study.

#### Scope

The following provides examples of the scope of each type of remedial investigation that would be associated with the three types of remedial action.

- Remedial investigations for initial remedial measures may involve sampling wastes contained in drums to test for compatibility, as well as other limited sampling and monitoring efforts specifically needed to select or make effective use of initial remedial measures.
- Remedial investigations for source control remedial actions may involve more intensive sampling, surveys, and monitoring efforts, focused at or near the area where the hazardous substances originally were located. Limited off-site investigations may be included when necessary to document the migration of contamination to other areas.
- Remedial investigations for off-site remedial actions should use all existing information and may involve extensive data collection activities. These remedial investigations may be more extensive in terms of the area covered and the extent of monitoring and sampling.

In special situations, a remedial investigation for off-site actions may be combined with remedial investigations for initial remedial measures or source control action. A combination of source control and off-site action investigations would be appropriate when wastes have migrated off-site, but a significant amount still remains on site, or when available data are not adequate to determine whether either type of action, on its own, will provide the solution to site problems. The scoping decision about the type of remedial action needed may be revised as additional information is gathered during the remedial investigation, and the remaining investigation and subsequent feasibility study may be revised to focus

on source control or off-site actions, as appropriate.

Normally, however, remedial investigations for off-site action are treated separately from other remedial investigations and funded only if there is substantial evidence of a threat to public health from contamination that has migrated beyond the area where the hazardous substances were originally located, and significant reason to believe that Fund-financed action can achieve adequate protection of public health, welfare, and the environment.

#### Activities and Tasks

Typically, remedial investigations involve a sequence of activities and tasks, such as the following:

- Preliminary work to prepare for site investigations. This may include site visits, definition of boundary conditions, preparation of a site map, and establishment of a site office if necessary.
- Site investigations. These may include, as appropriate waste characterization, hydrogeologic investigations, soils and sediments investigations, surface water investigations, and air investigations. These can include magnetometer, resistivity, and other remote sensing activities.
- Identification of preliminary remedial technologies and categories of remedies that may be appropriate.

#### Data Needed

A major purpose of a remedial investigation will be to provide data to support the selection of a remedial action. An investigation for source control actions should provide answers to questions such as the following:

- Should an impermeable barrier and clay cap be used to prevent contamination of groundwater?
- Is incineration or reclamation a viable option?
- Is on-site treatment a viable option, and if so, what category of treatment (e.g., biological, physical, chemical, thermal) should be investigated?
- Will substances continue to migrate off-site if no action is taken?

A remedial investigation for off-site measures should address questions such as:

- Does the volume of contaminated groundwater make treatment impracticable?
- Are reliable technologies available to treat the identified contaminants at the site?
- Do technologies exist to effectively remove contaminated sediments from the site?
- Will the off-site contamination continue to pose a threat if no action is taken?
- Will the action assure the future use of the affected resource (e.g., continued supply of drinking water from a threatened aquifer)?

The final report of the remedial investigation presents the data collected and the results of the site investigations in relation to the preliminary remedial technologies developed.

Additional requirements during both the remedial investigation and feasibility study include the submission of periodic technical progress reports and financial management reports by the contractors; assistance in development and implementation of community relations plans, conduct and documentation of sampling and analyses in accordance with chain-of-custody procedures, development of a safety plan for personnel on site, and a quality assurance/quality control plan for all sampling, analysis, and data handling.

#### FEASIBILITY STUDY

The feasibility study is conducted for the purposes of developing and evaluating alternatives, recommending the appropriate cost-effective remedial action, preparing an environmental assessment, and developing a conceptual design for the recommended action. The NCP decision process involves the development of alternatives, initial screening, and detailed analysis of the remaining alternatives. For some sites, this process can be accomplished ex-

peditionally. In other cases, the process will require many iterations of alternatives development, screening, and refinement. Described below is the basic sequence of tasks undertaken in the feasibility study.

#### Development of Alternatives

This task involves the establishment of remedial response objectives, the identification of appropriate remedial technologies, and incorporation of objectives and technologies into site-specific remedial alternatives. Alternatives should include non-cleanup options (e.g., alternative water supply, relocation) as well as a no-action option.

#### Initial Screening of Alternatives

The alternatives are screened on the basis of the following considerations: cost, effects on health and the environment, and engineering feasibility. During this screening process, USEPA encourages project review meetings, with the participation of USEPA and state representatives, and the engineer conducting the feasibility study, if appropriate. USEPA believes these working meetings will be useful for a variety of purposes: to solve any problems that have arisen in developing and screening alternatives; to ensure that the alternatives under consideration are reasonably likely to represent final alternatives; and to enable planning for necessary reviews by USEPA and other federal agencies.

#### Detailed Analysis of Alternatives

This task involved a detailed development of remaining alternatives, a cost analysis, an environmental assessment, and an evaluation and recommendation of the cost-effective alternative. Alternatives remaining after screening should be developed to include the following factors, as appropriate:

- Description of appropriate treatment and disposal technologies
- Special engineering considerations required to implement the alternative (e.g., pilot treatment facility)
- Environmental impacts and proposed methods for mitigating any adverse effects
- Operation, maintenance, and monitoring requirements of the completed remedy
- Off-site disposal needs and transportation plans
- Temporary storage requirements
- Safety requirements for remedial implementation
- A description of how the alternative could be phased into individual operable units
- A description of how the alternative could be segmented into areas to allow implementation of differing phases of the alternative

Each alternative should be described using these factors or other descriptive information needed to complete the cost-effective evaluation described at the end of this section.

#### Analysis of Costs

Cost estimation is an essential part of the detailed analysis of alternatives. In performing the cost analysis, both monetary costs of the remedial alternatives and associated non-monetary costs should be evaluated.

Monetary costs should be calculated in terms of the present worth of the remedial alternatives over the planning period. Cost estimates should be adequate to cover the effective and dependable operation of the remedial measure during the remedial action planning period. This period is the lesser of: (1) the period of potential exposure to the contaminated materials in the absence of remedial action; or (2) 20 years. The same planning period is used for each remedial action alternative considered.

Cost Estimation. Monetary costs of a remedial action alternative include direct and indirect capital costs and direct and indirect operating costs. Direct capital costs might include acquisition of land, right-of-ways, or easements; acquisition and installation of facilities, structures, equipment, initial supplies, or other assets,

and relocation costs. Indirect capital costs would include costs of design engineering, field exploration and engineering services, start-up costs such as operator training, overhead and profit, and contingency allowances consistent with the cost estimates' level of precision and detail. Direct operating costs include annual recurring costs for operation and maintenance such as labor, materials, utilities, and transportation and disposal. Indirect operating costs include administrative overhead and profit on direct operating costs.

The various components of costs are calculated on the basis of market prices prevailing at the time of the cost analysis (i.e., the entire analysis is performed in real dollars denominated in the year of the analysis). Revenues generated through recovery of energy or other resources, and accruing to the party or parties financing the remedial action, are deducted from the costs of the remedial action. The analysis should also include out-of-pocket costs to the local community resulting from alternatives such as relocation or provision of alternate water supplies.

Based on available information at the time of the study, the cost analysis should also clearly show estimates of costs to the Fund over the planning period for each remedial action alternative.

**Discount rate.** The most recent rate mandated by the Office of Management and Budget—currently 10%—should be used in the feasibility study.

**Salvage Value.** Land purchased for remedial measures, including land used as part of the treatment process or for ultimate disposal or residues, where complete restoration of the land to original conditions is not expected, may be assumed to have a salvage value at the end of the planning period less than or equal to its prevailing market value at the time of analysis. Estimated diminution in market value must be substantiated and will be subject to approval by USEPA. Otherwise, in calculating the salvage value of land, the land value should be appreciated at a compound rate of 3% annually (in real terms) over the planning period, unless the use of a greater or lesser percentage can be justified based on historical differences between local land cost escalation and construction cost escalation. Right-of-way easements may be considered to have a salvage value not greater than the prevailing market value at the time of analysis.

Structures and other site improvements may have a salvage value if there is an identified use for them at the end of the planning period. In this case, salvage value can be estimated using straight-line depreciation during the useful life of the facilities. This method may also be used to estimate salvage value at the end of the planning period for phased additions of process or auxiliary equipment.

Documentation should be provided in the cost analysis if it is determined that the useful life of any major component of the remedy will be less than the planning period. When the anticipated useful life of a facility is greater than the designated planning period for the remedial action, salvage value can be claimed for equipment if it can be clearly demonstrated that a specific market or reuse opportunity will exist.

Remedial action alternatives may have associated costs to public health, the environment, or public welfare, such as urban and community effects or use of scarce resources and energy. When alternatives appear to differ significantly in their associated non-monetary costs, the specific cost elements should be presented and evaluated. Particularly important in this regard is the assessment of any variations in public health and environmental costs among remedial alternatives.

#### **Analysis of Effects**

Remedial alternatives in any category of remedial action considered should be analyzed for possible adverse environmental impacts and for possible adverse effects on worker safety and health. At a minimum, an analysis of effects should include an evaluation of each alternative's environmental effects, an analysis of measures to mitigate adverse effects, physical or legal constraints, and com-

pliance with CERCLA or other regulatory requirements. Additional analysis of effects of source control and off-site remedial actions should be done, as described below.

**Source Control Remedial Actions.** The analysis of source control alternatives investigates whether, for the life of the remedial alternative, the affected population is effectively protected from exposure to hazardous substances that could threaten public health, welfare, and the environment. This investigation is presented in the form of a comparison between the situation currently existing (or that might exist in the future if the action under consideration is not taken), and the situation expected to occur following implementation of each alternative source control action.

Alternatives for source control action that are considered in a detailed analysis should be reasonably expected to achieve the control and containment of the source of contamination. The analysis must indicate the degree of containment expected from implementation of each of the alternatives. All methods of likely migration of substances into the environment should be investigated to the extent feasible. To the extent possible, the analysis should also consider the fate of particular substances in the environment and the suitability of the proposed remedial alternatives for control of the substances.

**Off-Site Remedial Actions.** The analysis of remedial alternatives must explicitly consider the extent to which each alternative mitigates or minimizes the threat of harm to public health, welfare, and the environment. Alternatives which cannot be shown to effectively reduce or eliminate the hazard to an acceptable level should be rejected. If no technologies are available to adequately mitigate the threat (for example, to produce drinking water of an acceptable quality), the plans for remedial action at a site may be reconsidered to determine if non-cleanup methods, such as provision of alternative water supplies, is possible.

When analyzing off-site remedial alternatives, a comparison should be made of the existing situation (and reasonable projections of what might be expected to occur without remedial action) with the situation expected following implementation of off-site remedial alternatives.

#### **Cost-Effective Evaluation of Alternatives**

The evaluation of alternatives to determine cost effectiveness should include the analysis of cost and effects described above. Specific criteria should be developed in these and other appropriate areas for use in evaluating each alternative. Typical criteria used for evaluation of alternatives includes an assessment in each of the following areas:

- Reliability of the remedial technology
- Flexibility during implementation of alternatives, including phasing of alternatives into operable units and segmenting alternatives into project areas on the site
- Institutional requirements to implement the alternative
- Operation and maintenance requirements
- Public acceptance
- Environmental effects and mitigation needs
- Safety requirements
- Cost of the remedial alternative

#### **SELECTING THE REMEDIAL ALTERNATIVE**

After completion of the feasibility study, a recommended plan is transmitted from the State and USEPA Regional office to USEPA headquarters for selection of the alternative that represents an appropriate extent of remedy. Where appropriate, USEPA obtains scientific expertise from other agencies that have a role in the remedial action program. The local community is also offered the opportunity to review and comment on the recommended remedial action.

The Assistant Administrator for USEPA's Office of Solid Waste and Emergency Response considers the recommended plan, feasibility study and other documentation to select the cost-effective remedial action. An important part of this process is the require-

ment of section 104(c)(4) of CERCLA to balance the need for protection of public health, welfare, and the environment at the site where remedial action is being considered and the availability of Fund monies to respond to other sites. USEPA may choose to exercise this "Fund-balancing" requirement in selecting the remedy for a site.

Following selection of a remedial alternative, a conceptual design is prepared; it includes the engineering approach, implementation schedule, special implementation requirements, institutional requirements, phasing and segmenting considerations, design criteria, preliminary site and facility layouts, budget cost estimates (including operation and maintenance costs), outline safety plans and impacts on cost.

### REMEDIAL DESIGN

Following completion of the feasibility study and approval of the remedy by USEPA and the State, a remedial design will be prepared. Funding will be provided through the same mechanisms used in the remedial investigation and feasibility study phase (i.e., cooperative agreement or Superfund State contract).

Where USEPA has the lead, the final design and implementation activities will be managed by the U.S. Army Corps of Engineers in accordance with the interagency agreement of Feb. 3, 1982. States assuming lead management roles will be responsible for undertaking design and implementation activities.

Formal advertisement for contracts is the preferred method for implementation of remedial actions. Therefore, the remedial design will usually result in a set of contract documents, including

plans and specifications, that describe the remedy in sufficient detail to allow preparation of competitive bids.

### CONCLUSIONS

USEPA has developed a rational decision making process for selecting and implementing the appropriate extent of remedy at priority hazardous waste sites. The process consists of five steps: (1) a remedial action master plan, (2) remedial investigation, (3) feasibility study, (4) selection of a remedial alternative, and (5) remedial design. The effort required to develop each of these steps will be evaluated individually for each site. In this way, projects will address only the activities needed to focus on remedial actions. Three categories of remedial action have been established to correspond to typical site conditions: (1) initial remedial measures, (2) source control actions, and (3) off-site remedial actions. Use of these categories facilitates quick action where needed and allows USEPA to tailor remedies to particular sites.

Data collection efforts (remedial investigations) and feasibility studies must be focused on specific remedial alternatives. Remedial alternatives are analyzed for engineering feasibility, health and environmental effects, and present worth costs (including operation and maintenance costs and salvage values, as appropriate).

The success of this remedial planning process depends on a close working relationship between USEPA and the State, and on the contributions made by local communities, contractors responsible for conducting the studies, and other Federal agencies.

# ALTERNATIVES TO GROUND WATER PUMPING FOR CONTROLLING HAZARDOUS WASTE LEACHATES

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## INTRODUCTION

Many techniques are available for controlling groundwater contamination from hazardous waste management facilities including pumping, removal (excavation), subsurface drains, low permeability barriers, and *in situ* treatment. Groundwater pumping systems are very commonly used because of their large range of applicability and low installation costs.

Pumping systems can be designed to perform almost any function such as adjusting potentiometric surfaces, containing leachate plumes to prevent further migration, and removing contaminated ground water. The chief technical advantages of pumping systems are:

- Applicability—usable in confined and unconfined aquifers of rock or unconsolidated materials under any conditions of homogeneity and isotropy
- Design flexibility—usable for injection as well as extraction regardless of the depth of contamination
- Construction flexibility—able to be installed using a variety of readily available materials by most qualified well drillers
- Operational flexibility—easy to repair most systems components or modify the system or its operation as site conditions dictate

Although there are many advantages to using ground water pumping techniques, some distinct disadvantages to their use exist. The main technical disadvantages of pumping are that it requires:

- Extensive design data—on the site's hydrogeology and leachate characteristics so that the system's components and operating conditions can be designed or selected properly
- Effluent treatment—or some other means of managing well discharges
- Continuous monitoring—to verify adequacy of system design and function and to safeguard against component (e.g., pump) failure which can result in contaminant escape
- Permeable aquifers—otherwise the system cannot function efficiently or effectively
- Leachate compatibility—in terms of the leachate's ability to move in ground water to the wells and not deteriorate well materials.
- Dilution—leachate may significantly dilute with groundwater making it necessary to pump larger volumes of groundwater to remove contaminant.

Of these requirements, aquifer permeability and leachate compatibility are the most common reasons for seeking an alternative to ground water pumping.

Probably the single most significant drawback to using ground water pumping is the high operation and maintenance (O&M) costs typically associated with the system after installation. Many times this is overlooked in remedial action planning especially when capital (installation) costs are much higher for other options. Minimizing long-term costs is particularly crucial to site remediation under Superfund, because states must pay all O&M costs.

Key O&M costs for pumping systems include: treating the con-

taminated discharge, providing electricity for the pumps, maintaining and repairing system components, and monitoring system performance. While other remedial actions also have these O&M costs associated with them, pumping costs are frequently higher because system operation is more demanding. For example, a subsurface drain may require the same amount of effluent treatment, maintenance, and monitoring as a pumping system. However, electrical requirements will be lower because the leachate is collected by gravity flow. Low permeability barriers will have very low O&M costs, especially if leachate treatment is not required. Consequently, these techniques may be more cost effective than pumping in the long run even though their installation costs are higher.

In the remaining sections of this paper, the authors describe alternate technologies for controlling ground water contamination in cases where pumping is inappropriate. Also discussed are the conditions under which an alternate technology might be a more effective remedial action than pumping.

## ALTERNATIVES TO GROUND WATER PUMPING

A number of alternative remedial techniques are available in the event ground water pumping is deemed technically or economically impractical. An often selected option involves excavating the source of contamination with subsequent disposal or treatment of the excavated wastes on- or off-site.

Subsurface drains can be installed to form a continuous hydraulic barrier in which contaminated water seeping into the drain is collected and pumped to a treatment facility. A low permeability barrier wall can be installed around the site to prevent the flow of contaminated groundwater into or out of the surrounding area.

Finally, *in situ* treatment techniques may be applicable in some cases where the waste can be neutralized, detoxified, flushed, or treated directly while in-place. These four alternatives to ground water pumping are described briefly below.

### Removal and Treatment/Disposal

Many times the source of the pollution is removed. Contaminated earth materials may be excavated using conventional construction equipment such as backhoes, draglines and front-end loaders. The excavation of drums is more complex and usually involves the use of specialized drum handling equipment such as backhoe mounted drum grapplers. Following proper safety procedures is paramount in removal operations.

Excavated waste materials may be disposed of in an approved chemical landfill, they may be incinerated on- or off-site, or they may be treated using other techniques such as solidification or encapsulation. Solidification techniques incorporate the waste materials in a chemical matrix such as cement, lime, or a polymer so that the wastes cannot leach out of the matrix. Disposal costs can then be reduced if the solidified waste can be considered a non-hazardous material. Encapsulation techniques form an im-

permeable polymeric capsule around the waste container, preventing leakage of waste out of the container.

Removal and disposal/treatment techniques are short-term actions that are applicable to many sites where the wastes are accessible. Waste removal is ineffective, however, for contaminants that have already leached from the site. Excavation of all contaminated substances (including groundwater and the strata through which it flows) is rarely performed because of the high cost of treatment or disposal of large volumes of material. Consequently, some additional remedial measure is usually required to complete site restoration.

### Subsurface Drains

A subsurface drain consists of a narrow trench dug to a designated depth below the ground water table. A perforated drainage pipe is installed on the floor of the trench and the trench is backfilled with gravel or crushed rock. This system forms a continuous permeable wall in which ground water seeps into the gravel packing, enters the drainage pipe, and is carried by gravity flow to a central collection point. The contaminated water is then pumped from the collection area to a treatment facility. Subsurface drains are most applicable to areas of low and/or varying permeabilities and groundwater flow rates.

Subsurface drainage is often used in conjunction with low permeability barrier walls. It can be used inside of a downgradient barrier wall to collect contaminated water prior to its reaching the wall. It can be constructed within barriers that encircle sites to prevent the "bathtub effect." It can also be used outside an upgradient wall to retard seepage of clean water through the wall and into the site.

The use of subsurface drains is similar to ground water pumping in that the collected contaminated water must be treated and disposed of properly. Subsurface drainage as a remedial approach suffers from some of the same problems as pumping technologies (i.e., long-term operation and maintenance costs). However, subsurface drainage can be used in low permeability strata where ground water pumping would not form a continuous hydraulic barrier. Depending on its placement, a subsurface drain may be able to intercept a concentrated leachate prior to dilution with groundwater and therefore avoid pumping large volumes of polluted groundwater. However, handling the concentrated, aggressive leachate may require the use of special materials. Operation and maintenance requirements are typically lower with drains than with wells because most of the flow in drains is caused by gravity.

### Barriers

An underground, vertical barrier wall can be installed around a polluting disposal site to impede or completely cut off groundwater flow into and out of the site. The most effective application of barriers is to completely encircle the site and key the bottom of the barrier wall into an underlying impermeable formation.

There are a number of barrier wall materials that have been used successfully. All form relatively impermeable structures when properly installed, and thus, cut-off any substantial flows through the barrier. The most common technique is to use a clay slurry, which forms a relatively low permeability barrier because of the swelling of the clay particles in water. Slurry walls are presently being used at many hazardous waste disposal sites to cut-off flow of contaminated groundwater plumes. A variation of the clay slurry wall is to use an asphaltic emulsion to form the continuous barrier. Concrete is also used as a barrier material, particularly when a greater degree of structural strength is required. The barrier wall system to be installed at the Love Canal site will be constructed of concrete.

Where applicable, local materials can also be used to form low permeability barrier walls. In California, San Francisco Bay muds having hydraulic conductivities as low as  $1 \times 10^{-8}$  cm/sec have been used to form barrier walls at waste disposal sites.

Sheet piling and grout injection have been used to form low permeability barriers, however, their use is not common. Sheet piling is expensive and often cannot be used in strata containing

boulders where the possibility of pile deflection and subsequent misalignment and gapping is high. Similarly, grout injection (in which a wall is formed by injecting grout into adjacent boreholes to produce interconnected soil/grout cylinders) frequently does not form a continuous low permeability seal. Particular attention must be paid to the compatibility of the barrier material and to the waste being contained to avoid the material being rendered useless because the waste causes a significant change in permeability characteristics.

Barrier walls are often used with other techniques such as clay capping and subsurface drainage to reduce infiltration and prevent the accumulation of groundwater behind the barrier wall. While installation costs for barrier walls are much higher than for pumping systems, O&M costs are generally much lower. However, if subsurface drainage or pumping is used in conjunction with the wall, O&M costs will be significant.

### In-Situ Technologies

*In-situ* techniques have been used on a limited basis in the past to clean-up underground contamination caused by hazardous material spills. They are generally short-term approaches which include biodegradation, soil flushing/solution mining, and neutralization/detoxification. In certain situations, they have been or could have been used as remedial techniques to treat contaminant plumes from waste disposal sites.

Biodegradation (or bioreclamation) is a microbiological treatment technique originally developed to detoxify leakage from underground gasoline storage tanks. In the bioreclamation technique, contaminated groundwater is pumped to the surface where nutrients and a bacteria (cultured to degrade the specific contaminant) are added. Then, the contaminated water is aerated and reinjected into the contaminant plume. Aerobic microbial degradation of the contaminant plume can then take place underground. Assuming the source of the contamination is removed, contaminant levels are gradually reduced to a residual level in the groundwater.

Soil flushing or solution mining is a technique in which water, a surfactant, or a solvent, is injected near an area of contamination to wash hazardous chemicals from a contaminated soil. The contaminated solvent is then pumped from the subsurface and sent to a treatment or disposal facility. If the solvent is treated to remove the contaminants, it can then be reinjected into the area of contamination. Generally water is used so that new pollutants are not introduced. This technique was used at the Goose Farm Site, Plumsted Township, New Jersey, to flush contaminants with water from contaminated soil beneath a drum disposal pit.

Neutralization/detoxification is an *in-situ* technique where a chemical is added to contaminated water to neutralize the adverse characteristics of the contaminant. In this technique alteration rather than removal is the goal. Underground injection of a sodium hypochlorite solution has been used to successfully treat cyanide contaminated groundwater resulting from the indiscriminate dumping of hazardous wastes. Dilute solutions of acids or bases can be used for pH neutralization. Other potential neutralization/detoxification agents may include calcium salts (for phosphates), hydrogen peroxide (chemical oxidation), and ferrous sulfate (chemical reducing agent). Another *in-situ* treatment technique is to inject catalysts into the subsurface that will cause organic contaminants to polymerize and become relatively immobile. This technique has been used to control the contaminant plume from an underground leak of acrylate monomers.

As with removal operations, *in-situ* treatment is generally conducted on a one-time basis. Consequently, there are no long-term O&M costs. The applicability of *in-situ* treatment is limited by the contaminants involved and the treatment techniques currently available, and thus, is not used widely. The cost of *in-situ* treatment varies widely with site conditions and the technology to be used.

### Selection of Alternatives

The conditions that prohibit the use of pumping for groundwater restoration will, in part, determine which alternatives may be ap-



Table 1.  
Relative Effectiveness and Cost of Alternatives to Ground Water Pumping.

Alternative	Applicability	Relative Effectiveness <sup>(1)</sup>	Relative Cost <sup>(1)</sup>	Comments
REMOVAL	<ul style="list-style-type: none"> <li>• Low permeability materials</li> <li>• Immobile or aggressive contaminants</li> </ul>	<ul style="list-style-type: none"> <li>• Eliminates source of leachate but does not affect off-site or deep contamination</li> </ul>	<ul style="list-style-type: none"> <li>• Higher in the short term but may equalize if long-term actions would have been required</li> </ul>	<ul style="list-style-type: none"> <li>• Proper treatment and disposal required</li> <li>• Special safety precautions must be taken during excavation</li> <li>• Most appropriate for small sites where a high hazard to drinking water supplies exists, where insoluble wastes could not be removed by pumping alone, or where long term treatment would be too costly</li> </ul>
BARRIERS	<ul style="list-style-type: none"> <li>• Immobile or some aggressive contaminants</li> <li>• Where long-term activities would be required by a pumping system</li> </ul>	<ul style="list-style-type: none"> <li>• As effective if not more so provided barrier is designed and maintained properly and barrier material is resistant to the contaminants</li> </ul>	<ul style="list-style-type: none"> <li>• Higher in the short term but lower over time</li> <li>• Could be much less if little treatment is needed</li> </ul>	<ul style="list-style-type: none"> <li>• Generally wall base must be keyed into an impermeable layer</li> <li>• Site capping and other measures generally required depending on wall placement</li> </ul>
SUBSURFACE DRAINS	<ul style="list-style-type: none"> <li>• Low permeability materials</li> <li>• Where long-term activities would be required by a pumping system</li> </ul>	<ul style="list-style-type: none"> <li>• As effective if not more so, provided drain is designed and maintained properly, and drain materials are resistant to waste materials are compatible</li> <li>• May avoid dilution of leachate with groundwater</li> </ul>	<ul style="list-style-type: none"> <li>• Higher in the short term but could equalize over time depending on pumping and treating requirements and duration of activities</li> </ul>	<ul style="list-style-type: none"> <li>• Proper treatment of drainage required</li> <li>• Not generally applicable to contamination in deep bedrock</li> <li>• Typically less difficult to operate and maintain than a pumping system</li> </ul>
IN-SITU TREATMENT	<ul style="list-style-type: none"> <li>• Some immobile or aggressive contaminants</li> <li>• Where long-term activities would be required by a pumping system</li> </ul>	<ul style="list-style-type: none"> <li>• Variable depending on the nature of the contamination and the site's hydrogeology</li> </ul>	<ul style="list-style-type: none"> <li>• Variable, but could be less in some instances</li> </ul>	<ul style="list-style-type: none"> <li>• Applications somewhat limited</li> <li>• Little performance data available</li> </ul>

<sup>(1)</sup>Relative to ground water pumping systems

plicable. When the contaminated layers are of very low permeability, removal or subsurface drainage may be feasible. When the contaminants in the groundwater are either relatively immobile or will aggressively attack well materials, removal, low permeability barriers, and *in-situ* treatment may be alternatives.

In some cases, pumping will be technically feasible but not cost effective because it may be required for a long duration and result in pumping unreasonable volumes of water. Subsurface drains, barriers, and *in-situ* treatment may be applicable in these instances.

The relative effectiveness and cost of these alternatives compared to pumping are outlined in Table 1.

The appropriateness of the alternatives to groundwater pumping that are available will depend on a variety of factors including:

- Site requirements (e.g., appropriate hydrogeologic setting)
- Areal extent of the contamination
- Nature of the contamination
- Capital and O&M costs

**Table 2.**  
**Relative Comparison of Several Factors in Remedial Action Selection.**

Remedial Action	Factors in Selection					
	Key Site Requirements	Areal Extent of Contamination	Depth of Contamination	Nature of Contamination	Capital Costs	Long-term O&M Costs
Pumping	Permeable earth materials	Any	Any	Must be mobile ground water and not aggressively deteriorate construction materials	Relative low	High because of pumping and treating requirements
Removal	Extent of contamination limited to easily removable (i.e., unconsolidated) earth materials	Relatively small	Relative shallow	Practically any provided proper safety precautions are taken	High	None
Subsurface Drains	None	Any	Limited only the cost of excavating bedrock and by the capabilities of the trenching equipment	Same as pumping	Moderate to high	Moderate to high because of pumping and treating requirements
Barriers	Generally impermeable layer required to key wall into	Any	Same as for subsurface drains	Must not aggressively deteriorate wall materials	Moderate to high	Relatively low
In-Situ Treatment	Same as pumping	More applicable to smaller sites	Limited by the requirements of the treatment technique to be used	Limited by the applicability of the treatment technique to be used	Variable depending on the treatment technique to be used	None if source removed before treatment

The limitations of the five technologies in terms of these factors are found in Table 2.

There are many significant factors in remedial action selection. To select the best remedial action scenario for a given site, it is essential to identify and evaluate all factors for each of the viable options. In the case of groundwater pumping, it is critical to assess costs as well as technical factors. This is especially true of long-term O&M costs, which may reduce pumping to an economically unattractive alternative.

## SUMMARY

Pumping is an effective and widely used technology for remediating groundwater contamination. Nevertheless, in some cases pumping is either not technically feasible or not cost effective. A variety of alternatives to pumping are available for these cases. However, the applicability of the alternative may also be limited. Careful consideration must be given to all significant factors in selecting the best remedial action.

# THE EXHUMATION PROGRAM FOR THE SCA WILSONVILLE SITE

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## INTRODUCTION

Once the agreement to exhumate wastes from Wilsonville was signed, the task of putting this multifaceted project together began in earnest. What had happened in the past was no longer an issue to be dealt with. The wastes were to be removed in the most safe and expeditious manner.

## ORGANIZATION

A project of this nature required the assembling of a team of individuals with various specialties who could work toward a common goal. Management positions were filled by personnel from several SCA Chemical Services facilities who had experience in Project Management, Landfill Operations, Safety Procedures, Laboratory Operations, and Accounting Procedures. The various staff positions were to be filled locally by equipment operators, material handlers, laborers, lab technicians, and other support individuals. An organizational chart for the project is shown in Fig. 1.

## PRE-OPERATIONAL PREPARATIONS

Prior to the start of exhumation activities, a series of construction and purchasing activities took place at the site. The purpose of such operations was to transform a closed landfill which had not been operated for four years into a full-fledged landfill facility operating in the reverse mode. The preparations involved included the following:

- Renovation of the existing office building to house the administrative staff
- Renovation of the existing equipment warehouse into a personnel building which housed the various employee support functions such as:
  - Shower facilities
  - Lockers
  - Safety equipment storage
  - Lunch facilities
  - Equipment repair
- Upgrading of the site roadways which had been used during filling operations along with construction of new roadways to the trench areas and staging areas
- Construction of staging areas for drums, trailers, and mobile equipment
- Upgrading and expanding of the electrical, telephone, and water distribution systems to provide services to the exhumation trenches and the mobile laboratory
- Equipment Procurement—This consisted of the purchase of approximately 1.5 million dollars of operations, laboratory, safety, administrative, and transportation equipment to be used throughout the project (Table 1).
- Personnel Hiring—The hiring of all employees below the manager level began approximately three months before operations were scheduled to begin. Skilled labor was located fairly easily due to the high rate of unemployment in the area and the proximity to other chemical plants.
- Employee Training—The training of all operational and safety personnel began approximately two weeks before operations began. The training programs undertaken were as follows:

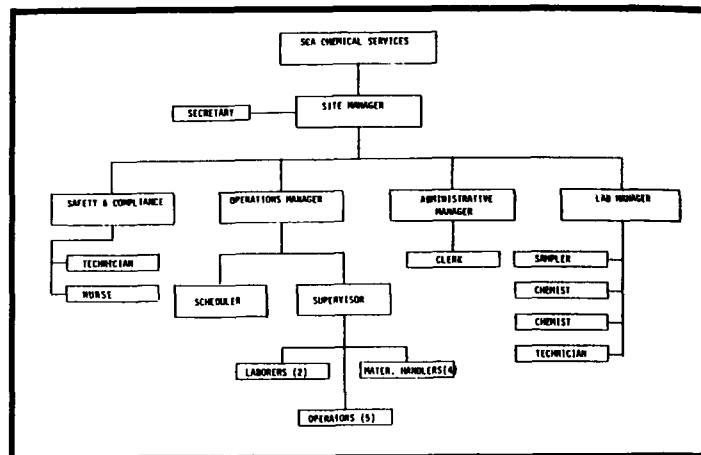


Figure 1.  
Wilsonville Site Exhumation Program, Organization Chart

Table 1.  
Equipment List

- |                                 |                      |
|---------------------------------|----------------------|
| 1. Backhoe/Loader               | 10. Staging Trailers |
| 2. Front End Loader             | 11. Fork Lift        |
| 3. Supersucker Vacuum Truck     | 12. Drum Crusher     |
| 4. Drum Hoist Truck             | 13. Truck Scale      |
| 5. Water Truck                  | 14. Pick-up Truck    |
| 6. Yard Horse Tractor           | 15. Emergency Van    |
| 7. Fire Truck                   | 16. Compactors       |
| 8. Calgon Air Purification Unit | 17. Box Trailers     |
| 9. Canopy Structure             | 18. Tankers          |
|                                 | 19. Dump Trailers    |

- Equipment training
- Fire fighting training
- Use of safety gear
- Operations training
- Engineering consisted of the following:
  - A base topographic map in aid in the restoration of the site to the existing grades
  - A metal detection survey to accurately locate the perimeter boundaries of each trench
  - A hydrogeological study to aid in the development of procedures to deal with groundwater movement during operations and to designate areas of soil borrow for lining and capping of the exhumed trench
- Monitoring Network—Including the installation of six sampling stations for measurement of particulates and vapor emissions caused by the exhumation operation. This consisted of the placement at five locations of sampling pumps and carbon tubes for vapor absorption and Hi-volume air samples for particulate measurement. A series of groundwater monitoring wells and surface water monitoring points had previously been established both during and after original landfill operations.

## OPERATIONS

### Removal Operations

**Equipment placement**—Before beginning any of the removal operations, all equipment must be placed at area to be excavated. Excavations will begin at the end of each trench opposite the entry road to the trench. The extent of the area to be excavated was determined by the markers left during the initial metal detection survey and as verified by use of the onsite metal detector. Once the end line of drums has been determined, the canopy structure is moved into place. The canopy was located to overlap the area to be excavated. Upon positioning of the canopy, all required electrical connections for equipment attached to the structure were made. Once the canopy was in place, all mobile operating equipment was placed along the excavation boundaries as shown in Fig. 2.

**Cap removal and excavation**—Before proceeding with the cap removal, the perimeter of the excavation area must be protected from surface runoff with the construction of a small runoff control berm. Clay from the cap should be used for this exercise. The cap will then be removed to expose the uppermost lift of drums over the area to be worked and always under the canopy. The clay cover will be removed utilizing a rubber tired front end loader. Soil material removed is segregated as follows: (1) Topsoil for later use for vegetative growth, (2) Clay for lining and capping the trenches, and (3) Miscellaneous soils, mine spoils, tree trunks, etc., to be placed between the upper and lower clay layer.

As the cap is being removed, a hand auger is used to probe the remaining depth to the top drum lift. This probing will assist the operator in the depth of cut to be taken to eliminate the potential for puncturing drums. The site metal detector will also be used to ascertain relative depths to metal drums.

The soil removed will require testing in accordance with the sampling and analysis section of this paper. If it is determined to be hazardous, it must be loaded into bulk solid trailers for shipment off site. During the cap removal process, a vertical excavation shall be made just forward of the drum location to provide a bench area from which to begin removal operations. The depth of this section shall be at least equal to the base of the uppermost drum lift. The excavation shall be made as close to the first lift of drums as possible without contacting drums with the backhoe.

**Drum removal**—Before drum removal can begin, it is necessary to remove small quantities of soil from around the surface of the drums. This should be accomplished with the use of non-sparking hand tools or a soil vacuum such as the Supersucker.

Once this soil has been removed, the drum should be visually inspected for deterioration. If the drum is leaking or is not in a physical condition to be lifted out of the excavation, the drum should re-

main in the excavation until the liquid contents are either pumped from the drum or the drum is overpacked.

If the drum is in a condition which would allow for hoisting from the trench, the drum should be rolled out of its location to a point where it can be fitted with the sling from the hoist and removed from the trench. Once removed, it should be placed on the staging trailer.

If the drum contains liquid and cannot be hoisted from the trench, the contents should be pumped from the drum using drum pumps. This material should be pumped to a clean drum.

If the drum contains solids and cannot be lifted from the trench, the drum should be overpacked and hoisted from the trench. If the contents of the drum have leaked to the surrounding soil, the liquid should be vacuumed with the vacuum truck. The soil which has subsequently become hazardous should be either vacuumed or shoveled from the excavation and placed in the bulk solids trailer for removal off site.

As the operation proceeds from drum to drum the soil between drums should be mechanically shoveled from the trench to the daily soil staging area for testing. Drums which have leaked their contents and are now empty should be removed from the excavation and sent to the drum crusher.

### Contaminated Soil and Sludge Removal

Soil which is excavated from the trenches can be classified as hazardous or non-hazardous depending upon the degree of chemical contamination. All soil which is removed from between drums, from the sidewalls or from the base of the excavation during a day's operation should be placed in the soil staging area adjacent to the excavation. This area should be bermed to prevent infiltration of surface water runoff. During rainstorms, the soil should be covered with a PVC liner.

At the end of each workday, the laboratory will sample the pile for analysis and classify the material as hazardous or non-hazardous. If the material is classified as hazardous, it should be loaded into a bulk solids dump trailer for disposal offsite. If the laboratory classifies the material as non-hazardous, it can be used as backfill for the trenches. If this soil is not immediately usable, it should be stockpiled with other similar materials in the three stockpile classifications previously mentioned.

Sludge and bulk solids which were originally disposed as waste material must be disposed off site. This material, when encountered, shall be removed by a backhoe and placed in a bulk solids dump trailer. If the viscosity of the material is low, it may be vacuumed with the Supersucker or placed in fiber pack drums if found to be incinerable.

**Free liquid removal**—The presence of leachate in the trenches is highly likely and will present numerous operational difficulties. When encountered, this liquid should be tested and vacuumed with the Supersucker or pumped directly to a bulk liquids tanker parked at the side of the trench. If vacuumed with the Supersucker, the liquid will require transfer to bulk liquid tankers.

### Backfill Operations

**Clay baseliner**—After removal of all waste has taken place in a minimum of 30 ft of the trench and the walls and base have been determined to be nonhazardous, the lining of the base of the excavation should take place. Inspection of the base and sidewalls should take place to detect the presence of sand lenses.

Since this strata represents a possible path of migration, it should be sealed with clay during the baseliner operation. Clay from the nonhazardous clay stockpile should be loaded into the trench utilizing the front end loader. The clay should be placed in 12-24 in. lifts and compacted using a plate compactor. Three feet of clay shall be placed along the base of the excavation in this manner. Where necessary, the clay liner shall be dished up the sidewalls to intersect sand layers.

**Lime neutralization liner**—The volume between the 3 ft baseliner and the 4 ft cap will be filled with mine spoils, clay soils,

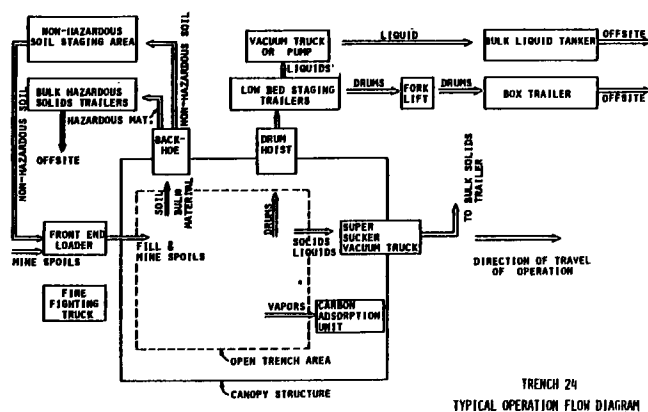


Figure 2.  
Trench 24  
Typical Operation Flow Diagram

and soils other than clay. The amount of this material required will vary from trench to trench, depending upon the volume of material (drums, soil, sludges) which are removed for off site disposal.

Before placing mine spoils into the trench, the Laboratory Manager shall be consulted to determine the quantity of lime to be placed below the mine spoils to neutralize the effect of any leaching. This lime should be spread uniformly on the base.

**Mine spoils**—The gob pile should be utilized to fill the remainder of the excavation to an elevation just below the base of the cap. The mine spoils should be loaded into the on-site dump truck with the front-end loader. The dump truck will then transport the material to the trench for unloading into the excavation. The loader or plate compactor shall be utilized to compact this layer before placement of the top cap.

**Clay cap**—After the mine spoils have been placed into the trench, the installation of the clay cap should begin. Construction of this layer will consist of 12-24 in. lifts of clay which should be compacted with the front end loader or plate compactor. The total thickness of this cap will be 4 ft upon completion.

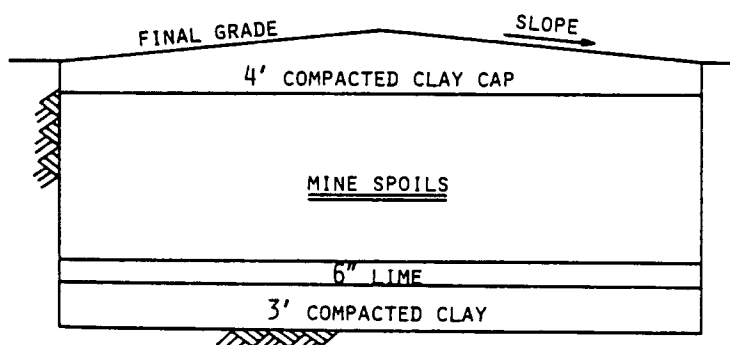
The top elevation of the cap will match the existing elevation of the trench before exhumation was begun. The baseline topographic map should be utilized to determine appropriate elevations. The cap should be crowned on a 5% slope to enhance rapid runoff of precipitation. Only after the cap has been compacted should the canopy be moved to its next position along the trench. For a depiction of the final trench cross section, see Fig. 3.

**Top soil and seeding**—Upon completion of the exhumation and backfill for an entire trench, the area of the trench shall be covered with 6 in. of topsoil previously stockpiled and seeded with perennial ryegrass. Seeding shall be mechanical.

#### Staging Operations

**Low bed staging**—During exhumation of a trench, two modified low bed trailers will be used to stage drums until the laboratory has completed its analysis and determined the appropriate bulking requirements or treatment/disposal option. The trailers will be placed along the sides of the excavation and receive drums which are hoisted from the trench.

Drummed liquids which are removed from the trenches should be placed on a staging trailer and affixed with a consecutively numbered drum tag. The material handlers will then open the drums to allow sample taking. Drummed solids which are removed from the trenches should be placed on the staging trailer, affixed with a drum label, and opened for sampling.



(NOT TO SCALE)

Figure 3.  
Trench 24  
Final Cross Section

**Bulk soil/sludge staging**—During exhumation of drums, substantial quantities of soil and sludges contained between and around the drums will be excavated from the trench. The excavated soil will be staged in an area alongside the trench. This area will be bermed and lined with twenty mil PVC. The size of the area should be sufficient to store at least three days of excavated soils. During rainfall events, this area should be covered with twenty mil PVC liner to prevent the infiltration of water.

Sludges and bulk solid wastes which were originally landfilled should be excavated from the trench and placed directly into the bulk solids dump trailer. Soils which were backfilled during operations should be removed from the trenches and placed in a pile with that day's excavated soil in the soil staging area.

At the end of each day, a sample will be taken by the laboratory for analysis. If the soil is determined to be hazardous, it will be placed into the bulk solids dump trailer for disposal offsite or the pile will be segregated at the direction of the Laboratory Manager and retested.

Soils which are determined non-hazardous will be utilized as backfill to the trenches. This soil will remain in the staging area until utilized as backfill or stockpiled further away from the excavation.

#### Bulk liquids staging

Once a drum of liquid has been identified as being compatible with the contents of a bulk tanker, the contents shall be pumped directly into the tanker for shipment off site. A drum pump shall be inserted into the bung hole and the contents pumped completely into the tanker. The empty drum should be removed from the staging trailer and transferred to the drum crusher. This process will continue until the tanker has been filled at which time it will be prepared for shipment offsite.

When liquid leachate is encountered in the trenches, the liquid shall be vacuumed with the Supersucker vacuum truck or pumped directly into the bulk tanker designated for aqueous waste. To minimize handling, it is preferable to pump directly from the trench to the tanker.

Liquid which is being pumped from Well G-107 as part of the effort to control leachate migration should be pumped directly into the appropriate liquid tanker.

**Drummed liquids staging**—Drums of liquids which cannot be immediately bulked into tankers must be routed as follows:

- If the drum can be bulked with future drums which are identified on the grid sheets, it should be placed into the drum storage building provided the drum will be bulked within 90 days of its removal.
- If the drum cannot be bulked with any future drums, it should be loaded onto the appropriate box trailer for a disposal/treatment offsite.

**Drummed solids staging**—Drums of solid material should be loaded onto box trailers depending upon the disposal facility chosen.

**Empty drum staging**—Drums which have been crushed after liquid removal should be placed into the staged bulk solids trailer for disposal as bulk.

#### Drum Crushing Procedures

As drums are emptied of either solids, sludges, or liquids, they are to be stored on a dump truck until a full load is achieved. Drums are then hauled to the drum crusher.

At the drum crusher station, the drums are to be checked for the presence of minor quantities of liquids. If liquids are encountered, the drum should be emptied into a container and transferred to the bulk liquids trailer which was used to receive the majority of liquid in the drum. If greater than 4 in. of sludge are present at the base of the drum, this material shall be shoveled and transferred to the bulk solids trailer. Drums will then be crushed, two at a time, and the crushed drums reloaded onto the same dump truck

for transfer to the bulk solids trailer.

## SAMPLING AND ANALYSIS

### Sampling

Once the drums are placed on the staging trailers, they should be opened and sampled with either a sampling thief for liquids or a coring tool for solids. The samples will be placed in bottles and transported to the laboratory for analysis.

Before transport of any bulk liquid or solid materials, the laboratory will receive a sample for analysis and designation of the appropriate handling method.

### Analysis

Analysis of all samples will take place in the site laboratory which is housed in a 70 ft x 12 ft trailer. The laboratory contains the following major equipment for analysis:

- Gas Chromatograph/Mass Spectrometer
- Atomic Absorption Unit
- Karl Fisher Titrator
- Calorimeter
- TOC/TC/TIC Analyzer
- pH/Ion Meters
- Distilled Water
- Centrifuge
- G. C. FID Unit
- Viscometer

The laboratory analysis will direct the operational crews as to the destination of all materials exhumed from the trenches. It will also determine the appropriate treatment/disposal option for each waste. In addition to the sampling and analysis of each drum of waste, the laboratory is responsible for analysis of vapor and particulate samples taken at the site perimeter.

At the end of each day, soil which was excavated from the trenches will be sampled by the laboratory for classification as hazardous or non-hazardous. The comparison of the soil analysis will be made with the USEPA Multimedia Environmental Goals For Land Ecological Criteria.

## SELECTION OF TREATMENT/DISPOSAL OPTIONS

After sampling and analysis, but prior to any repackaging or bulking (as appropriate), it will be necessary to determine the most appropriate method of treatment and/or disposal of the exhumed wastes. In making this determination, SCA will consider:

- Protection of human health and the environment
- The availability and appropriateness of permitted treatment/disposal facilities
- Costs

SCA will evaluate the options available by waste type of determine the advantages and disadvantages of each. SCA will then select the preferred option and make appropriate arrangements.

The treatment/disposal techniques which are, at this time, the most appropriate include:

- Incineration—Controlled combustion to thermally destroy waste materials, converting the waste into harmless gases and inert solids. Parameters used to evaluate a waste type for this technique include: BTU value, organic chlorine, organic sulfur, heavy metals, total solids, ash, etc.
- Aqueous Treatment/Detoxification—Includes oxidation, reduction, coagulation, distillation, precipitation, and neutralization. Parameters used to evaluate a waste type for this technique include: water content, flash point, pH, acidity, alkalinity, TOC, cyanide, sulfide, metals, etc.
- Secured landfill—For wastes that can neither be chemically treated nor thermally destroyed. Parameters used to evaluate a waste type for this technique are similar to those listed above.

## LOADING AND TRANSPORTATION

### Treatment/Disposal Facility Arrangements

Upon completion of the laboratory analysis and a designation by the laboratory of the appropriate disposal facility, the Operations Manager will direct the loading of drums onto the box trailer. Since most of the drums shipped off site will be solids destined for a secure landfill drums can be loaded onto the box trailer as soon as they have been analyzed, unless they contain solid materials which cannot be disposed of at a particular secure landfill. The drums will be loaded onto the trailers from the low beds with the use of the fork lift and hand operated two-wheelers. All box trailers should contain a layer of absorbent on their base to absorb any leaking drums.

Upon filling of a bulk liquids tanker, a composite analysis by the laboratory will be undertaken. Upon completion of the analysis, the laboratory will designate the appropriate treatment facility to receive the waste.

Upon filling of a bulk solids dump trailer, the laboratory will sample, analyze, and designate the appropriate disposal facility to receive the waste.

### Transportation Contractor Arrangements

Upon completion of loading of either a box, dump, or liquid trailer and upon designation of the disposal/treatment facility, the following steps will be undertaken:

- The Laboratory Manager will notify the Transportation Dispatcher of the destination of the waste containing trailer. He will also forward the appropriate manifest documents to the Dispatcher with the laboratory data filled in.
- The Dispatcher will call the transportation contractor to schedule a pickup of the load and will complete the remaining information on the manifest documents.

### Manifest Preparations

The Dispatcher will finalize all information on the manifest documents for transfer to the truck driver upon pickup.

### Vehicle Inspection and Preparation

Before a trailer is allowed to leave the exhumation area, the Operations Supervisor must visually inspect the entire vehicle including but not limited to the following items:

- Correct liner installation (if installed)
- Secured cover tarpaulin
- Locked lift gate
- Proper placarding
- Proper tractor to trailer hitch
- Cleanliness
- Excess waste levels
- Tire conditions

Any corrections should be made in the exhumation area.

Before a bulk liquids tanker is allowed to leave the exhumation area, the Operations Supervisor must visually inspect the entire vehicle including but not limited to the following items:

- Closed valve positions
- Secured hatches
- Excess liquid levels
- Proper placarding
- Proper tractor to trailer hitch
- Cleanliness
- Proper venting
- Tire conditions

Any corrections should be made in the exhumation area.

Before a box trailer is allowed to leave the exhumation area, the Operations Supervisor must visually inspect the entire vehicle including but not limited to the following:

- Correct layer of absorbent

- Quantities of bagged absorbent
- Leaking drums
- Proper packing inside van
- Locked rear doors
- Proper trailer to tractor hitch
- Proper placarding
- Cleanliness
- Condition of tires

Any corrections should be made in the exhumation area.

Loaded vehicles will then be hauled to the vehicle wash area, using the on-site yard horse. Cleaning of vehicles should be accomplished by scraping, or brushing where possible, to minimize the generation of contaminated wash water. When absolutely necessary, water washing should be accomplished using a high pressure low volume nozzle.

The yard horse should bring the loaded trailer to the Zone I area where the transfer of trailers will be accomplished. The transportation contractor will attach to the loaded trailer and the yard horse will attach to the empty trailer for placement in the exhumation staging area.

Upon entering the facility, all trailers and tractors should be weighed empty for comparison with loaded weights. After trailer transfer, the transportation contractor shall bring his loaded vehicle to the truck scale for weighing. The Dispatcher will determine the shipment weight which will be recorded on the manifest.

Once a vehicle is prepared to leave the site, the Operations Manager will call the designated disposal facility for notification of shipment and estimated time of arrival. All drivers will be given a specified route to travel with instructions not to vary from this route. They also will be given a list of emergency numbers and a copy of the site contingency plan.

#### RECORDKEEPING AND DOCUMENTATION

Once a drum is removed from the excavation, it should be affixed with a drum tag containing a preprinted number. The purpose of this tag is to provide a unique drum identification number to each drum which is exhumed.

The drum/bulk data form is the principal recordkeeping tool to be used during exhumation of drums and bulk materials from the landfill. A copy of the form is shown in Fig. 4.

All waste which is transported off site must be accompanied by at least one manifest depending on the state of treatment/disposal of the shipped materials. At a minimum, all waste must have a completed Illinois manifest.

#### MEDICAL MONITORING AND SURVEILLANCE

Physical Examinations are required of all individuals before commencing work at the site. The preliminary examination will be used as a baseline to monitor any changes in an individual's health during the exhumation period. It will be compared with the succeeding yearly physicals given to all employees. In addition to the yearly examination, all employees working in the exhumation area will be tested quarterly for blood, liver and urine functions.

#### SAFETY PROGRAM

A comprehensive safety program has been developed to protect workers from the potential effects of materials buried in the trenches. The equipment utilized is as follows:

- Full protective suits
- Air line respirators fed from tanks filled by a breathing air compressor
- Emergency pressure demand air systems
- Protective shoes, gloves and hats

All employees which enter Zone II (the trench area) are required to be suited to various degrees as determined by the Safety Manager.

A fire truck is parked at the excavation site at all times. The unit is equipped to fight fires with water, foam, or dry chemicals.

Portable fire extinguishers are also placed around the trench and on all operating equipment.

Continuous monitoring is undertaken at the trench for the following:

- Total organic vapors
- Mercury
- Explosion potential

#### SPILL PREVENTION AND CONTINGENCY PLANS

A spill prevention and countermeasure plan has been developed for the site personnel and truck drivers transporting waste. All on-site personnel have been trained in this area.

A contingency plan has been developed in conjunction with the local county emergency services officer regarding emergencies which could affect residents of Wilsonville and surrounding towns.

Arrangements have been made with area hospitals in the event of an employee requiring treatment for injuries incurred on-site. A full time nurse and an emergency van are on standby in the event of an emergency.

#### SECURITY

The control of access by individuals to various sections of the site represents one of the most important operational considerations.

#### DRUM/BULK DATA FORM

Sampling	Date Sampled: _____
Drum ID#: _____	Time: _____
Estimated Liquid Quantity: _____	
Grid Location: _____	
Staging Trailer Number: _____	
Sampler's Name: _____	
Drum Condition: _____	
Physical Appearance of the Drum/Bulk Contents: _____	
Odor: _____	
Color: _____	
pH: _____ %Liquid: _____	
Laboratory	
Date of Analysis: _____	
Analytical Data: _____	
_____	
_____	
Compatibility: _____	
Hazard: _____	
Waste ID: _____	
T/D: _____	
R/D Referral: _____	
Approval	
Lab: _____	Date: _____
Site Manager: _____	Date: _____

Figure 4.  
Drum/Bulk Data Form



The entire site is divided into two major areas for purposes of access control. The areas are designated as Zones I and II and are shown in Fig. 5.

Zone I will include the administration building and associated parking area along with the guard house. Activities to be undertaken in this Zone are purely administrative. No handling or storage of waste materials of any type should be undertaken in this Zone. Only the transport of waste materials in containers should occur in this Zone. Activities undertaken in this area are as follows:

- Sign in/sign out of all individuals entering and leaving the site by the security officer in the guard house
- Office support activities
- Visitor and employee parking

Zone II will include the remainder of the 130 acre site. Included in this area will be the drum storage building, maintenance building, the 25 trenches to be exhumed and the mine spoils pile. Entry to this area will be via a gate segregating Zone I from Zone II. Activities to be undertaken in this area are as follows:

- Receipt of material and supplies
- Exhumation of all trenches
- Vehicle maintenance and operational employee support areas
- Laboratory operations
- Long-term drum storage
- Transport vehicle staging

Upon entering the site each day, all employees must present their badges to the guard and sign the log before proceeding to their designated areas. All employees wearing orange badges will be allowed access to Zone I; however, only employees wearing green badges will be allowed access to Zone II.

Visitors are defined as all individuals who are not employed by SCA Chemical Services on site. No admittance of visitors shall be allowed unless pre-approved by the Site Manager, Operations Manager, Laboratory Manager, Safety Manager, or Accounting Manager.

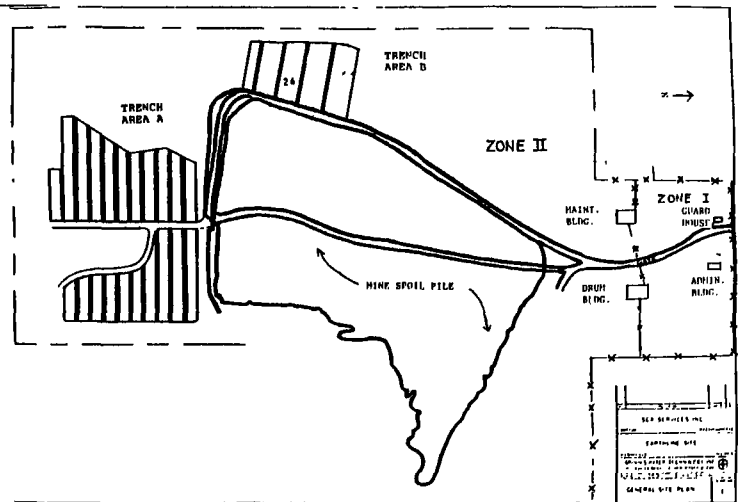


Figure 5.  
General Site Plan

All visitors who are approved to enter Zone II must sign a release. All drivers of waste transport vehicles or material delivery vehicles will be allowed access to Zone II provided they comply with the requirements of the liability release. All visitors, including drivers, must remain in their vehicles at all times.

The use of an on-site security force will be required throughout the duration of the project. The force size will vary throughout the duration of the project as needs change. Twenty-four hour coverage will be required. The guard house gate shall be closed and locked at all times after the operational hours of the site.

#### CONCLUSION

The entire project is scheduled to last four years during which approximately 85,000 drums will be exhumed. Numerous techniques will be developed throughout the operation which are expected to lay the groundwork for future projects of this nature.

# PCB'S AT SUPERFUND SITES: REMEDIAL ACTION EXPERIENCES

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## INTRODUCTION

Under the Comprehensive Emergency Response, Contingency, and Liability Act of 1980 (Superfund), three types of response actions were identified: (1) emergency actions, (2) planned removals, and (3) remedial actions. Remedial actions have the longest time frame, i.e., greater than six months to implement.

Lehigh Electric and Engineering Company Site in Old Forge, Pennsylvania, was the first USEPA-lead remedial action program under Superfund. As a result of being the first, there were many interesting and new procedures that were developed and lessons that were learned in cleaning up uncontrolled sites.

In addition, efforts to clean up this site were particularly interesting because of the high level of citizen interest, input and involvement in the actions needed to plan and conduct a cleanup of the site. Further, this is the first site where the USEPA and U.S. Army Corps of Engineers worked together as a team to develop a plan and contract for the cleanup services.

Lehigh Electric and Engineering is a 4.4 acre site located in Old Forge, Pennsylvania, adjacent to the Lackawanna River. The site was originally a coal breaker and a steam-powered electric generation facility. Since the early 1960s, it has been used as an electric equipment storage and repair facility. There is one main building in the center of the property that was originally the electric generating station.

## USEPA'S INITIAL INVOLVEMENT

In Mar. 1981, the USEPA was notified by an anonymous source of the existence of a transformer storage yard in Old Forge, Pa., at which improper handling of PCB-containing equipment may have occurred. The USEPA, along with its Technical Assistance Team Contractor (Ecology and Environment, Inc.) and the Pennsylvania Department of Environmental Resources (DER) conducted the initial inspection of the site from Mar. 26 to Mar. 28, gathering soil samples and water and sediment samples from the Lackawanna River.

The initial soil sample analyses indicated the presence of PCB at elevated levels (i.e., 5000 ppm). The USEPA On-Scene Coordinator (OSC) determined that additional sampling must be performed at the site to assess the degree of contamination, and that the site must be secured. On Mar. 31, 1981, USEPA Headquarters issued \$50,000 in Environmental Emergency Funds to perform these activities.

Many activities occurred during the month of April, including:

- Issuance of an Administrative Warrant to USEPA providing for access to the site
- Collection of 50 soil samples by USEPA in a grid pattern to determine the extent of surface contamination
- Taking of aerial photography utilizing the Enviropod during site fly-overs
- Construction of a 6 ft high chainlink fence around the perimeter of the site to provide security

- Holding of a town meeting to inform the local residents of the USEPA's initial findings.

An Administrative Warrant was required to allow the USEPA to take measures necessary to evaluate and secure the site since the property in question was privately owned. The second round of soil sampling showed the presence of PCB in the surface soil up to 65,000 ppm. The USEPA EPIC remote sensing laboratory located in Warrenton, Virginia, completed a photo interpretation analysis of the infrared imagery obtained from the overflight of the site in April. Their analysis indicated gross contamination of the site with transformer oil. They also saw evidence of distressed vegetative activity at the site resulting from the spillage of oil.

By May 1981, it was determined that the site was contaminated with PCB's; it had been secured to minimize any further contact of the local population with the contamination, and a community relations effort had been initiated to keep local citizens apprised of activities there. The next step was to determine the extent of any migration of the contamination to off-site residential areas.

A comprehensive air quality monitoring survey was performed by the USEPA Emergency Response Team (ERT). The team was requested by the OSC to sample air quality throughout the site and adjacent residential areas to determine if organic vapors, such as trichlorobenzene, were emanating from the site. The study found no indication of harmful levels of organic vapors in the air surrounding the site. There were odors present at the site. However, it was the opinion of ERT personnel that the odors were aromatic in nature and similar to mineral oil vapors, posing no threat to human health.

In May, the ERT Environmental Emergency Response Mobile Laboratory was brought to the site. The ERT conducted extensive soil sampling and analysis to determine if airborne transport of PCB from a rudimentary incinerator operated on-site had contaminated the local neighborhood. Soil samples were obtained from 17 residents' yards in the area and were analyzed on-site in the mobile lab. Laboratory analysis indicated that no PCB contamination of properties adjacent to the site had occurred.

The ERT also obtained additional soil samples from the extremely oil-saturated areas on-site. These areas were targeted from the infrared imagery obtained during the aerial overflight. Sample analyses indicated PCB contamination in the saturated areas to be extremely high, i.e., up to 59,000 ppm, which probably resulted from the indiscriminate handling of dielectric fluids.

By June of 1981, the OSC had secured and assessed the site, determined that PCB contamination did indeed exist, and that the contamination was not migrating off-site to the nearby residential areas. At that point, it was decided that no further emergency activity was needed at the site, and that remedial cleanup activity under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 should be pursued.

## REMEDIAL ACTION PLANNING ACTIVITIES

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provides for government cleanup of

hazardous waste disposal sites which are abandoned, or where liable responsible parties do not have the resources to perform an adequate cleanup. It allows the government to clean up sites where responsible parties do have the resources to do so but refuse. In such instances, the government can sue the responsible parties to recover the cost of the Superfund financed cleanup in order to replenish the fund.

In order to receive Superfund money for cleanup, a site must be on the National Priority List, on which sites are prioritized through the use of hazardous site ranking system. In the summer of 1981, the Lehigh Electric Site was rated and submitted. In the month of Oct., USEPA published what was known as the "List of 100." This list was actually a compilation of the 115 highest ranked hazardous waste disposal sites in the nation. The Lehigh Electric Site appeared on this list and, therefore, was eligible to receive Superfund money for site cleanup.

All necessary administrative requirements were satisfied, and in Oct. 1981, Roy F. Weston, Inc., the Zone 2 A/E Contractor, was tasked to perform a site investigation and feasibility study. These tasks would be used to evaluate the degree and extent of PCB contamination at the Lehigh Electric Site, and would provide the information on which to base a cleanup strategy and design.

At the Lehigh Electric Site, as at most uncontrolled hazardous waste disposal sites, USEPA had to deal, not only with the cleanup of the contaminated medium (in this case soil), but also with the source of the PCB, the electrical equipment which was still on-site. In order to facilitate the removal of equipment from the site as soon as possible, USEPA decided to divide both the engineering studies and the actual cleanup into two distinct phases (Table 1). Phase I was to deal with the removal of all equipment and material from the site surface. Phase II was to deal with removal of the contaminated soil.

**Table 1.**  
**A/E Tasks at Lehigh Electric Site**

**Phase I:**

1. Site Survey and Map
2. Inventory and Categorize Equipment
3. Technology, Options, Cost Evaluation
4. Environmental Impact Assessment
5. Preparation of Plans and Specifications
6. Community Relations Support

**Phase II:**

1. Description of Current Situation
2. Investigative Support
3. Site Investigation
4. Preliminary Remedial Alternatives
5. Site Investigation Analysis
6. Final Report—Field Investigation
7. Identify Objectives and Evaluate Criteria
8. Identify Alternatives
9. Evaluation of Alternatives
10. Conceptual Design
11. Final Report
12. Community Relations Support

During the Phase I engineering studies, Roy F. Weston, Inc., compiled a detailed inventory of all electrical equipment on the site. After the inventory was completed, the USEPA Environmental Response Team's Mobile Laboratory was brought to the Lehigh Electric Site for a second time. USEPA then samples every transformer and other piece of equipment on-site. With the aid of the mobile laboratory, they were able to determine whether or not the equipment contained PCB liquids (Table 2).

The classification of equipment on-site was based upon the PCB concentration. The categories were: greater than 500 ppm of PCB; between 50-500 ppm of PCB; and less than 50 ppm of PCB. The analytical results allowed USEPA to establish the disposal technique for the equipment in accordance with the TSCA regulations.

Upon completion of the inventory and categorizing of equipment, WESTON delivered a draft design for the Phase I cleanup.

**Table 2.**  
**PCB Contamination Summary**

Equipment	Units	PCB Concentration		
		≤ 50	50 < x < 500	500
Transformers	1,136	957	157	22
Capacitors	1,053	0	0	1,053
Electrical Equipment	306	290	8	8
Miscellaneous Equipment <sup>1</sup>	1,000	1,000	0	0
Total Pieces	3,495	2,247	1,650	1,083
Volume Gal	25,000	18,750	5,000	1,250

<sup>1</sup>Estimated

At this point in time, a decision had to be made as to whether or not the U.S. Army Corps of Engineers would get involved with the Phase I cleanup.

### U.S. ARMY COE INVOLVEMENT

On Feb. 3, 1982, the USEPA and the U.S. Army Corps of Engineers signed an inter-agency agreement whereby the COE was to perform the design, bidding, and construction management on Superfund site cleanups when USEPA had the project lead. USEPA was to take the project from initial site investigation up through the feasibility study, alternative selection, and concept design stages. The reason for this agreement is that the COE has expertise in contract management and resources already in place to take on the task.

In April 1982, the details to implement this agreement were still being finalized. The USEPA presented the history and status of the Lehigh Electric Site to the COE, explained how far along the project was and also the political/community sensitivity involved. For the COE to take on the design and contract management for the Phase I cleanup at this point in time would be a challenge. This was due, not only to the sensitivity of the project and the COE beginning their activities relatively late in the project, but also because it was the first USEPA lead Superfund cleanup in the country and was sure to be in a "fish bowl" as far as publicity and public/industry interest was concerned. The COE accepted the assignment and assured USEPA that they would meet the target date of July 30, 1982 for having a contractor on-site.

A concentrated team effort was made by the Omaha District of the COE Missouri River Division, the Baltimore District of the COE North Atlantic Division, Roy F. Weston, Inc., and the USEPA to finalize a design and bid package to advertise in a matter of weeks rather than months. Due to the constraint of the July 30 starting date, the design for Phase I cleanup had to be accomplished in a minimum amount of time.

Bids were received by the COE for the Phase I cleanup on June 15. Judging from the bids and feedback USEPA received from the contractors, their goal of assembling an "Invitation for Bid" type proposal detailed enough to get the job completed yet leaving the contractor some flexibility as to how to perform the cleanup was accomplished. The USEPA was pleased with the response to the IFB and that the lowest bid was below their estimate.

A contract was awarded the contract to perform the Lehigh Electric Site Phase I cleanup in July. However, before the cleanup began, additional measures were taken by USEPA to safeguard the residents of the area during the contract period. First, ambient air monitoring samples were collected on and around the site in order to establish background readings of PCB. The analytical results indicated that PCB was not detectable with a detection limit of 3 ug/m<sup>3</sup>. This background was to be used as a baseline for the air monitoring program which was to be implemented during the cleanup.

Secondly, working through the Pennsylvania Department of Environmental Resources and the Pennsylvania Emergency Management Agency, USEPA requested that an evacuation plan be prepared in the event of a catastrophe at the site during cleanup. The worst case situation that USEPA worked out was the ignition of a 6,000 gal load of fuel oil after it had been used to flush trans-

formers with PCB concentrations of greater than 500 ppm. In such a situation, the burning fuel smoke plume would carry with it noxious and possibly toxic odors and particulate matter.

The County Civil Defense Coordinator established a 0.5 mile radius of evacuation, using the site as ground zero, in which the population would be notified of an emergency and would proceed to designated staging points in the event of a call for evacuation. The plan was presented to the communities of Old Force and Moosic Boroughs and was well received by police, firemen, and local elected officials and citizens.

The cleanup contractor began work on July 30, 1982. Their first task was to prepare the site. This task included clearing and grubbing, grading, bringing work trailers on-site, and setting of a snow fence as the demarcation line between the "clean" and "dirty" area. For the purpose of the Phase I site cleanup, the site was divided into two areas, clean and dirty. The dirty area was where all the equipment was located. The clean area contained no equipment and was to be used as a staging area for the drained equipment. The area designations were not to be construed as identifying the soil contamination levels in those areas.

### CONCLUSIONS

The foregoing description of activities at this site portrays a rational and progressive approach to cleanup. However, often the actuality of progress and activity was considerably more chaotic as a result of the "fast track" nature of the equipment removal, the pressures being brought to bear on USEPA, the COE and the Contractor to assure the initiation of construction in July 1982, and the fact that all parties were at the forefront of developing administrative and technical procedures for implementation of the program.

A very interesting aspect of the program was USEPA's desire to deviate from the normal emergency cleanup contractual methods of "time and materials" contracts to more of a "fixed price" contract. This was unusual because fixed price contracts assume everything is known about the site. At Lehigh Electric and Engineering, the plans and specifications were originally put together without a total knowledge of the contents of the electrical equipment at the site. Therefore, a concept of lump sum and unit price contract with estimated quantities had to be developed and implemented. In addition, most of the contractors with the background necessary to implement and manage programs such as this are oil and hazardous material cleanup contractors. These contrac-

tors generally respond on an emergency basis and have historically been paid for their services on a time and materials basis because of the unquantified nature of the level of effort needed to clean up any given spill situation.

These firms, for the most part, do not have a long history of working with engineering plans and specifications directing their cleanup. They utilize their own historical background and make decisions as the spill and the response unfolds. Therefore, USEPA and the Contractor were concerned that a specification be developed in a manner that would result in bids being submitted for the cleanup. As a result, baseline actions were included in the specifications. The manner of accomplishing the baseline actions were left up to the contractor. An example is the construction of the vehicle and equipment decontamination facilities. It was specified that an emergency shower was needed in the "dirty" area which the decontamination facility straddled. A design for the decontamination facility was provided, including specifications for slope, foundation construction, and types of materials. The successful construction contractor placed his emergency shower in the equipment decontamination portion of this facility. Therefore, it can be seen that baseline requirements for spill control, safety and emergency response, and basic construction actions were identified, but manner of implementation was left, as much as possible, to the construction contractor.

This approach resulted in the submittal of twelve bids. This was determined by the Corps of Engineers to be a satisfactory number once a contract was awarded and work begun.

This program also showed that the USEPA-U.S. COE agreement works. The COE was able to provide USEPA with considerable guidance on the format of the specifications including methods to control prices, particularly in the development of the context of the specifications, the pricing schedule and the measurement and payment section. They are also showing that the agreement works through successful construction management at the Lehigh Electric.

Activities that have taken place include the cleanup of the electrical and other miscellaneous equipment and the soil and groundwater investigation needed to implement a cleanup of the contaminated land. The next step in the Lehigh Project will be to develop plans and specifications and then contract for the cleanup of the estimated 11,000 yd<sup>3</sup> contaminated soil. Because of PCB's low solubility in water, there is apparently no groundwater contamination at the site.

# EVALUATION OF REMEDIAL ACTIONS FOR GROUNDWATER CONTAMINATION AT LOVE CANAL, NEW YORK

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## INTRODUCTION

During the coming years, considerable effort and resources will be committed to the investigation and clean up of groundwater contamination caused by hazardous waste disposal, spills and other activities. The enactment of the "Superfund" legislation (Public Law 96-152) will precipitate the spending of large sums of money to contain and clean up inactive sites and spills of hazardous substances. To optimize the limited resources available for the solution of these problems, and maximize the protection of public health and the environment, remedial actions must be adequately selected, designed and monitored.

Groundwater modeling is an excellent planning tool that can assist in the evaluation and selection of remedial actions. Modeling provides quantitative analyses of site hydrology and allows prediction of the effects of proposed remedial actions on the fate of subsurface contaminants.

Simulation of remedial actions during the planning stages can provide decision makers with considerable insight for making decisions on appropriate actions to be taken at a site. Such a tool, applied from the outset of a remedial action, can reduce trial and error, costs, and time on a project. Modeling, in addition, provides the means to predict future consequences of planned actions.

## LOVE CANAL CASE STUDY

### Background

In early 1980, the USEPA wanted to assess the hydrogeology of the Love Canal area, Niagara Falls, N.Y. As part of this groundwater investigation, the existing groundwater remedial measures were evaluated.

The Love Canal site is located on the east side of the City of Niagara Falls, N.Y. (Fig. 1). The 6.5 ha landfill at Love Canal operated for a 25 to 30 year period, and the recent remedial actions instituted at the site are described in Leonard, *et al.*<sup>1</sup>

The typical strata at the Love Canal site are shown in Fig. 2. In very general terms, the groundwater hydrology includes, from the surface down: (1) a shallow groundwater system that is seasonably saturated and consists of silt fill and silty sand, (2) a bed of confining material composed of clay and till, (3) a deep groundwater system in the Lockport Dolomite, and (4) the relatively impermeable Rochester Shale. In this paper, the authors are concerned with the hydrology of the shallow system. The analysis of the deep system is discussed in the original report to the USEPA<sup>2</sup> and will be published separately.

### Shallow System Hydrogeology

The shallow system at Love Canal is located in the upper units of silty sand and silt fill. It is bounded on the north by Bergholtz Creek, on the west by Cayuga Creek, and on the south by the Little Niagara River (Fig. 3).

Flow in the shallow system may be discontinuous and seasonably saturated. Field observations showed that the direction of surface and shallow groundwater flow (before remedial action) was from

the northeast to southwest, toward the Niagara River from about Read Avenue (Fig. 1), an area which includes about two-thirds of the site.<sup>1</sup>

From about Read Avenue, north, the direction of surface water and shallow groundwater movement was toward the northwest. This conclusion is supported by vegetation damage to the north of the canal.<sup>1</sup>

Given these observations on groundwater movement, and noting that much of the chemical waste was placed in the southern end of the canal, it is not surprising that the problem of contaminated leachate movement into sumps and storm sewers was far more serious on the 97th Street (west) side of the landfill, and more particularly on 97th Street between Wheatfield Avenue and Frontier Avenue (near the south end of the canal). Field data indicate that the water-table gradient is very low and that a slight mounding of water within the fill could have resulted in migration of contaminants in all directions from the fill.

### Remedial Actions Instituted

In summary, remedial action at Love Canal consisted of installing barrier drains, a clay cap,<sup>3</sup> and a wastewater treatment plant. The barrier drains are approximately 5.5 m below grade and 1.2 m across, containing French drains consisting of perforated tile pipe, about 0.6 m of uniformly sized gravel, and sand backfill to the surface. The drains were designed to intercept shallow lateral contami-

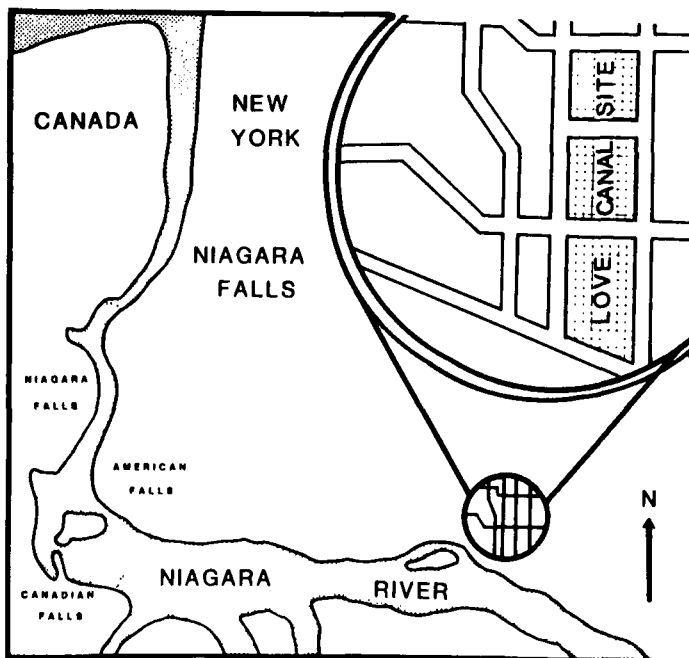


Figure 1.  
The location of the Love Canal Site in Niagara Falls, New York.<sup>1</sup>

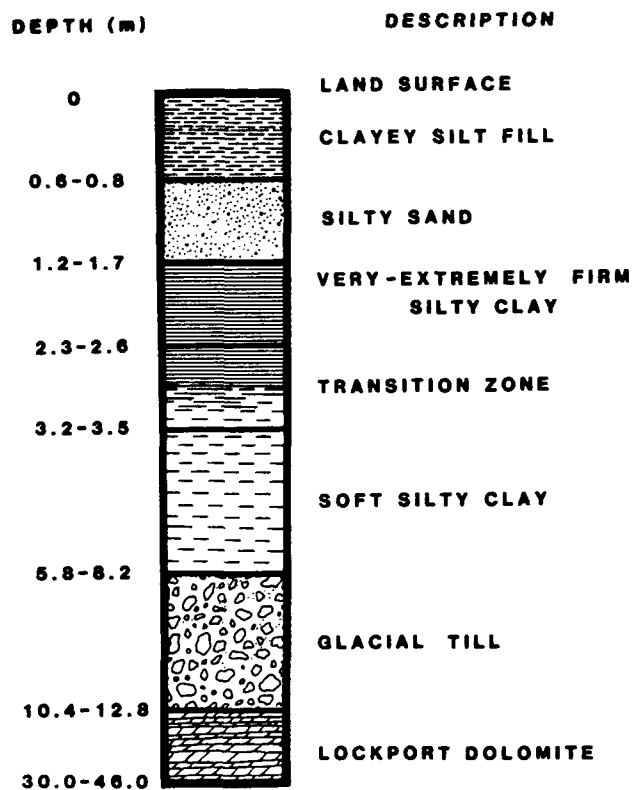


Figure 2.  
Typical Strata in the Love Canal Landfill Area as Modified.<sup>4</sup>

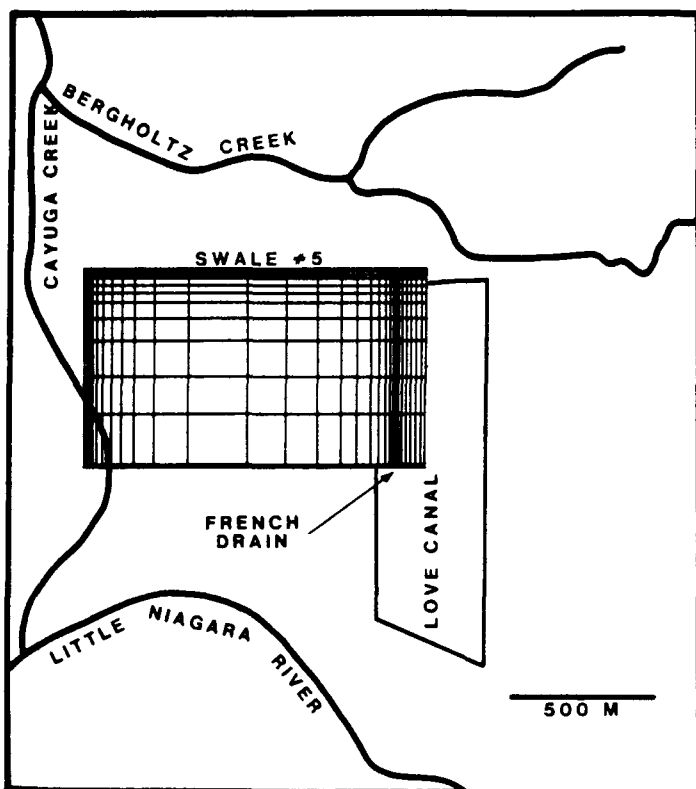


Figure 3.  
Two-Dimensional, 28 x 12 Model Grid for the Shallow Groundwater System at Love Canal.

nant flow; the clay cap was designed to reduce infiltration. Construction of the French drain commenced in the southern sector in Oct. 1978 and was completed in Feb. 1979. The central and nor-

thern sector drains were begun June 1979 and finished Dec. 1979.

Following the remedial action, the shallow hydrologic units at Love Canal now consist of the following:

- Clay cap; 1 m thick; hydraulic conductivity is  $10^{-9}$  m/s<sup>4</sup>.
- Barrier drain; 5.5 m below grade; hydraulic conductivity is  $10^{-5}$  m/s<sup>6</sup>.
- Silty sand and silt fill; approximately 3.7 m thick; hydraulic conductivity is great than or equal to  $10^{-7}$  m/s<sup>7</sup>.
- Hard clay, transition clay, soft clay, and glacial till; 7.9 m thick; hydraulic conductivity is  $10^{-10}$  to  $10^{-11}$  m/s<sup>1,6</sup>.

These units are variable in thickness and lenticular. In addition to these units, storm-sewer and sanitary-sewer excavations as well as other backfill may act as conduits. Some of the low-lying areas and channels were filled with miscellaneous materials, and are referred to as swales. Swales may be preferential routes of water movement, depending on the fill material.

#### Shallow System Model

The shallow hydrogeologic system at Love Canal is complex. Given the time constraints for this study, many simplifying assumptions had to be made,<sup>2</sup> resulting in a highly idealized model. It was assumed that the system is a water-table aquifer and was modeled using the USGS two-dimensional code<sup>4</sup> for groundwater flow. The model simulated the area shown in Fig. 3 using a 28x12 block-centered, finite-difference grid. Cayuga Creek was treated as a constant head boundary to the west. Cayuga Creek was modeled as a straight line; a simplification justified by the extremely low gradient in the adjacent area. Swale No. 5<sup>3</sup> (see Fig. 3) was assumed to form a no-flow boundary on the north since it approximately parallels the groundwater flow lines.

The southern boundary was approximated as no-flow and was placed far enough from the swale so as not to affect the results of computed heads close to the swale. Because this boundary is somewhat arbitrary, it is placed approximately at the east-west centerline. For the eastern boundary, the canal was assumed to be a no-flow boundary due to the apparent groundwater mounding in its north end, creating a possible groundwater divide.<sup>2</sup>

Subsequent to the completion of this study, it was learned that a water line under 97th Street near Colvin Boulevard was broken for several weeks prior to the field measurement of groundwater levels, and that this break was a source for the groundwater mound.<sup>9</sup> This postulated cause for the mound does not affect the eastern boundary condition in the model, since the French drain causes an equivalent effect. Thus, the model is considered symmetric about the north-south centerline of the canal. Because of complex geology, limited data, and approximate symmetry, only one quarter of the flow system is simulated.

The shallow system is very complex, possibly being unsaturated in some locations and containing areas with different hydraulic conductivities. The model used to simulate flow in the shallow system is a highly idealized representation of this system. However, through its use, insight is gained as to the flow regime of the shallow system. In an attempt to account for the major features of the shallow system, the model was used under three general hydrologic conditions: (1) homogeneous flow parameters, (2) heterogeneous parameters where a zone containing a higher hydraulic conductivity is used to represent utility trench backfill, swale or sand lens, and (3) heterogeneous parameters where the remedial drainage system is represented by a zone of high hydraulic conductivity.

Important assumptions used in the shallow system model include:

- The shallow system is unconfined, porous, isotropic and heterogeneous
- Groundwater flow and parameters in the shallow system can be vertically averaged over the aquifer thickness
- Both quasi-steady-state (annually averaged conditions) and transient flow are assumed
- The shallow system is 3.7 m thick, with the bottom elevation located at 171.3 m above mean sea level

- The shallow system is composed of silty sand and clayey silt fill and has been estimated to have a  $K$  equal to or greater than  $10^{-7}$  m/s<sup>7</sup>. The probable range of  $K$  for the shallow system is  $10^{-5}$  to  $10^{-7}$  m/s.
- Specific yield for the silty sand and clayey silt fill ranges from 3-30%, while silt averages 18% with a range of 3-19%.<sup>10</sup> A specific yield value of 15% with a range of 10-20% is assumed. The specific yield is assumed equivalent to the effective porosity in the unconfined case
- The shallow system has a constant head boundary of 171.6 m above MSL on the west at Cayuga Creek
- The middle of the canal (parallel to its length) is approximated as a no-flow (symmetry) condition.
- Major evapotranspiration (ET) occurs for 180 days, May through October (i.e., the growing season), at an average annual rate of 0.33 m/yr, varying from 0.28 to 0.38 m/yr. Maximum depth to which ET occurs is 1.83 to 3.05 m with a 2.44 m average.
- Recharge occurs at an annual rate of 0.068 to 0.183 m/yr with an average of 0.124 m/yr. Recharge occurs in two approximately equal surges in Nov.-Dec. and Mar.-Apr.

The French drain is simulated as a row of cells 1.22 m wide in the model. The simulated drain is about 15 m from the canal edge. The bottom of the drain was constructed about 5.5 m below grade. Therefore, the blocks representing the drain were set at constant head at that elevation. The constant head was fixed at 0.03 m above the base so that the blocks representing the drain were partially saturated and therefore, part of the modeled area. The computer code was modified to provide a printout of constant head flux rates for each finite-difference block, i.e., the volume of groundwater discharged (or recharged) at constant head blocks per time.

Data on volume of treated water collected by the drain has been recorded at the Love Canal treatment plant. Dr. Nick Kolak, New York State Department of Environmental Conservation, provided monthly drain flow data for the period Aug. 1979 through Feb. 1981, as shown in Table 1.

Table 1.  
Monthly Volume of Water Treated by the  
Love Canal Treatment Plant

Month	Total <sup>1</sup> Volume	Ave Daily Volume	Ave Flux <sup>2</sup> Rate of Fr Drain
1980			
	m <sup>3</sup>	m <sup>3</sup> /dx $10^{-7}$ m <sup>3</sup> /d/m	
Jan	1,797.	58.0	2.4
Mar	1,479.	48.8	2.0
June	1,206.	40.2	1.7
Sept	890.	29.7	1.3

1. Provided by New York State Department of Environmental Conservation.

2. Total length of French drain is 2731 m.

### Model Calibration and Sensitivity Analysis

The two-dimensional groundwater flow model developed with the above input parameters was calibrated against the measured drainflux. Sensitivity analyses were conducted for hydraulic conductivity, effective porosity and recharge/evapotranspiration by varying, in turn, each parameter within the specified limits, while holding all others constant. The results of these sensitivity analyses provided simulated drain flux values for comparison with the observed drain flux. In this manner, the best match of simulated versus observed flux indicates the best combination of parameter estimates for the simplified shallow system model.

The results of sensitivity runs for shallow system hydraulic conductivities of  $10^{-7}$  and  $10^{-6}$  m/s, respectively, and specific yields of 15% for various combinations of ET and recharge are shown in Fig. 4.

Effective porosity, or specific yield, affects the rate of drainage during transient conditions. The best results of this sensitivity analyses are shown in Fig. 5.

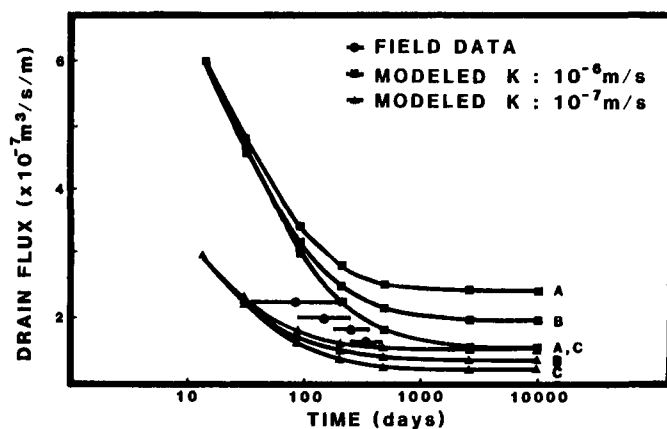


Figure 4.

Sensitivity of Modeled Results on the French Drain Flow Rate Per Lineal Length Over Time for Various Combinations of Hydraulic Conductivity ( $K$ ), Evapotranspiration ( $ET$ ) and Recharge ( $R$ ). Curve A Represents Low  $ET$  and High  $R$ ; Curve B, Medium  $ET$  and  $R$ ; and Curve C, High  $ET$  and Low  $R$ .

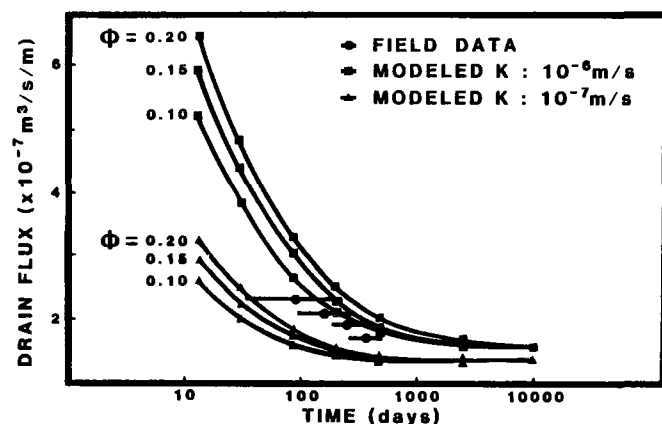


Figure 5.

Sensitivity of Modeled Results on the French Drain Flow Rate Per Lineal Length Over Time for Various Combinations of Hydraulic Conductivity ( $K$ ) and Specific Yield ( $\phi$ ).

Definite conclusions can be drawn from these sensitivity analyses. An average, or bulk, hydraulic conductivity for the shallow system is between  $10^{-6}$  and  $10^{-7}$  m/s with a specific yield of 10-15%. The observed flow rates are completely bracketed by the modeled flow rate curves using these ranges of values.

Although the above analyses treat the shallow system as a homogeneous media with averaged properties, the system really is heterogeneous. Inserting earth materials of various hydraulic conductivities into the model may provide results that would match the field data better than the simplified assumptions represented by Figs. 4 and 5. In Fig. 6, for example, the results of a simulation with two higher permeability zones ( $K$  of  $10^{-4}$  m/s and  $K$  of  $10^{-5}$  m/s) are shown. The shallow system in Fig. 6 has a  $K$  of  $10^{-7}$  m/s, but the addition of the higher permeability zones effectively increase the flow rate in the drain to a fairly close fit to the observed flow rates. A better match could probably be obtained by adjusting the parameters further. However, the information gained would be of little value since there is no way to determine the validity of these more complex simulations.

### Water Table Configuration

The effects created by the French drain on the shallow system water table are shown in Fig. 7. The top curve represents the head distribution in the shallow system with a  $K$  of  $10^{-7}$  m/s. For comparison, the lower curve represents a higher permeability material with a value of  $K$  at  $10^{-4}$  m/s. In the areas where hydraulic conductivity is  $10^{-7}$  m/s, the zone of influence of the drain extends about 55 m from the drain.



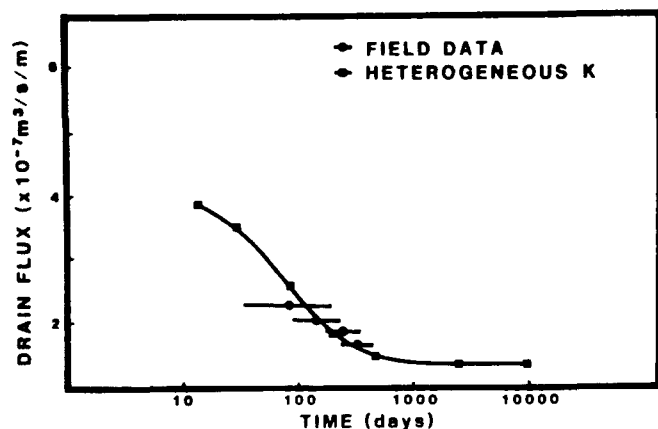


Figure 6.

Modeled Results of the French Drain Flow Rate Per Lineal Length Over Time for a Heterogeneous Aquifer of Clay and Sand.

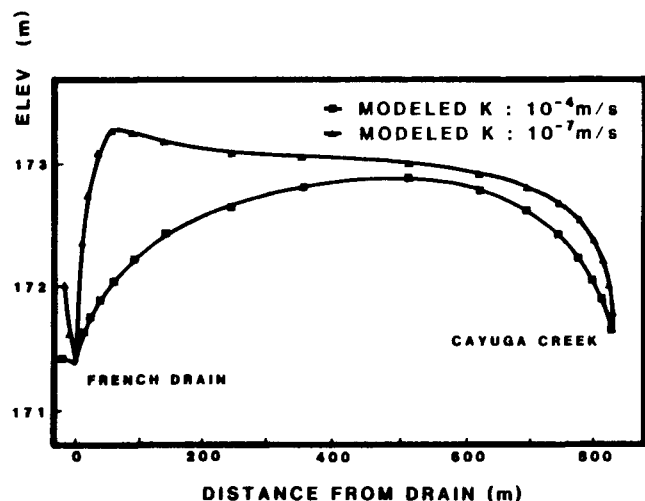


Figure 7.

Predicted Effects of Two Values of Hydraulic Conductivity on the Shape of the Water Table with Installed French Drain.

In those areas where material with a  $K$  of  $10^{-4}$  m/s occurs, the zone of influence would extend about 518 m from the drain, if continuous high permeability material extended that far. Thus, in these zones of influence, the French drain would cause a reversal of flow direction back toward the drain.

### Seasonal Effects

Seasonal effects on the shallow system and remedial actions will lower the water table during the summer and raise the water table during the late fall and early spring. A hypothetical well hydrograph for a well 176 m west of the French drain and associated drain flow rates over time, beginning Oct. 1, 1979 and extending into 1981 is shown in Fig. 8. With a simplified two-season model, the hydrograph illustrates the water-table highs that occur in early spring and the lows in late summer. Paralleling the water-table level changes, the drain flow rates declined over the summer of 1980 and closely match the observed values. Drain flow rates increased again the early spring of 1981.

### Time to Achieve Steady State in Drain Discharge

Modeling results indicate that the drain should achieve a steady-state condition in about three years, reaching 90% of the steady-state value in about one year. Thus, the shallow system at Love Canal was approximately at equilibrium with respect to the French drain, ignoring the seasonal fluctuations in head at the time of this study.

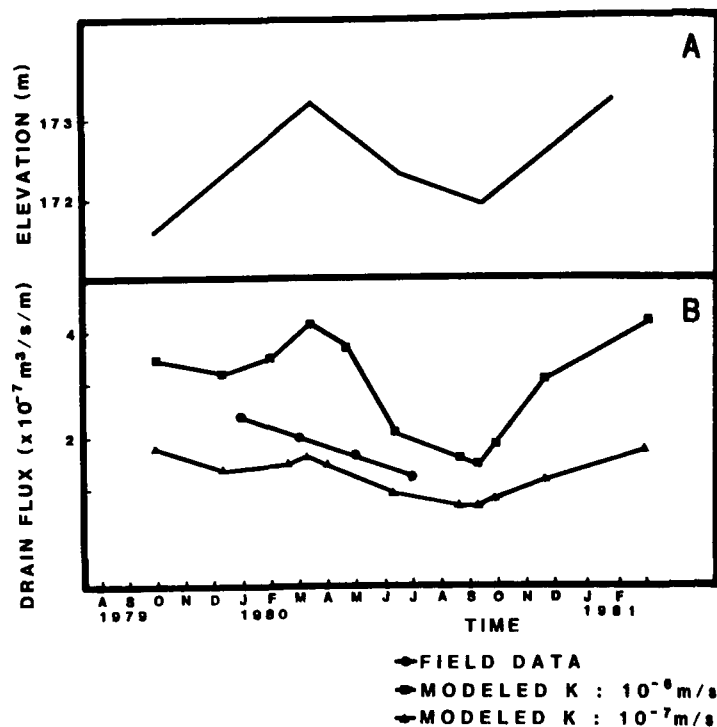


Figure 8.

Predicted Hydrograph for a Well 76 m west of the French Drain (Fig. 8A) and Predicted French Drain Flow Rate Per Lineal Length Over Time for Two Values of Hydraulic Conductivities as Compared to Field Data Available as of January 1981 (Fig. 8B)

### Travel Time and Flow Velocity

The predictions presented here are posed in terms of probable conditions based on the best estimates for the hydrologic parameters. If a continuing monitoring program is maintained, improved estimates of hydrologic parameters can be determined. This, in turn, can result in refinement of predictions with less uncertainty.

Predictions of travel time and flow velocity are based on the equation:

$$v = \frac{Ki}{\phi} \quad (1)$$

where  $v$  = interstitial velocity

$K$  = estimated hydraulic conductivity

$i$  = head gradient provided by the models

$\phi$  = effective porosity (specific yield)

Using Equation 1, groundwater velocities for various hydrologic parameters representing the hypothetical shallow systems and swales or sand lenses were calculated and are shown in Table 2. As may be seen, the various combinations of parameters produce velocities ranging from 0.02 to 19 m/yr. These values may be used to estimate travel times and distances for contaminants traveling with the velocity of water.

Table 2.  
Groundwater Flow Velocity for Various Parameter Combinations  
(Effective Porosity = 0.15)

Hydraulic Conductivity	Gradient	Interstitial Pore Velocity
m/s	m/m	m/yr
$1.0 \times 10^{-4}$	0.0010	19.00
$1.0 \times 10^{-5}$	0.0010	1.90
$1.0 \times 10^{-6}$	0.0012	0.23
$1.0 \times 10^{-7}$	0.0013	0.02

## Conclusions from the Love Canal Modeling

Conclusions and predictions which have been drawn from this modeling study for a hypothetical, average shallow system ( $K$  of  $10^{-6}$  m/s) are:

- Without the remedial actions taken to date, the groundwater in the average shallow system would have migrated up to an additional 1.8 m away from the canal in the next 5 years.
- For the average shallow system, the area of influence of the French drain will encompass all groundwater which may have been contaminated by subsurface migration over the past 30 years. The area of influence for material with a  $K$  of  $10^{-6}$  m/s extends out 70 m from the canal while the groundwater traveled only about 10 m from the canal during those 30 years (assuming a more conservative effective porosity of 10%).
- With the remedial actions installed to date, the French drain will cause all groundwater presently existing between the canal and drain to be discharged to the drain during the next 5 years. Outside the drain, groundwater will flow back to the drain from as far as about 70 m from the canal during the next 5 years. These predictions assume an average shallow system  $K$  of  $10^{-6}$  m/s, effective porosity of 10%, and gradient of 0.036.

Conclusions and predictions which have been made for the highest permeability zone hypothesized ( $K$  of  $10^{-4}$  m/s) are:

- Without the remedial actions, the groundwater in material with a  $K$  of  $10^{-4}$  m/s (effective porosity of 15%) would travel in the next 5 years up to an additional 96 m to a maximum distance of 675 m from the canal. The probability of this occurring is unknown, but most likely is low because of the discontinuous, heterogeneous nature of the shallow system.
- In swales, sand lenses, utility trench backfill, or other higher permeability zones, the drain's area of influence could extend out 533 m ( $K$  of  $10^{-4}$  m/s) while groundwater could have traveled about 570 m during the past 30 years (assuming effective porosity of 15%). Therefore, the drain should cause most of the groundwater that could have been contaminated during the past 30 years in these higher permeability zones to begin flowing back toward the drain.
- With the remedial actions taken to date, all the groundwater in material with  $K$  of  $10^{-4}$  m/s and effective porosity of 15% between the drain and canal will be discharged to the drain. All groundwater out to a distance of about 275 m from the canal will be discharged to the drain during the next 5 years.
- Less than 11 years will be required for groundwater which originated at the canal 30 years ago to be drawn back to the French drain in material with  $K$  of  $10^{-4}$  m/s and effective porosity of 15%. This disregards attenuation effects on contaminants and assumes a maximum travel distance of 580 ft from the canal over the past 30 years.

## ALTERNATIVE TRANSPORT MECHANISM

The above analysis of the extent of groundwater contamination at Love Canal is based on the assumption that the contaminants were transported via subsurface flow only. An alternate mode of travel which was not considered in this study is that of overland flow. Additional insights into the problems at Love Canal can be gained by considering the case at West Valley, NY. Here, burial trenches for disposal of solid radioactive waste were excavated in glacial till with a low hydraulic conductivity similar to that observed at Love Canal, about  $5 \times 10^{-10}$  m/s.<sup>11</sup>

Prudic and Randall<sup>11</sup> observed that above the water table, fractures and root tubes extended 3 to 4.5 m below the natural land surface. Preliminary simulations suggested that the hydraulic conductivity in these fractured tills is an order of magnitude greater than the unfractured till. It is thought that the fractured till allowed recharge to reach the trenches, and since the material surrounding the trenches has a much lower hydraulic conductivity, water began to fill up the trenches. As a result, water overflowed in the older trenches briefly in 1975 until they were pumped out. Therefore,

most soil and shallow groundwater contamination away from the West Valley site has been attributed to an intermediate transport mechanism of overland flow.

It is difficult to assess if similar overland flow of contaminants occurred at Love Canal. The hydrogeologic conditions at the two sites are similar, and any interpretation of the mechanisms of contamination at Love Canal should allow for this possibility. This is especially valid considering the reported exposure of the waste in Love Canal to surface recharge at various times during its existence.<sup>9</sup>

## SUMMARY

The utilization of computer modeling to assess and predict the effectiveness of remedial actions for groundwater contamination cases can provide the decision maker with an important tool in selecting the best plan. From generic and specific modeling applications, insight can be gained on operating characteristics of the remedial method. If employed in the design phase, a modeling study can provide reasonable estimates of the amounts of contaminated groundwater produced, extent of contaminant migration over time and the required life span of remedial operations. These data will assist the engineer in optimizing the final remedial design.

Although solute transport models may be necessary for some contamination problems, much information can be gained by considering groundwater flow alone. These applications have been described in detail by Nelson<sup>12</sup> and are demonstrated by the modeling applications to the Love Canal area described in this paper.

Field investigations of groundwater contamination cases should be carried out in such a manner as to facilitate a responsive, yet scientific, appraisal of the situation. The best approach to such an investigation is through an iterative, feed-back system linking data collection with analysis. Through this phased approach, the collection of large amounts of data that may be largely useless will be avoided. Resources will be maximized to produce the most acceptable results for all parties involved. This iterative approach is outlined as:

- The review and analysis of existing data
- The performance of preliminary modeling to gain a better understanding of the hydrogeologic system
- The determination of further data requirements and field work, based, in part, on preliminary modeling results
- The analysis of the additional data
- The refinement of the preliminary model and determination of further data requirements
- Continuation of the above iteration of data collection, analysis, and interpretation until an acceptable level of confidence is attained

Following this general pattern provides a flexible approach to investigating groundwater problems. Integration of analysis and interpretation with data collection can allow the investigator to dispense with unnecessary data and, therefore, reduce cost. The use of groundwater models, as described in this paper, can assist in even greater cost savings by allowing the investigator to achieve a better understanding of the groundwater system and contaminant behavior in the subsurface.

Because of the time constraints imposed on the Love Canal study, this type of iteration and feedback was not possible and the groundwater investigation preceded the laboratory analysis. Even with the lack of data and the time constraints (three months to complete the study), it was still possible to make calculations that gave valuable insight into the groundwater flow regime at Love Canal. This fact is proven by data made available only recently, the monthly French drain flow rate for the period from Aug. 1979 through Feb. 1981 are given in Table 3. The comparison of these observed flow rates versus the predicted flow rates over the same period (Fig. 9) provides additional confidence in the validity of the model.

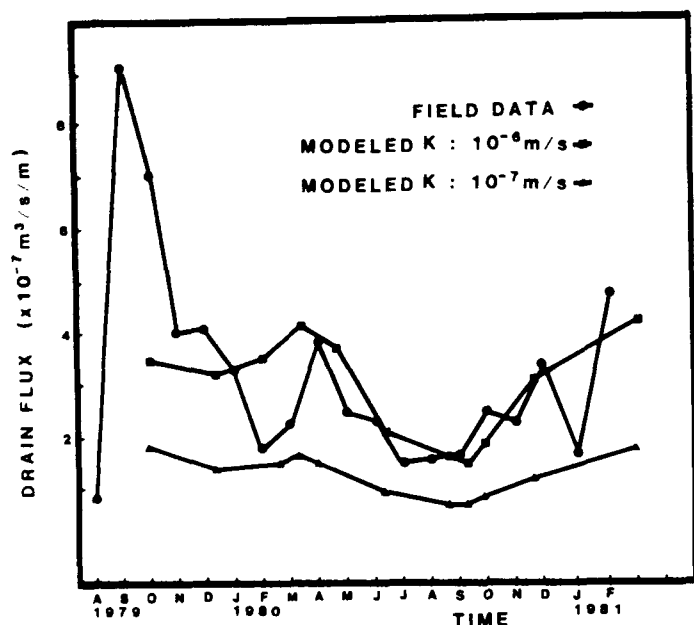


Figure 9.  
Predicted French Drain Flow Rate Per Lineal Length Over Time for  
Two Values of Hydraulic Conductivity as Compared to Field Data  
Available as of July 1982.

## ACKNOWLEDGEMENTS

The authors wish to express thanks to Dr. Nick Kolak and the New York State Department of Environmental Conservation for providing operational data on the French drain at Love Canal. The work upon which part of the Love Canal case study is based was performed under Subcontract No. 1-619-026-222-003D to GCA/Technology Division pursuant to USEPA Contract No. 68-02-3168, Technical Service Area 3, Work Assignment No. 26.

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Table 3.  
Monthly Volume of Water Treated by the Love Canal Treatment Plant

Month	Total Volume <sup>1</sup> m <sup>3</sup>	Ave. Daily Volume m <sup>3</sup> /d	Ave. Flux Rate <sup>2</sup> of French Drain x10 <sup>-7</sup> m <sup>3</sup> /d/m
Aug 1979	491.9	15.8	0.836
Sep	5,197.0	173.0	9.280
Oct	4,140.0	133.0	7.150
Nov	2,288.0	76.1	4.070
Dec	2,390.0	77.0	4.170
Jan 1980	1,846.0	61.4	2.350
Feb	972.5	33.5	1.760
Mar	1,333.0	42.9	2.320
Apr	2,181.0	72.6	3.900
May	1,422.0	46.4	2.510
June	1,272.0	42.3	2.320
July	868.3	28.0	1.490
Aug	934.6	30.1	1.580
Sep	922.5	31.4	1.670
Oct	1,425.0	45.9	2.510
Nov	1,300.0	43.2	2.320
Dec	1,972.0	63.5	3.440
Jan 1981	910.4	30.3	1.670
Feb	2,520.0	89.8	4.820

1. Provided by New York State Department of Environmental Conservation.

2. Total length of French drain is 2731 m.

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# MONITORING CHLORINATED HYDROCARBONS IN GROUNDWATER

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## INTRODUCTION

Groundwater contamination by chlorinated hydrocarbons has been found at numerous sites around this country and others. The literature contains examples of sites where contaminated groundwater would be expected, but just as many where contaminated water was found at unpredictable lateral and vertical locations and at unexpected concentrations. Trichloroethylene (TCE) and related chemicals seem to be the most common of the groundwater contaminants. The literature, coupled with experience at sites across the country, has led to several considerations in groundwater monitoring activities at such sites and to several conclusions about subsurface migration of some chlorinated organics.

The authors' purpose in this paper is to discuss these considerations and conclusions so that they may spawn criticism or further development. The authors believe that it is necessary to develop and provide, to all concerned, the basic information required to efficiently conduct remedial actions at groundwater contaminated sites. Several sites are discussed only in terms of their general features, but are based on real sites and illustrate both the complexity of natural hydrogeologic systems and the difficulties of monitoring chlorinated hydrocarbons below the water table.

Specific information on contamination by chlorinated organic compounds has been the subject of very few technical publications. This is probably the result of a lack of knowledge on the subject as well as the confidentiality of much of the available data. Additionally, the physical properties and the migration characteristics of these compounds do not lend themselves easily to standard principles of hydrogeological investigations. This latter consideration has become a strong incentive toward research activities in this area.

The following discussion, though not exhaustive, presents a summary of the available information on some chlorinated organics in the subsurface and some of their pertinent physical properties as they would affect subsurface migration. Although numerous chlorinated compounds exist and probably have variable transport characteristics, only the listed compounds in Table 1 have been considered here.

## Significant Physical-Chemical Properties

Information on the occurrence, migration and fate of particular chlorinated organics in an unsaturated environment is relatively rare. Some of what is available is site-specific and cannot yet be transferred to the public. The literature does provide important physical characteristics of the compounds of concern here, as well as some of their characteristics in dilute aqueous solution. The properties of these compounds, which appear to be of the most importance in attempting to predict subsurface movement, are given in Table 1.

One obvious property of the compounds is their relatively high vapor pressure and low boiling point. Experiments conducted by Dilling, *et al.*<sup>1</sup> provide information on the time required for an initial 1 mg/l aqueous solution of each listed compound to decrease (evaporate) 50% and 90% in concentration (at 25 °C). In general,

the listed compounds decreased 50% in less than 0.5 hr and decreased 90% in about 1.5 hr. The values are not unique because of uncontrolled variations, but they do indicate a rapid decrease in concentration from open containers at 25 °C.

Dilling repeated the experiments after adding certain "contaminants" to the initial solution. These "contaminants" were dry bentonite, peat moss, sand, and dolomite. The experiments were again repeated with the contaminants in closed containers. All of these experiments were an attempt to determine which of the contaminants increased the rate of disappearance of the organic compounds from the aqueous solution. The authors concluded that peat moss (organics matter) was the most effective in "adsorbing" the chlorinated compounds from the sealed container.

Although these experiments were simple, the implication exists that the higher the organic content of the soil, the better able they will be in adsorbing a release of chlorinated organics at least from a dilute aqueous solution.

Table 1.  
Physical Properties of Selected Chlorinated Hydrocarbons  
of Low Molecular Weight

Constituent	Solubility in Water (mg/l)	Liquid Density (gm/cc)	Dielectric (20 °C)	Vapor Pres. (mmHg @ 20 °C)	Biodeg.**
carbon tetrachloride	800	1.59	2.238	91	D
chloroform	8,000	1.49	4.806	192	A
methylene chloride	16,700	1.49	9.08	438	D
trichloroethylene	1,100	1.45	3.4	74	A
1,1,1 trichloroethane	4,400	1.33	---	100	B
tetrachloroethylene	150	1.62	---	19	A
water	---	1.00	80.37	17.5	--
chlorobenzene	500	1.10	5.708	9	D
1,2,4-trichlorobenzene	28.6	1.45	---	< 1	T

\*A—Significant degradation with gradual adaptation—in aerobic aqueous solution.

B—Slow to moderate biodegradative activity, concomitant with significant rate of volatilization.

D—Significant degradation with rapid adaptation.

T—Significant degradation with gradual adaptation followed by deadaptive process (toxicity).

1—from Weast<sup>11</sup>.

2—from Tabak, *et al.*<sup>12</sup>.

Another important physical property of the chlorinated hydrocarbons of concern here is their high liquid densities; all are greater than water near 20 °C (Fig. 1).<sup>2</sup> According to the National Research Council "if the chlorinated compounds were spilled or released as a slug they would tend to settle in any receiving water before dispersion, volatilization, emulsification or solubilization takes place".<sup>3</sup>

This density factor, when considered in terms of a liquid spill on land or a release to the subsurface (tank leakage) will assist in the downward migration through both the unsaturated and saturated zones. One particular case, described generally in Saines<sup>4</sup> recognized the high density of a contaminant solution and its migration

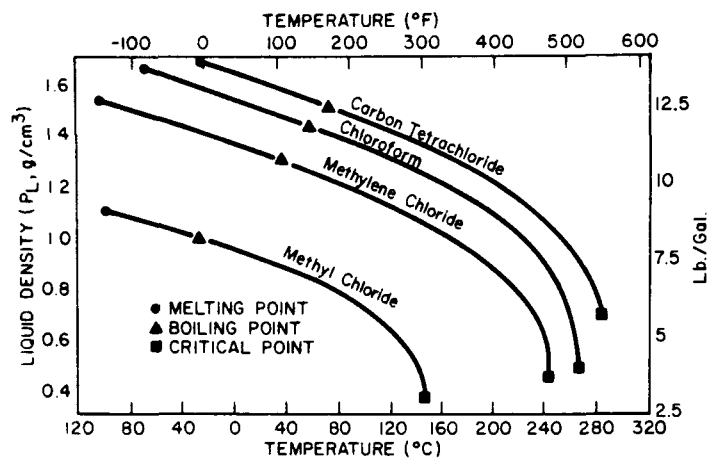


Figure 1.

Liquid Density of Selected Chloromethanes at Various Temperatures  
From Yaws, 1976<sup>2</sup>

by gravity rather than by the hydraulic gradient. The schematic in Fig. 2 illustrates a particular hydrogeologic situation where dense leachate had moved beyond the normal groundwater discharge point. Although some production wells may have induced the migration across the river somewhat, the denser-than-water leachate promoted migration down the slope.

Studies to determine the effects of organic leachate on the permeability of clay liners<sup>4</sup> have concluded that other factors are involved in affecting the rate of organic leachate movement in the subsurface. Specifically, the ability of some organic solvents to structurally alter the clay and make the clay more permeable has been observed. Although none of the specific chlorinated compounds of concern here were tested, the neutral non-polar compound xylene was used. Of the four classes of organic fluids tested, namely, acidic, basic, neutral polar and neutral non-polar, the chlorinated organics are of the neutral non-polar type. All four of the different clayey soils treated with xylene showed a very rapid increase in permeability followed by a leveling at a permeability about two orders of magnitude greater than the clay's permeability to water. These increases are much greater than can be attributed just to viscosity/density of xylene. They hypothesize that structural changes had occurred in the clay.

It is not suggested here that the xylene typifies the affects of TCE or other chlorinated solvents in the tested clays, however, it is not unreasonable to assume that they would act in a similar fashion. Some work by Green *et al.*<sup>6</sup> does support this contention in studies. The experimenters tested the effects of several reagent-grade organic fluids on three clayey soils: xylene, carbon tetrachloride and trichloroethylene. The experiment, designed to obtain a permeability of the particular solvent through the clay, showed that the solvents initially exhibited a permeability about one order of magnitude less than that of water. Those solvents with low dielectric constants (including xylene, carbon tetrachloride and trichloroethylene), caused significant degradation of the clay soils. After a period of days, these solvents would break through the test columns and allow a bulk transfer (or release) of the solvent through the column. The solvents of low dielectric constants caused an obvious shrinking and cracking of the clays in both consolidometer and column tests. The authors developed an empirical relationship between the permeability, the solvent's dielectric constant and the packed bulk clay density before breakthrough. Results of these tests may be significant in developing predictions of direct releases of solvents (tank spills, leaks or other bulk loss) onto unsaturated sediments.

### UNSATURATED ZONE TRANSPORT

At several locations, soil samples obtained during the drilling of monitoring wells or exploratory borings, were analyzed for suspected chlorinated organics. The procedure was generally one of hydraulically collecting an undisturbed sample below the lead

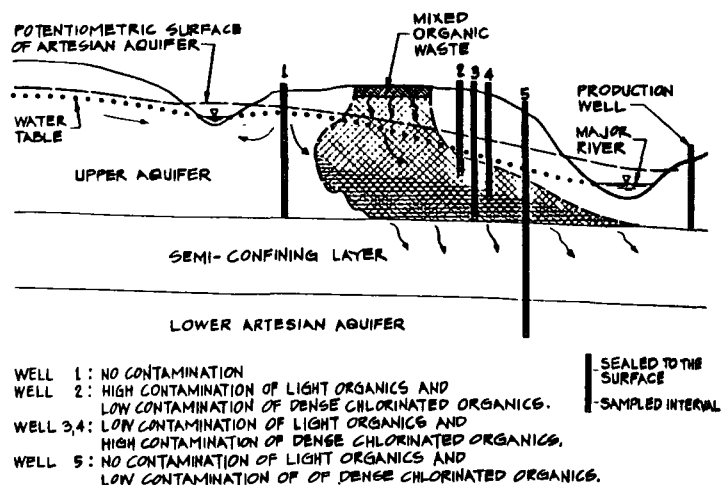


Figure 2.

General Pattern of Monitoring Wells in a  
Simplified Multi-Aquifer Setting

auger, minimizing its air exposure, and transporting the sample to a laboratory. The actual procedures are detailed in recommended sampling methods.<sup>7</sup>

Results of the laboratory testing provided some interesting conclusions about the migration of specific constituents in the subsurface. Negative results for chlorinated hydrocarbons in unsaturated sediments (especially coarser-grade) do not allow one to conclude that a source at the surface above the sample's location did not exist (Fig. 3). Detailed data from soil column experiments<sup>4</sup> using a mass balance approach indicate that virtually all trichloroethylene from a 1 mg/l aqueous solution could be accounted for either by volatilization or by the liquid collected after passing through a sandy soil. The average soil composition was 92% sand, 5.9% silt, 2.1% clay and 0.087% organic carbon. Though the TCE was slowed to approximately one-half the velocity of the standard water tracer, it was not adsorbed on the soil particles. This non-adsorbent tendency of TCE and perhaps other compounds on soil particles may account for the observed negative results in the soil samples discussed above.

These studies also involved column experiments for other organics which indicated a much higher tendency than the TCE to be retained in the soil. This group included such compounds as chlorobenzene, 1,2-dichlorobenzene and 1,2,4-trichlorobenzene. When compared to TCE, the laboratory tests indicate that these compounds would be a lesser threat for groundwater contamination since they are better adsorbed on the soil particles. Data obtained from field studies at several sites indicate that this conclusion

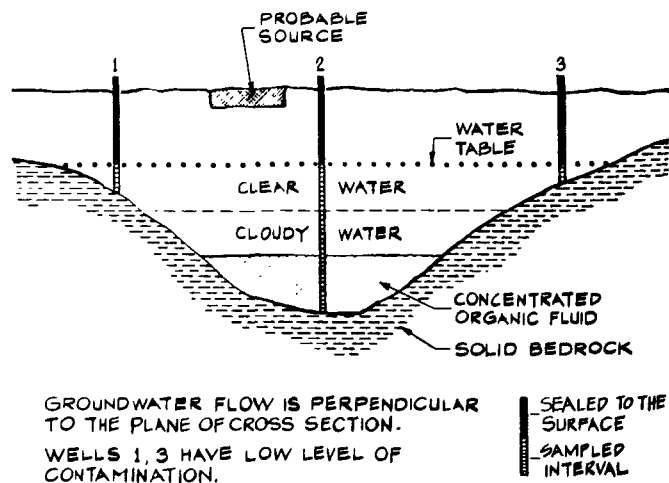


Figure 3.

General Pattern of Monitoring Wells in a  
Gravel-Filled Bedrock Channel

is indeed the case. But this effect probably results from both the greater adsorptive capability and also greater tendency toward biodegradability of these compounds.

In predicting the degree of possible attenuation, investigators<sup>8</sup> have found that the most significant properties of the soil are its bulk density and the soils' organic carbon content. A mathematical model, based on the organic compound's solubility and the organic carbon content of the soil, was used to predict the retardation of individual compounds as they moved through a soil column. The retardation factors listed in Table 2 provide a relative indication of how fast the particular compound travels through the sandy soil tested. Of significance also was the volatility of the compounds from the soil was reduced by about an order of magnitude. The implications upon release of a concentrated slug on top or within sediments are obvious in that loss through volatilization becomes much less of an attenuation factor.

**Table 2.**  
**Retention of Organic Compounds by Soils**  
(Adapted from Wilson, *et al.*<sup>8</sup>)

Compound	Water Solubility (mg/l)	Predicted Retardation Factor*
chloroform	8000	1.2
1,2-dichloroethane	8690	1.2
tetrachloroethylene	150	3.2
trichloroethylene	1100	1.6 - 2.0
chlorobenzene	500	1.9
1,4-dichlorobenzene	79	4.0
1,2,4-trichlorobenzene	28.6	7.0
toluene	515	1.8

\*Retardation Factor = interstitial water velocity  
velocity of compound

## SATURATED ZONE MIGRATION

Although the results of laboratory column experiments are of prime importance, further studies similar to those conducted by Roberts, *et al.*<sup>10</sup> are necessary. These studies (sponsored by the Groundwater Research Laboratory at Ada) attempted to determine transport properties of organics compounds within an aquifer. The behavior of several types of organic compounds were analyzed by means of a series of observation wells surrounding an injection well.

In this study, Roberts *et al.* considered the aquifer as a quasi-closed vessel where inflow and outflow from an aquifer-element could be mathematically adapted to the stimulus-response concept. This approach was used to develop relationships of contaminant concentrations versus time in the observation wells. Based on the shape of a semi-logarithmic plot, conclusions were made on the relative importance of the mechanisms of dispersion, adsorption and biodegradation active within the aquifer.

Of those organics tested, chlorobenzene was most rapidly transported with a half-time of response about 40 times less than that of a chloride tracer. The primary retention mechanism appeared to be adsorption. The dichlorobenzene isomers and 1, 2, 4 trichlorobenzene were more strongly adsorbed than chlorobenzene, and naphthalene which is a fused benzene ring seemed to undergo some biodegradation. Although results are presented for essentially just benzene compounds and do not necessarily reflect the behavior of all chlorinated organics, they generally indicate that some attenuation processes are active within a confined aquifer.

Giger and Kubica<sup>9</sup> reported on groundwater contaminated by the compound, tetrachloroethylene in wells near Dubendorf, Switzerland. Levels of up to 1 mg/l were determined from some groundwater samples. The authors concluded: "this organic solvent is reasonably soluble in water, has a low tendency to adsorb compared to pesticides and petroleum hydrocarbons, and is only very slowly degraded. Thus, it is likely to be transported with the water flow and to be quite mobile as well as long-lived in the groundwater environment."

In general, aquifer contamination by TCE and other organics solvents has been found where groundwater samples had been analyzed for these constituents. Owing to the widespread use of these chemicals, it is probable that there are many more local instances of contamination which will go unnoticed. Even in those areas known to be affected, often the time of release, concentration/volume of the release, nature of the release (i.e. spill or seep) and the source itself cannot be determined. Therefore, economic practicality has dictated that rehabilitation efforts be directed toward wastewater treatment, rather than exploration, monitoring, and rehabilitation of the aquifer itself.

## MONITORING CONSIDERATIONS

Effective groundwater monitoring at a site contaminated by chlorinated hydrocarbons requires the collection of more site details, more carefully collected water quality data and more technical than at sites of inorganic or light hydrocarbon contamination. The advantage of having historical information on type, quantity, rate, location of waste disposal or release cannot be overstated. However, this is usually the most limited information available. Generally, the monitoring program must be developed by progressively obtaining subsurface information until the major hydrogeologic controls on lateral and vertical migration are determined. It then becomes a matter of identifying the limits of the contaminants in both the vertical and lateral directions. Of course, data on concentration levels in both the sediments and groundwater can and should be obtained concurrently with the hydrogeologic information.

Somewhat standardized monitoring procedures for sites of contaminated groundwater have been developed. Detailed procedures for obtaining groundwater and sediment samples<sup>7</sup> emphasize specific problems and solutions for sampling volatile organic compounds. The discussion here provides observations at sites of active monitoring where standard hydrogeologic assumptions and procedures may have to be altered where chlorinated hydrocarbons are present. The following list provides some specific considerations:

- Sites of active monitoring seem to indicate that a strong relationship exists between the relative density of the chlorinated compounds and their apparent migration below the water table. Examples of the generalized subsurface features and findings at several sites are presented in Figs. 2, 3 and 4.
- The assumption that a (normal hydraulically impermeable layer) clayey unit of  $10^{-7}$  cm/sec or less permeability will function as a barrier to downward migration of a concentrated release is not necessarily true.
- Where concentrations of total chlorinated organic compounds exceed several mg/l in groundwater (or in sediments), consideration should be given to bentonite's capability of providing an impermeable barrier or seal. The fact that laboratory tests show that some organic solvents will attack the structure of clay implies that some aqueous concentration level exists, above which the clay's ability to prevent migration becomes questionable. For monitoring wells, it can be seen that the bentonite pellets or slurries used for isolating the monitored interval may not be appropriate where high levels of these organics exist.
- Monitoring wells should be constructed so that the vertical distribution of contaminants can be identified, above and below a "confining" layer if chlorinated organics are present (at any aqueous concentration level).
- Technical evaluations must consider the slope of the top of an "impermeable base," such as solid granite, as one of the significant methods for prediction of migration of a dense slug of contaminant. It is possible that if this slope is different than the water table (or potentiometric) slope, the migration rate and direction is not necessarily estimated by standard hydraulics.
- The seepage or release of chlorinated hydrocarbons onto a sandy sediment, where organic matter in the soil is low, provides a high probability that the chlorinated organic will reach the water table even if the depth to the saturated zone is 30 m or more. The rate of downward movement in the unsaturated zone will, of course,

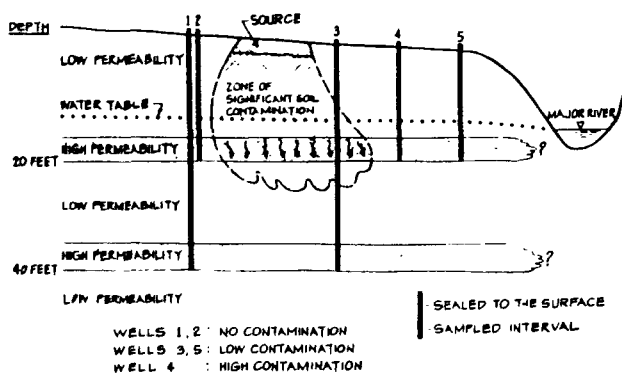


Figure 4.

#### Generalized Appearance of Contamination Plume in a Multiple Groundwater Flow System

be a function of the flushing action of precipitation or other surface water driving forces.

- A monitoring program designed to determine the effectiveness of a well withdrawal system must consider the effect of the density of a concentrated slug of chlorinated organic. Studies have shown that the pumping of a slug below the water table requires a much larger pump (with no plastic or rubber internal motor parts) in order to lift the denser fluid out of the well and into a collection vessel. Because the density of the fluid requires this extra power, then the monitoring wells must be located closer to the source than would otherwise be necessary. These wells would provide measurements vertically within the affected aquifer and reflect changes in the thickness, shape and character of the slug.
- Because proposed standards for specific solvents in drinking water are about 0.5 mg/l or less, the disposal or loss of only a small volume of solvent can cause concern. The procedures and degree of accuracy must be established for laboratories conducting analyses for these organic solvents. The utility of TOX (total organic halogen) scans, gas chromatography results or GC/MS results should be discussed prior to testing.
- Monitoring well construction should consider possible interactions among various chlorinated and non-chlorinated solvents which may influence the behavior of complex mixtures.

#### DATA REQUIREMENTS FOR MONITORING AND REMEDIAL ACTION DESIGN

Listed below are the categories of information that must be included for the waste disposal site and the immediate surrounding vicinity. The data must be scrutinized, especially with regard to the vertical and lateral extent of groundwater quality degradation. A detailed knowledge of the instruments of contaminant detection and migration must be obtained. For instance, assume that a water sample taken from a water supply well exhibits a small degree of contamination. If this well is open in several producing zones, this sample may say nothing more than a problem is indicated. The sample should therefore, not be used to identify the vertical, lateral or degree of contamination of a particular zone. The issue is compounded by problems associated with sampling and laboratory analysis. Clearly, it is of critical importance that interpretation of available data be made in full knowledge of how the data have been obtained.

- Geologic. A description of geologic structure and stratigraphy is necessary. At the subject site, the actual areal and vertical extent of rock type and/or unconsolidated units must be known.
- Hydrologic. A description of each hydrologic unit including areal/vertical extent, hydraulic properties and identifying whether it is a confining unit, a permeable or producing zone, or a semi-confining interval is required. For producing zones, it is necessary to determine the lateral hydraulic gradient, recharge areas, unconfined or confined conditions, effective velocity of water, hydraulic relationship to other producing zones and to surface water.
- Water Use. One must determine (as much as possible) the past

and present groundwater use which has or may have had an influence on the groundwater flow beneath the site. A detailed knowledge of producing zones (as described above) and the location and construction of production wells are important factors, but are of particular concern where groundwater is extensively used.

- Water Quality. One should identify the water quality features of each producing zone in a vertical and lateral sense. Obviously, the differences involved in sampling from producing zones of 2 m thick and 30 m thick must be considered. As previously noted, the data for water samples must be interpreted in terms of the well construction, well location, sampling techniques and analytical testing.
- Chemical/Physical Properties of Leachate. This is a very important consideration which is not easily characterized if the history of operations is not fully known. The reactivity of the leachate with certain local clays and any liner material must be known. Other physical properties such as solubility, density, volatility can be directly related to the potential mobility of the organics in a subsurface environment. Knowledge of these properties of the leachate is particularly important in locating and designing off-site migration control systems.

One must also recognize the uncertainties involved in an investigation of this type. Information such as geologic correlation, past hydraulic gradients, operational history all are considerations which may have caused an area or pocket of contaminated groundwater to exist at a seemingly impossible location. The degrees of uncertainty are, of course, site specific, but awareness of the potential uncertainties may result in a data collection scheme that will minimize their consequences.

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# DRUM HANDLING PRACTICES AT ABANDONED SITES

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## INTRODUCTION

Land disposal of drums containing hazardous wastes has been a widespread practice throughout the United States. Many problems at abandoned waste disposal sites have been attributed to drum disposal. The results of a 1980 survey of remedial actions at 169 sites conducted by the USEPA indicates that about one quarter of all abandoned sites have major drum related problems.<sup>1</sup>

Past drum disposal practices have resulted in many instances of groundwater, air, soil and surface water contamination. At some sites explosions and fires have resulted from reactions of incompatible wastes which leaked from drums.

The cleanup of waste sites containing drums poses several hazards to field workers and to the environment. In many instances the integrity of the drums is poor and they are prone to rupture and leakage. The drum contents are frequently unknown and it is not unusual to find drums containing incompatible wastes in the same pit or trench. The hazard of cleaning up these waste drums is exacerbated in many instances, by the unsuitable site conditions in which they are found. Drums containing hazardous wastes have been found in a variety of environments including wetlands, the banks of rivers and streams and highly industrialized, confined areas.

Because of the safety and environmental hazards involved in handling drums and the widespread efforts currently underway to clean up hazardous waste sites, the USEPA Oil and Hazardous Materials Spills Branch in Edison, New Jersey, has undertaken a research effort to evaluate drum handling practices and improve upon the existing equipment and methods where safety and effectiveness are seriously lacking.

As a means of documenting the state of the art and identifying research needs, a manual reviewing the applicability, advantages and disadvantages of equipment and methodologies for handling drums was developed. The manual addressed the following activities:

- Detecting and locating drums
- Determining drum integrity
- Excavation and on-site transfer of drums
- Recontainerization and consolidation
- Storage and shipping

The selection and implementation of equipment and methods for handling drum related problems is made on a site-specific basis. Site-specific factors which affect the suitability of various equipment and methods include: the number of drums present at a site, depth of burial, accessibility of the site, integrity of the drums, site drainage, and types of waste present.

The typical sequence of activities involved in a site cleanup operation can logically be divided into five phases:

- I. Preliminary Site Assessment
- II. Field Investigation and Drum Detection
- III. Development of a Cleanup Strategy
- IV. Site Cleanup
- V. Temporary Storage and Transportation

The report focuses on equipment, methods and protocol that are used for activities undertaken during Phase II through V. Phase I,

the Preliminary Site Assessment is generally completed by the time the drum handling operation begins and is not considered in detail. Nevertheless, the cleanup contractor, and Federal and state officials will need to draw on information gathered during this phase to reduce safety hazards and the cost and time required for subsequent activities. Background data on the site can often provide a great deal of insight on the types of wastes, condition of the drums and site specific variables which will influence the selection of equipment.

As with Phase I, Phase II, Field Investigation and Drum Detection, relies upon a considerable amount of field work that has generally been completed by the time the drum handling operation is begun. Drum detection using aerial photography, geophysical surveying and soil sampling are examples of activities that are conducted in Phase II.

Phase III, Development of a Cleanup Strategy, provides an overview of the four major variables which effect the selection of equipment and methods for handling drums:

- Safety precautions
- Protective and mitigative measures for environmental releases
- Site specific conditions as they influence equipment selection and performance, and
- Costs

Phase IV considers equipment and methods for site cleanup after drum removal in terms of their applicability, safety, advantages, limitations and relative costs. Equipment and methods for temporary storage and transportation of wastes from drum cleanup operations are considered in Phase V.

The manual emphasizes both safety measures and measures for preventing or mitigating environmental releases during drum handling (Tables 1 and 2).

Although there are a variety of equipment types and methods available for handling drums at abandoned waste sites, there are several areas where the safety of the operation may be improved by additional research and development. As a result of discussions with cleanup contractors, equipment manufacturers, and USEPA and State officials, additional research and development is recommended in the following areas:

- Remote drum opening methods
- Protocols for handling lab packs and gas cylinders
- Recommendations for minimum compatibility testing
- Inventory of major equipment used for drum handling
- Further evaluation of the use of non-destructive methods for determining drum integrity.

The next phase of this project will develop equipment to satisfy one or more of these needs.

## DRUM HANDLING ACTIVITIES

### Detecting and Locating Drums

Detecting drums at an abandoned site involves the use of historic and background data on the site, aerial photography, geophysical surveying and sampling. Background data should be carefully ex-

amed since it can minimize the cost and increase the safety of subsequent activities. Aerial photography involves the use of historic aerial photographs to show changes in the site over time, such as filling in of trenches, or mounding of earth. It also includes the use of current aerial imagery (usually color or infrared) to show spills, seepage or changes in vegetation which may indicate the presence of drums.

The applicability, reliability and cost effectiveness of geophysical survey methods are highly dependent upon site specific characteristics. Magnetometry is generally the most useful survey tool for detecting drums. Metal detectors may be of value if drums are close to the surface. Ground penetrating radar is extremely sensitive but is easily subject to interference. Electromagnetics and electrical resistivity are often used together to determine the boundaries of leachate plumes rather than the location of drums, although electromagnetics has been used for locating drums. Frequently a combination of geophysical survey methods is recommended. The results of any geophysical survey must be verified by sampling.

### Determining Drum Integrity

Determining drum integrity is one of the most important and difficult aspects of the cleanup operation. Excavation and subsequent handling of unsound drums can result in spills and reactions which may jeopardize worker safety and public health.

The method generally used for determining drum integrity is to make a visual inspection of the drum surface for corrosion, leaks, swelling and missing bungs. This approach requires close contact with the drums, but is the only effective method available for determining drum integrity. A variety of non-destructive testing methods (i.e., eddy current, x-rays, ultrasonics) have been investigated as tools for determining integrity but all have been found to have serious drawbacks or limitations. Use of ultrasonics or eddy current, for example, requires that the surface of the drum be relatively clean and free from chipping paint in order to get accurate readings. Drums which have been buried are frequently covered with soil, residue and chipping paint and cannot be safely and easily cleaned. Also, the integrity of the under-side of the drum cannot be determined with these methods lifting it.

**Table 1.**  
**Safety Precautions for Drum Handling Activity**

#### POTENTIAL SAFETY HAZARD

#### SAFETY PRECAUTIONS

Unknown location and contents of drums can lead to unsuspected hazards

##### Locating Drums

- In conducting geophysical surveys, use hand held instruments rather than vehicle mounted systems where drums are close to the surface
- Conduct soil sampling only after the geophysical survey is completed to minimize the possibility of puncturing drums
- Use non-sparking tools for sampling
- Use direct-reading, air monitoring equipment to detect hot spots where contamination may pose a risk to worker safety

##### Determining Drum Integrity

- Any drum which is critically swollen should not be approached; they should be isolated using a barricade until the pressure can be relieved remotely
- Approach drums cautiously, relying on air monitoring equipment to indicate levels of hazards which require withdrawal from working area or use of additional safety equipment

##### Drum Excavation and Handling

- Where buried drums are suspected, conduct a geophysical survey before using any construction equipment to minimize the possibility of rupture
- Use the drum grapppler where possible and cost effective, to minimize close contact with the drums
- If the grapppler is not available, pump or overpack drums with poor integrity
- Use non-sparking hand tools and non-sparking bucket teeth on excavation equipment
- Where slings, yokes or other accessories must be used, workers should back away from the work area after attaching the accessory and before the drum is lifted
- Critically swollen drums should not be handled until pressure can be relieved
- Use plexiglas shields on vehicle cabs
- Use "morman bars" which fit over the teeth of excavation buckets to prevent drum puncture

Process of visual inspections require close contact with drums of unknown content

Exposure to toxic/hazardous vapors: rupture of drums

Release of toxic, hazardous vapors, rupture of drums

Mixing of incompatible wastes

Mixing of incompatible wastes

- Use direct-reading, air monitoring equipment when in close proximity to drums to detect any hot spots

##### Drum Opening

- Use remote drum opening methods where drums are unsound
- Conduct remotely operated drum opening from behind a plexiglas shield if backhoe mounted puncture is being used
- Isolate drum opening from other activities to minimize a chain reaction if an explosion or reaction did occur
- Use only non-sparking hand tools if drums are to be opened manually
- Remotely relieve the pressure of critically swollen drums before opening
- Clean up spills promptly to minimize mixing of incompatible materials

##### Staging Recontainerization

- Allow adequate spacing during staging of drums to provide rapid exit in case of emergency
- Perform on-site compatibility testing on all drums
- Drums which are leaking or prone to leakage or rupture should be overpacked or the contents transferred to a new drum before staging
- Clean up spills promptly to avoid mixing of incompatible wastes
- Intentional mixing of incompatible wastes such as acids and bases should be performed under controlled conditions in a reaction tank where temperature and vapor release can be monitored
- Monitor for hot spots using direct-reading air monitoring equipment

##### Storage and Transportation

- Segregate incompatible wastes using dikes
- Maintain weekly inspection schedule
- Allow adequate aisle space between drums to allow rapid exit of workers in case of emergency
- Clean up spills or leaks promptly
- Ensure adherence to DOT regulations regarding transport of incompatible wastes

**Table 2.**  
**Measures for Minimizing Environmental Releases During Drum Handling**

Potential Environmental Problem	Preventive Measures	Air Pollution	
Groundwater Contamination	<ul style="list-style-type: none"> <li>•Improve site drainage around the drum handling area and minimize run-on and run-off by constructing a system of dikes and trenches</li> <li>•Where groundwater is an important drinking water source, it may be necessary to hydrologically isolate the work area using well-point dewatering</li> <li>•Use liners to prevent leaching of spilled material into groundwater during drum handling, drum opening, recontainerization and decontamination</li> <li>•Use sorbents or vacuum equipment to clean up spills promptly</li> <li>•Locate temporary storage area on highest ground area available; install an impervious liner in the storage area and a dike around the perimeter of the area; utilize a sump pump to promptly remove spills and rainwater from storage area for proper handling</li> </ul>	<ul style="list-style-type: none"> <li>•Avoid uncontrolled mixing of incompatible wastes by 1) handling only one drum at a time during excavation; 2) isolating drum opening operation from staging and working areas; 3) pumping or overpacking leaking drums and 4) conducting compatibility tests on all drums</li> <li>•Promptly reseal drums following sampling</li> <li>•Any drum which is leaking or prone to rupture or leaking, promptly overpack or transfer the contents to a new drum</li> <li>•Utilize vacuum units which are equipped with vapor scrubbers</li> <li>•Where incompatible wastes are intentionally mixed (i.e., acids and bases for neutralization) in a "compatibility chamber" or tank, releases of vapors can be minimized by covering the tank with plastic liner</li> </ul>	
Surface Water Contamination	<ul style="list-style-type: none"> <li>•Construct dikes around the drum handling and storage areas</li> <li>•Construct a holding pond downslope of the site to contain contaminated run-off</li> <li>•Use sorbents or vacuum equipment to promptly cleanup spills</li> <li>•Design the dikes for temporary storage area to contain a minimum of 10% of total waste volume; ensure that holding capacity of storage area is not exceeded by utilizing a sump pump to promptly remove spills and rainwater for proper handling</li> </ul>	<ul style="list-style-type: none"> <li>•Use non-sparking hand tools, drum opening tools and explosion proof pumps when handling flammable, explosive or unknown waste</li> <li>•Avoid uncontrolled mixing of incompatible waste by 1) handling only one drum at a time, 2) pumping or overpacking drums with poor integrity, 3) isolating drum opening, and 4) conducting compatibility testing on all drums</li> <li>•Use sand or foams to suppress small fires before they spread</li> <li>•Avoid storage of explosives or reactive wastes in the vicinity of buildings</li> <li>•In a confined area, reduce concentration of explosives by venting to the atmosphere</li> <li>•Cover drums which are known to be water reactive</li> </ul>	

The safety of workers in close contact with the drums must be protected by the use of appropriate safety gear and equipment. A variety of direct-reading, air monitoring equipment is available to determine radioactivity, oxygen levels, levels of explosives, and concentrations of toxic gases. This equipment generally has remote sensing capabilities and alarms to warn field personnel of impending danger as they approach the drum.

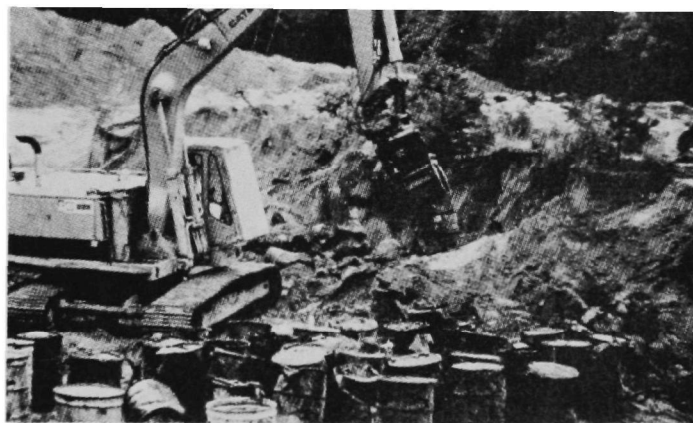
#### Excavation and On-Site Transfer of Drums

Some waste disposal sites may require certain pre-excavation activities to improve site access for heavy equipment, to drain a site to provide a more stable work surface, or to hydrologically isolate the site to prevent surface water and groundwater contamination.

Drum excavation is generally accomplished by using a combination of conventional excavation, lifting and loading equipment such as backhoes, front end loaders and bobcats, but with special equipment modifications or accessories adapted to hazardous waste sites. The most valuable piece of equipment for handling drums is the barrel grapppler (Fig. 1), which is a modified crawler-mounted backhoe with a rotating grapple head. The grapple attachment can rotate 360° along a given plane and is hydraulically self-adjusting in grip radius so that it can grab and lift various size containers as well as containers which are slightly dented or bent.

Other attachments include nonsparking buckets to prevent explosions, morman bars to cover the teeth of backhoes to avoid puncturing drums, plexiglas safety shields for vehicle cabs, and drum lifting attachments such as nylon yokes and metal hoists.

Equipment used in the excavation and staging of drums must be suitable for digging, grabbing, lifting, loading, and manipulating drums. Complete handling of a drum related problem usually requires a combination of equipment, particularly where the grapppler is not available.



**Figure 1.**  
Barrel Grapppler, removing drums from pit excavation  
(Courtesy of O.H. Materials Co., Findlay, Ohio)

When drums are found to be leaking or structurally unsound, the drum should be overpacked or the contents transferred to a new container in order to avoid spills or releases which could jeopardize worker safety. Where the grapppler is available, it is generally not necessary for the worker to be in contact with drums and spills or rupture of unsound drums may not be a threat to worker safety.

#### Drum Opening, Sampling and Compatibility Testing

Once a drum has been excavated, a series of activities are undertaken which lead to final disposal or treatment of the wastes. The first step is to segregate the drums based on their contents (liquids,

solids, gases, etc.). Next the drums are opened, sampled to determine compatibility and resealed. Drum opening and sampling should be performed in an isolated area in order to minimize the possibility of explosion and fires if drums spill or rupture. Drum opening tools include non-sparking hand tools, wrenches and deheaders and remotely operated plungers, debungers (Fig. 2) and backhoe attached spikes (Fig. 3.)

When remotely operated methods are used, further protection should be provided by conducting the operation from behind a plexiglas shield. Measures should be taken to contain and mitigate spills which occur during drum opening. In general, remote drum opening is recommended where drum integrity is poor or the wastes are suspected of being highly toxic.

Compatibility testing should consist of rapid, on-site procedures for segregating incompatible wastes based on such factors as reactivity, solubility, presence of oxidizers, water content, etc.<sup>3</sup> The waste drums containing similar wastes are consolidated in order to reduce the costs and time involved in cleanup and transportation.

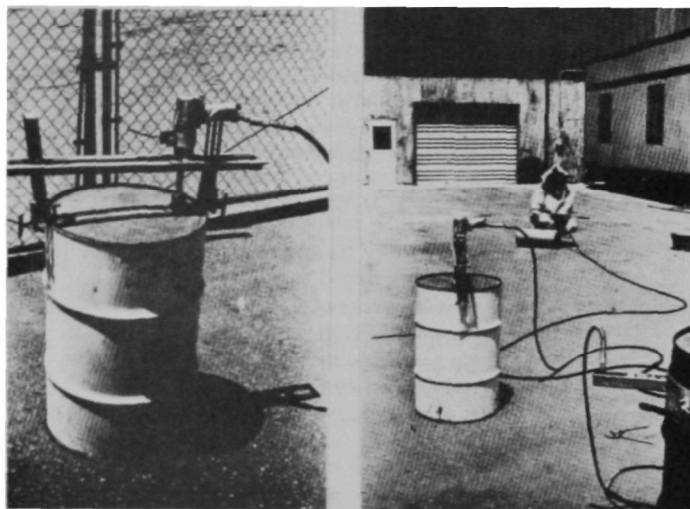


Figure 2.

Pneumatic Bung Wrench: Attachment to drum and remote operation setup



Figure 3.

Backhoe Spike (nonsparking) puncturing drum held by grappler  
(Courtesy of O.H. Materials Co., Findlay, Ohio)

### Recontainerization or Consolidation

There are a number of options available for consolidating wastes or for recontainerizing them, if consolidation is not possible. In general, use of vacuum trucks is recommended where there are a minimum of 30 to 40 drums which can be consolidated.

Industrial strength vacuum units are available for consolidating both solids and liquids. Skid mounted vacuum units are available for areas inaccessible to trucks or where the number of drums to be consolidated is small. When using vacuum equipment, care must be taken to avoid incompatible waste reactions which can result in costly damage to the vacuum cylinder. When incompatible waste reactions are possible, wastes should be allowed to react under carefully controlled conditions in a "compatibility" chamber prior to transfer to the vacuum truck.

If drums containing wastes cannot be consolidated because of incompatibility or where the number of drums is too small to make consolidation economical, they can be overpacked or their contents transferred to new drums for final disposal. This is frequently a more costly method of final disposal since drums and overpacks are bulky to transport. In weighing the relative costs of overpacking or consolidating wastes using vacuum equipment, the costs of decontaminating the vacuum equipment after use should also be included.

The final step in the cleanup process is decontamination. Equipment is rinsed in the contaminated work area and the contaminated rinse water is collected for treatment, if it is determined that it will contribute to groundwater or surface water contamination. Contaminated soils may be combined with sludges and solids and/or bulked, packed in drums, or treated on-site depending upon the volume of soils and the nature and concentration of contaminants.

Empty drums are also decontaminated in some cases depending upon the nature of the wastes which were stored in them. This process may be facilitated by a drum shredder. If the number of empty drums is small, they can be crushed and overpacked. If the drums are not considered hazardous they can be crushed and loaded in bulk onto vans or flat-bed trucks.

Decontamination of field workers, protective clothing and sampling equipment is an essential part of the final cleanup process. Procedures for decontamination can be found in several publications including a *Hazardous Waste Site Management Plan*,<sup>1</sup> and the *EPA Safety Manual for Hazardous Waste Site Investigations*.<sup>4</sup>

### Storage and Shipping

In some instances it may be necessary to store drums on-site temporarily until funds become available for final treatment/disposal or until a suitable disposal site is found. If drums are to remain on-site for a period of three or more months, then requirements for RCRA permitted facilities should be followed. These requirements include the following:

- Use of dikes or berms to enclose the storage area and to segregate incompatible waste types
- Installation of a base or liner which is impermeable to spills
- Sizing of each storage area (containing compatible wastes) so that it is adequate to contain at least 10% of the total waste volume in the event of a spill
- Design of the storage area so that drums are not in contact with rainwater or spills for more than 1 hour
- Weekly inspections

Transportation and final disposal of wastes from abandoned sites is governed by Department of Transportation regulations as well as by state laws, disposal facility requirements, and in the case of highly toxic materials, by the Toxic Substance Control Act.

### CONCLUSIONS

The selection and implementation of equipment for drum handling is made on a case by case basis based upon the following considerations:

- Safety of the field workers
- Protection from environmental releases which could jeopardize public health
- Site-specific factors which effect equipment performance
- Costs

There are a number of precautions which should be taken to protect field personnel. Many of these measures such as use of protective clothing, medical surveillance, communications, etc. apply to all waste investigations and cleanup operations and are not unique to drum handling. Other safety measures, such as use of non-

sparkling drum opening tools, or isolation of the drum opening operation are unique to drum handling.

In addition, precautions must be taken to minimize environmental releases. These include both measures for preventing spills, leaks and incompatible reactions as well as mitigative measures for containing and controlling spills or reactions which do occur.

Site specific variables such as accessibility of site, the number of drums, site drainage, drum integrity, etc., effect equipment performance and safety, and must be considered in selecting and implementing drum handling methods (Table 3).

**Table 3.**  
**Major Site Specific Variables Influencing Drum Handling Activities**

	Large Number of Drums vs Few Drums	Remote Site vs Accessible or Populated Site	High Water Table vs Low Water Table
DRUM LOCATION	Expenditure for remote sensing must be kept in perspective; if the number of buried drums is small, use a simple remote sensing tool, (i.e., metal detector), to locate drums; may not be worth the expense to quantify; hand-held tools are suitable for small sites whereas vehicle-towed equipment is sometimes needed at large sites	Remote site may require that geographical surveying be done manually rather than by vehicle; clearing and grubbing may be needed to conduct continued surveys	Presence of a high water table may prevent use of a vehicle to tow remote sensing equipment; if groundwater is saline, ground penetrating radar is likely to be unsuitable; interpretation of electro-magnetics data can be difficult if water table is low
DRUM INTEGRITY	Method of determining drum integrity depends more on type of waste than the actual number of drums	If the site is in urban area, air monitoring needs may be more intensive to assure population safety as well as worker safety; accessibility of lab to do quantitative analysis should be considered prior to undertaking quantitative sampling, especially if the site is remote	Drum integrity is likely to be poor in high groundwater areas; monitoring for drum integrity may be more intensive in area of high water table depending upon use of groundwater for drinking; if poor integrity is suspected in high groundwater area it may be necessary to improve site drainage or to hydrologically isolate the site before handling drums
EXCAVATION	Use highly mobile, high production equipment with large bucket capacities for large numbers of drums: backhoes, grapplers, rubber-tired loaders; use several equipment vehicle combinations for larger sites with over 500-1,000 drums to be removed; smaller sites (<500 drums) will require less of a variety of excavation vehicles; small vehicles such as front end loaders are economical for small sites	Remote sites may require special site preparation, such as clearing and grubbing for access road construction; may dictate transport of fewer, larger equipment types (backhoes, grapplers, crawler tractors, cranes) to disposal site  For readily accessible sites, equipment size and number not limited; favors mobile rubber-tired vehicles (Bobcats and backhoes)  If congested, urban site, may need smaller machinery (forklifts and backhoes vs. cranes for lifting and transfer; may also use hoists or slings to lift drums from congested areas	Water-logged sites may require surface runoff diversion with trenches and berms, and subsurface hydrologic isolation with wellpoint pumping or slurry-trench cut-off walls; wet muddy sites favor crawler-mounted vehicles vs. rubber-tired; swamp pads (extra-wide crawler tracks) and timber mats may also be useful; for dry sites, less site preparation is needed and mobile, rubber-tired vehicles can be used
DRUM OPENING	Large number (>500): backhoe plunger or remote conveyor should be considered  Small number: hand tools should be considered depending on conditions of drums and drum contents	Congested site favors manual or portable remote opening	Open drums in controlled area with secondary containment dikes or berms and liners
RECONTAINERIZATION AND CONSOLIDATION	For economic recontainerization, choose equipment suited to size of problem, keeping in mind possible incompatibility  Few drums: more prone to use overpacks, or small skid mounted units; large numbers of drums: vacuum trucks are more suitable for compatible wastes	If site is inaccessible, may need to use skid mounted units rather than vacuum trucks; if site is congested, drums should be staged, opened and consolidated in small groups to provide adequate spacing; if site is remote and wastes are biodegradable, contaminated soils could conceivably be left on site (determine on case by case basis); detonation of lab packs should not be considered in populated or congested areas	Generally does not affect recontainerization, unless the presence of a high water table prevents access by vacuum trucks
STORAGE/SHIPPING	DOT regulations are more concerned with the types of wastes rather than the quantity; large numbers: consolidation of compatible wastes for more economical shipping; few drums: usually overpack or transfer to a new drum before shipping	Storage area should be as distant as possible from populated areas; reactives and explosives should be stored away from buildings	In areas with high water table, storage area should be placed on highest ground possible

The final factor affecting the selection of equipment is costs. Because the number of drums, their contents and integrity are generally now known with any certainty at the outset of the cleanup operation, costs for cleanup can only be approximated. Costs can be minimized however, by the selection of the most cost-effective contractor and equipment types and by close management of the cleanup operation.

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# GEOTECHNICAL ASPECTS OF THE DESIGN AND CONSTRUCTION OF WASTE CONTAINMENT SYSTEMS

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## INTRODUCTION

Disposal of hazardous and toxic wastes in the subsurface environment has resulted in the widespread application of geotechnology to the design and construction of waste containment systems. The adaptation of conventional passive groundwater and surface water barriers to waste containment requires certain special considerations. In this paper, the authors present a systematic engineering approach to passive containment alternatives designed to mitigate contaminant migration. Certain design and construction aspects of the application of geotechnology to these systems are also present.

The three major passive containment components which are covered in detail are: 1) top seals, including covers of native clay, processed clay and polymeric (synthetic) membranes, 2) barrier walls, including soil-bentonite slurry trench walls, cement-bentonite slurry trench walls, and vibrating beam cutoff walls, and 3) bottom seals, including liners of native clay, processed clay, and polymeric membranes. Emphasis is placed on the geotechnical aspects of design and construction practices of waste encapsulation, including advantages and limitations. The functions of each of these components are defined. The design process is then detailed with emphasis on the difference between conventional applications versus waste containment applications (for example, slurry trench cutoff walls for waste containment must incorporate additional considerations in design as compared to their use to control groundwater during excavation).

Many site investigations are conducted by hydrogeologists to obtain data for assessment of contaminant migration. Subsequently, waste containment systems may be engineered as part of a pollution abatement program. It is essential that the geotechnical engineering information required be obtained during the site investigation phase in order to allow for a thorough, yet cost-effective, engineering design. In this paper, the authors present a guide to the engineering data required to enable geologists to plan and conduct subsurface investigations which will provide geotechnical as well as hydrogeological data for design.

## TYPES OF FACILITIES

Most waste disposal facilities can be classified (Table 1) in one of three categories: 1) past disposal sites referred to as abandoned,

inactive, retired, or uncontrolled, 2) existing active disposal sites such as sanitary or hazardous waste secure landfills, and 3) future disposal sites which could include waste treatment, recycling and disposal complexes. In this paper, the authors will limit the discussion to waste containment at past disposal sites. However, much of the geotechnology presented may be applicable to new site design and waste containment at active disposal sites. However, the engineer's ability to control the type of wastes for which waste containment systems must be designed and constructed to contain is limited.

## ENGINEERING APPROACH TO WASTE CONTAINMENT

The application of geotechnology to waste disposal requires an orderly, systematic approach which will permit the engineer to fully assess both the site and subsurface conditions and evaluate the applicability of containment alternatives. The project approach described below is for past uncontrolled disposal sites. The following four steps are required for each project and, although they are presented chronologically, there is a continual reassessment of the previous steps as the project progresses and more data becomes available:

- Review existing information including historical site data, geologic data, and groundwater data: It is necessary to obtain as much information as possible on the types of waste disposed, the timetable of waste disposal, and the previous disposal practices (i.e., drums, solid waste, lagoons). Air photos, which are generally readily available, can be extremely useful. Information regarding the subsurface conditions can be obtained from previous records and borings, from the site construction history, and from regional geologic information. Forming a conceptual model of the site and subsurface conditions at this time will enable the engineer to better plan and conduct site and subsurface investigations.
- Assess in detail existing site conditions, which include geologic conditions, groundwater conditions, and contamination distribution: Field work will probably be required at this state. The use of geophysical tools prior to test borings or monitoring well installations can provide valuable insight into the subsurface conditions<sup>1</sup> and will probably result in a more complete and cost effective boring and sampling program.
- Quantify site conditions, including the direction, volume and velocity of groundwater flow, the interaction of groundwater with surface water, the distribution of contamination in the groundwater system and the contaminant loading: The degree of sophistication of this quantification phase may vary from a simple model to a complex computer model.
- Develop the containment/treatment program: the portion of the program where the application of geotechnology receives the major emphasis.

Many subsurface investigations are conducted primarily as hydrogeologic investigations. Geotechnical physical property testing (Atterberg limit, grain size distribution, water content) may not normally be part of the routine investigation. If remedial action is anticipated, it may be desirable to have geotechnical engineering input during the site investigation phase to avoid future

Table 1.  
Waste Disposal Facility Classification.

Facility Category	Facility Description	Generic Names	Control of Wastes Disposed
I	Past Disposal site	abandoned inactive retired midnight dump uncontrolled site orphaned	Little to none
II	Active Disposal	secure landfill sanitary landfill	Some
III	Future Disposal	waste treatment complex recycling facility	Well-controlled



data gaps. Thus testing could include physical property tests as well as engineering property tests for strength, compressibility and permeability.

### CONTAINMENT ALTERNATIVES

A waste containment system can consist of many components (Fig. 1.). These components are classified in two general categories: (1) active and, (2) passive. Active components of a containment system are those which require ongoing energy input. Examples of active components are pumping wells, disposal wells, and treatment plants. Conversely, passive components of a containment system are those which do not require ongoing energy input. Examples of passive components include drain tile collection systems, liners, covers and barrier walls. Utilizing quantified site conditions, the geotechnical engineer should try to provide

components are required and/or feasible. It may also be necessary to develop alternates for every component in the system.

Finally, as required in most geotechnical engineering practices, field observations must confirm design assumptions. Construction inspection is critical for waste containment systems.

### COMPONENTS OF PASSIVE REMEDIAL SYSTEMS

Important details regarding each of the major components of passive waste containment systems and how geotechnical engineering technology is required for their design and construction are discussed below. Further discussion in this paper is limited to passive components of waste containment systems.

#### Top Seals (Covers)

The primary function of a top seal is generally to control water

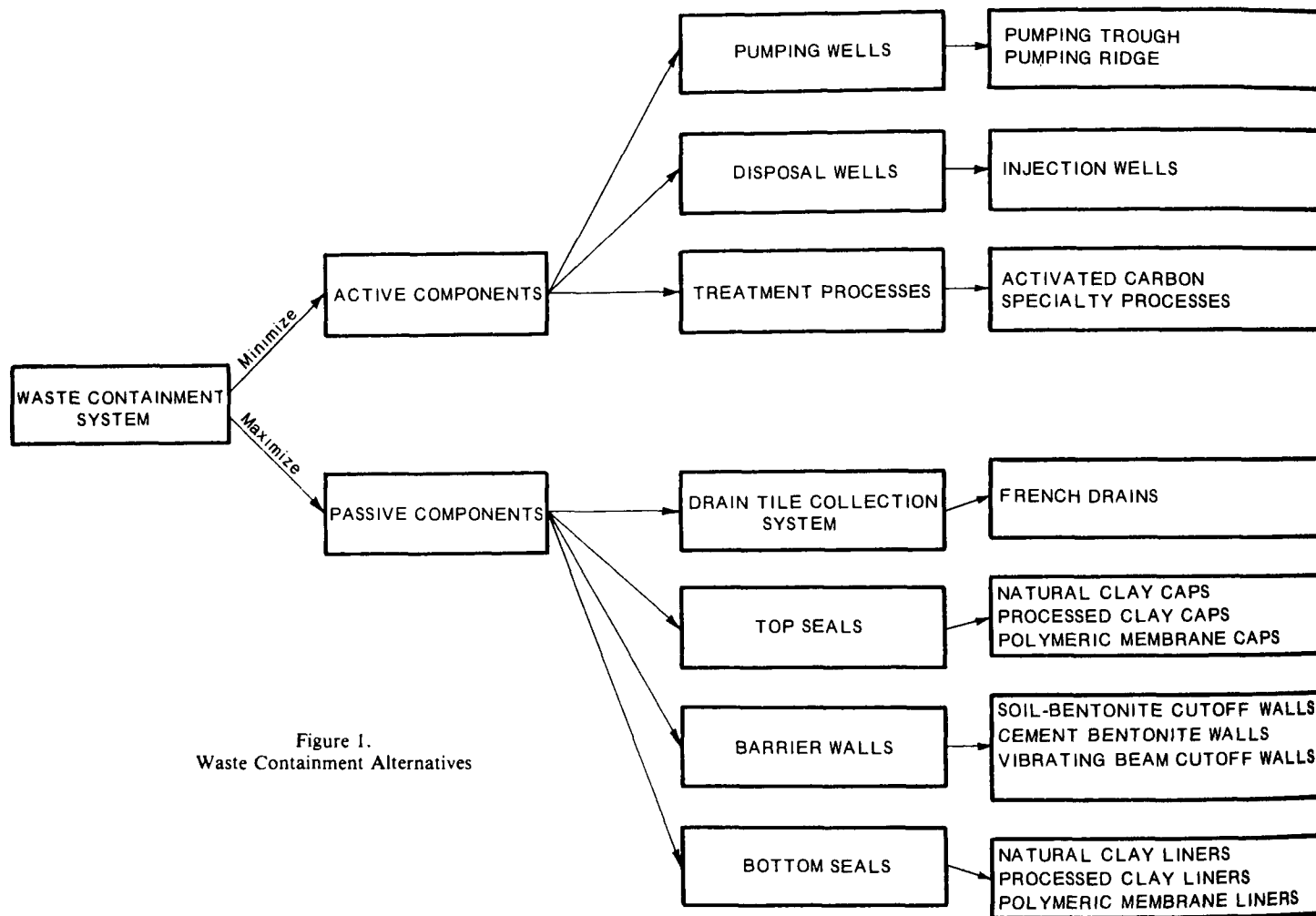


Figure 1.  
Waste Containment Alternatives

conclusions, recommendations, and design criteria to maximize the use of passive components of the containment program and to minimize the need for active components.

However, even passive components may require maintenance. For example, it is frequently necessary to keep vegetation roots from penetrating a clay cap. A passive system is generally therefore not a maintenance-free system.

In developing waste containment alternatives, one must balance the design approach for the site considering the magnitude and extent of the contamination problem, the available active and passive components, both the short and long term containment effectiveness, capital and operating costs, and the eventual termination of the system. After the development of containment alternatives, geotechnical engineers are often required to develop final design criteria. During the site quantification program it is necessary to make basic decisions as to which of the possible major

movement so as to maximize precipitation runoff and to minimize infiltration and subsequently leachate production by the land disposal facility. Geotechnical aspects of top sealing utilizing native clays, processed clays, and polymeric membranes are discussed in following subsections. Geotechnical input required for covers of bituminous and portland cements, tars, liquid and emulsified asphalts and bituminous fabrics are not discussed. For other aspects of cover design and construction, two manuals prepared by the U.S. Army Engineer Waterways Experiment Station are referenced.<sup>2,3</sup>

The USEPA states "Because clays will generally last longer than synthetic materials, clay caps rather than synthetic caps should usually be the materials chosen..."<sup>4</sup> However, to avoid the bathtub effect, wherein more water enters the facility than can drain out, "...will require the installation of a synthetic membrane cap whenever the bottom liner is synthetic."<sup>4</sup> Clear guidance is therefore

provided regarding the choice of cover materials.

**Native Clay Top Seals:** In general, the most cost effective top sealing can usually be completed utilizing native clay materials from local borrow sources. In many areas, local sources are available to provide compactible clays of relatively low permeability. If suitable clays are not available, the obvious decision would be to use another of the top sealing alternatives.

In testing clay covers, one must consider the natural variability in the material and the test method in order to provide an accurate representation of the hydraulic conductivity. Permeability should be determined in geotechnical laboratories utilizing permeability tests conducted in a triaxial cell where the stress and gradient conditions can be closely controlled. Since clay caps are designed to minimize precipitation infiltration, it is normally not necessary to utilize anything other than tap water as a permeant. Distilled water is not recommended.<sup>5</sup>

The thickness of a clay top seal is generally a minimum of 18 in. to 2 ft, based upon the following considerations. First, the top several inches of the clay cap cannot generally be as well compacted as the thickness remainder. Further, it may be difficult in the long term to maintain the clay density in the top few inches due to potential desiccation, cracking and frost action. Finally, the bottom of the clay cap may become somewhat contaminated with the subgrade material during installation. Therefore, the "effective thickness" of a nominal 2 ft cap may be on the order of 1 ft.

Native clay caps must be protected from erosion due to rain water, cracking due to drying, differential subgrade movement, penetration by deep tap roots of vegetation, and rutting due to traffic. In virtually all cases, the clay cap should be covered by a minimum of 6 to 12 in. of topsoil. Conventional hydrologic studies to determine erosion potential are required to prevent gullying and erosion of the clay top seal and topsoil. A typical section illustrating the use of a native clay cap is found in Fig. 2a.

A clay top seal can generally be placed on a slope which is not steeper than about two horizontal to one vertical. It is usually preferable to utilize flatter slopes such as three or four horizontal to one vertical. The flatter slope more readily permits compaction and reduces the risk of local slumping. A geotechnical analysis of slope stability may be required to assess the probability of instability. The thickness of the clay on side slopes may be slightly less than the thickness on top of the area. The larger side slope gradients enhance runoff greatly reducing the time available for precipitation to percolate downward into the waste containment area.

Construction inspection of clay top seals is particularly important. If the top seal is not covered soon after the clay is placed and compacted, precipitation can result in erosion of the clay top seal. Control of the cover thickness can be by accurate pre- and post-placement surveys or by probing during placement.

**Processed Clay Top Seals:** If natural clay is not available of sufficient quality, quantity, or price, alternate capping materials must be considered. Processed clay has become a common alternative to natural clay caps. Processed clay is typically a sodium montmorillonite from Wyoming, commonly called bentonite.

The construction of a processed clay cap requires: 1) the application of the bentonite at a controlled rate (e.g., 2 lb/ft<sup>2</sup>), 2) adequate mixing with in-place soils into a predetermined loose lift thickness, 3) compaction of the cap, and; 4) hydration of the bentonite. A 4 to 6 in. layer of clayey soil with a low hydraulic conductivity, generally around  $1 \times 10^{-7}$  cm/sec, is thereby formed. This cap is then subsequently covered to prevent desiccation and erosion as would be a cap of natural occurring clay.

The principal advantage of the processed clay cap is the relatively low hydraulic conductivity which can be achieved. The principal disadvantage relates to controlling a uniform application rate. Other disadvantages may be cost, depending upon the availability of naturally occurring clays, and the fact that since the seals are so thin there is little room for error.

The effectiveness of a processed clay top seal in reducing infiltration requires design and construction control of the subgrade

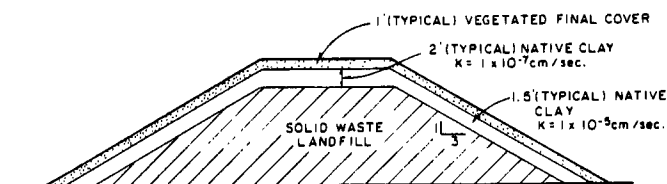


Figure 2a.  
Typical Section: Native Clay Top Seal

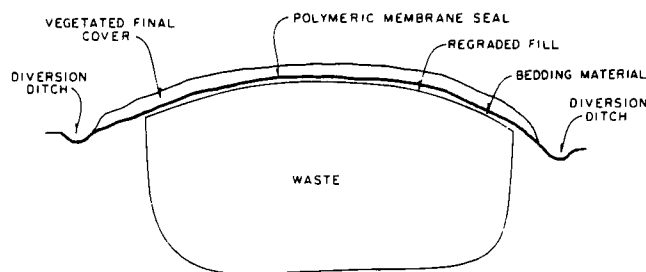


Figure 2b.  
Typical Section: Polymeric Membrane Topseal

materials, subgrade preparation, application rate, application uniformity, mixing, compaction, hydration and cover. Deficiencies in any one of these aspects can result in reduced top seal effectiveness.

The subgrade materials should be uniform and free of roots, sticks, cobbles, or other miscellaneous debris which would preclude a homogeneous blend for the specified seal thickness. Further, the material must have water content and material characteristics which will not impede the uniform blending of the processed clay throughout the soil matrix. This moisture content should be near optimum for the soil-bentonite mixture to aid in the subsequent compaction. Compaction studies in a geotechnical laboratory are therefore generally required to establish the moisture-density relationship for the soil-bentonite mixture. The subgrade must be sloped in such a way as to provide positive drainage characteristics and preclude ponding of precipitation upon the seal. The stability of the processed clay seal must also be considered. Slopes which are steeper than three horizontal to one vertical are not generally recommended. Steep slopes increase the risk of slumping.

The application rate is generally determined by consideration of the desired coefficient of permeability and the available subgrade materials. For a given coefficient of permeability, the application rate will vary with the soil type proposed for use in the top seal. Laboratory studies can be undertaken to investigate the relationships between coefficient of permeability, application rate, soil type, and degree of compaction. The specification can then be optimized with respect to these variables.

Field control of the application rate is essential if the top seal is to perform as predicted by the engineering studies. Three methods are generally employed to apply the powdered processed clay. The first involves the utilization of an agricultural-type lime spreader. The second involves the use of a pressurized container and distributor (Fig. 3). The third method uses hand-spreading.

With either of the first two methods the application rate can be checked by placing a relatively flat container (such as a trimmed cardboard, or a tarpaulin) beneath the spreader as it passes. The weight of the material deposited in the container can then be determined. The application rate is then computed as a weight per unit area. An additional check can be made by determining the total bentonite used for the total area treated. This results in the average application rate. Application rates should be checked frequently if mechanical applicators are employed.

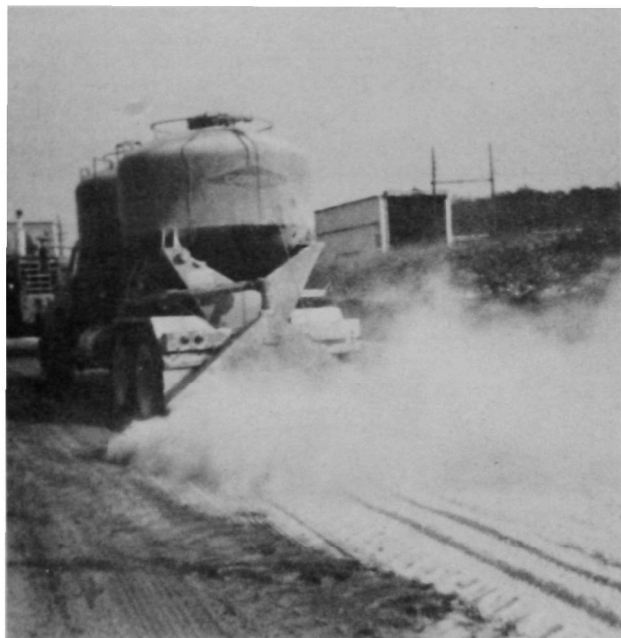


Figure 3a.  
Pressurized Tank and Distributor



Figure 3b.  
Close-up of Distributor

Figure 3.  
Application of Processed Clay

The processed clay can also be applied by hand-spreading the material from bags in pre-marked grid squares. The bags are broken open and the material is raked into an "uniform" thickness across the grid. Hand-spreading may be more costly, but tighter control can generally be maintained. The probability of zones with inadequate application rates can be reduced with hand-spreading as compared with mechanical equipment application.

As soon as possible after the application of the processed clay is completed, the material is thoroughly mixed with the subgrade. Mixing should result in a uniform blend of processed clay and subgrade soils for a top seal of specified thickness. Adjustable rotary tillers appear to provide a positive means to control top seal thickness and homogeneity. These tillers can blend the soil and pro-

cessed clay with depth control devices, and can result in a fairly uniform layer thickness. Agricultural disks, graders, and other equipment have also been used but control is more difficult.

Immediately after blending, the processed clay top seal is compacted to the minimum density determined during the design studies. Compaction is generally with smooth-drummed or pneumatic rollers. Sheepsfoot or padfoot rollers are not permitted.

Hydration of the processed clay cap is usually from infiltrating precipitation. Should the site hydrology characteristics show there is a potential for contaminated water to reach the top seal, the cap should be prehydrated with uncontaminated water.

Cover of processed clay top seals to prevent desiccation and erosion is required, as with top seals of native clays. The cover thickness required for processed clay seals is generally greater than that required for native clay caps. This is because there is little margin for disturbance without jeopardizing the seal integrity.

**Polymeric Membrane Top Seals:** Polymeric membranes can be utilized as top seals for waste containment.<sup>6</sup> In the past, these have only received limited usage due to their relatively high cost. Polymeric membranes are available in a wide range of material types from numerous manufacturers and distributors. Examples of polymeric membranes include polyethylene, chlorinated polyethylene, chlorosulfonated polyethylene, polyvinyl chloride, butyl rubber, and neoprene. This paper is limited to discussion of the geotechnical aspects of polymeric membrane usage. Additional information regarding the advantages and disadvantages of the available membranes can be obtained from cited references.<sup>7,8</sup>

From a geotechnical standpoint, the most important aspects of utilizing a polymeric membrane as a top seal are the subgrade material, subgrade preparation, slope and final cover (Fig. 26). Equally important to these geotechnical aspects is the membrane design, placement procedures, field joining of seams, and field testing of the membrane and field welds, all of which are beyond the scope of this paper.

The subgrade soils must be free of materials which could puncture the membrane top seal including sticks, large stones, and miscellaneous debris. Further, the subgrade should be graded and compacted to provide for runoff and to prevent liquid ponding. The final cover is typically approximately 18 in. thick and vegetated to minimize erosion. The cover is necessary to protect the membrane from trafficking, and ultraviolet degradation. Careful consideration of slide slopes is required to preclude sliding of cover materials along the membrane top seal. As precipitation infiltrates the cover and flows along the membrane, a saturated and weakened zone in the cover material may develop causing a slump of the cover material.

### Barrier Walls

The containment of contaminant migration from existing disposal sites or impoundments frequently necessitates some sort of a subsurface barrier to horizontal groundwater flow. Barrier walls are presently typically constructed as soil-bentonite slurry trench cutoff walls, cement-bentonite slurry trench cutoff walls, and vibrating beam cutoff walls. For barrier walls to be effective, they must generally key into an impermeable stratum of natural materials beneath the site. However, this requirement is not always essential, depending upon the hydrogeologic conditions.

**Soil-Bentonite Slurry Trench Cutoff Walls:** The method of constructing soil-bentonite slurry trench cutoff walls is well documented.<sup>9,10</sup> A trench is excavated below the ground surface and trench stability maintained utilizing a slurry of bentonite and water. This slurry maintains trench stability in much the same way as a drilling fluid maintains borehole stability. The bentonite-water slurry is designed by the geotechnical engineer to have certain density, viscosity, and filtrate loss properties which allow for the formation of a filter cake along the walls of the trench and which results in a computed factor of safety for trench stability greater than 1.0.

Trench depths are generally limited to about 35 ft using conventional backhoes. In order to achieve greater depths, a modified

dipper stick is required, which can usually be provided by specialty slurry wall contractors. To go deeper than 53 ft usually requires the utilization of a clamshell. An extended stick backhoe capable of excavating to depth of 73 ft has also been developed.<sup>11</sup> Clamshell digging is typically slower, and can increase the cost of the barrier wall.

Once the trench is excavated, the result is a trench filled with bentonite-water slurry. It is then necessary to backfill the trench. The backfill normally consists of a matrix of a material with or without natural fines, which is mixed with the bentonite-water slurry. The backfill materials are mixed and generally controlled on the basis of slump. The backfill is usually mixed to a consistency of high-slump concrete, and then the trench is backfilled. Care must be taken to achieve a uniform mixing of the backfill, and to avoid entrapment of pockets of pure bentonite-water slurry in the trench. A schematic of the excavating and backfill procedure is shown in Fig. 4 while a typical section of the completed soil-bentonite cutoff wall is shown in Fig. 5.

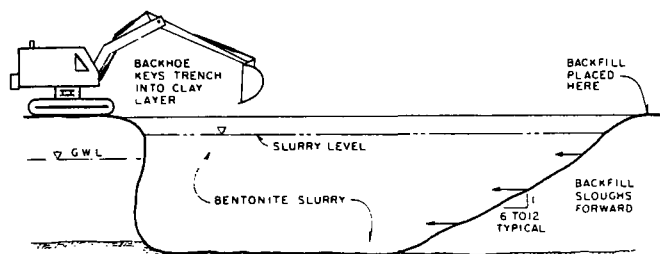


Figure 4.  
Schematic Section of Slurry Trench Excavation and Backfill

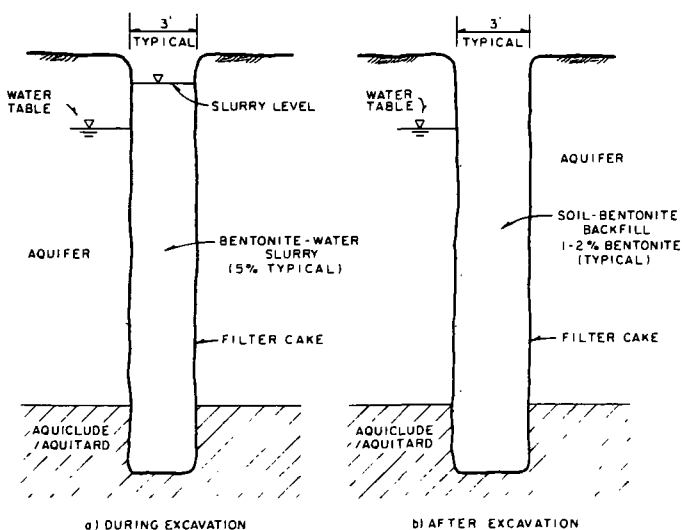


Figure 5.  
Typical Section: Soil-Bentonite Slurry Trench Cutoff Wall

Much has been written regarding the design of soil-bentonite cutoff walls for conventional groundwater control applications.<sup>9,10,11,12,13,14</sup> In order to design soil-bentonite slurry walls for waste containment, studies are required beyond those normally required for other applications. Chemical analysis of the samples of on-site materials considered as potential backfill materials should be considered. If on-site materials are contaminated consideration of the use of off-site borrow areas to provide the backfill materials must be made.

Once the potential source or sources of backfill materials is identified, waste compatibility testing is typically conducted. Several bentonites are available which are identified as being contaminant resistance. Contamination resistance is a relative term and it should be recognized that treated bentonite is not totally contam-

inant resistant to all contaminants at all concentrations. Contaminated soils may inhibit or reverse the hydration of the bentonite. Conversely, backfill mixed with contaminated soils may be subject to smaller property changes when subjected to pollutants than backfills mixed with uncontaminated soils.<sup>9</sup>

Upon selection of a backfill source or sources, the geotechnical design studies are typically undertaken. These studies should include, as a minimum, analysis of trench stability, backfill mix design, waste compatibility, and the site-specific subsurface conditions. From these studies the project specifications can be prepared. The question of compatibility between the waste and the cutoff wall is approached in two steps. First, the nature of the liquid waste or leachate must be characterized. A review of the published information investigating the pore fluid effects upon clay behavior<sup>9,15,16,17</sup> can then be made to allow a preliminary assessment of the compatibility. After the preliminary compatibility assessment is made, a laboratory testing program can be designed and conducted to provide site-specific waste compatibility data.

Once the waste capability program has been developed, samples of backfill need to be created and tested in the laboratory utilizing the bentonites under consideration. The most important of these laboratory tests is the *triaxial* permeability test.<sup>18,19</sup> The test is typically conducted ultimately utilizing the site leachate, liquid waste or groundwater as the final permeant. The samples are first set up in a triaxial cell, consolidated, and permeated with water. Initial hydration of the bentonite must be with the water planned for use during construction, and not distilled water or water from some other source. Off-site water may be necessary if the only available on-site water is contaminated so as to preclude adequate hydration of the bentonite. The bentonite utilized in the testing program must also be that planned for project usage. Permeability versus time and volume change versus time can then be calculated from the test data.

The tests are conducted to determine the change in permeability in response to the waste liquid. Typical results are presented in Fig. 6. The data are evaluated in terms of pore volume displace-

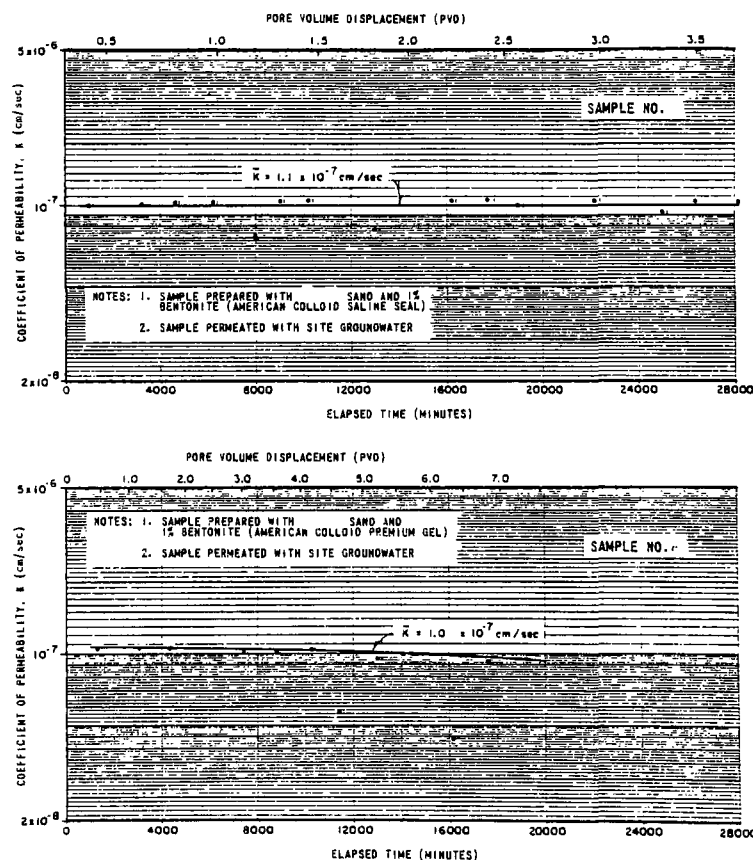


Figure 6.  
Permeability Test Results

ment as well as time. Pore volume displacement appears to provide an acceptable means at this time to account for "time" effects of the waste upon the material. Generally, three to five pore volumes are required to establish equilibrium for these particular tests, no degradation in permeability was observed with either untreated or treated bentonite. Bentonite suppliers often conduct permeability tests free of charge to clients that do not have suitable laboratory capabilities. These tests are conducted in fixed wall permeameters as shown in Fig. 7. A complete discussion of permeability testing to determine the permeant affect on fine-grained soils.<sup>5,18,19</sup>

When applying cutoff wall geotechnology to waste containment, laboratory verification of the slurry and backfill properties is essential prior to the start of construction. Shown in Fig. 8 is the effect of bentonite content and type on slurry viscosity for a given mixing water. The Marsh viscosity in seconds is

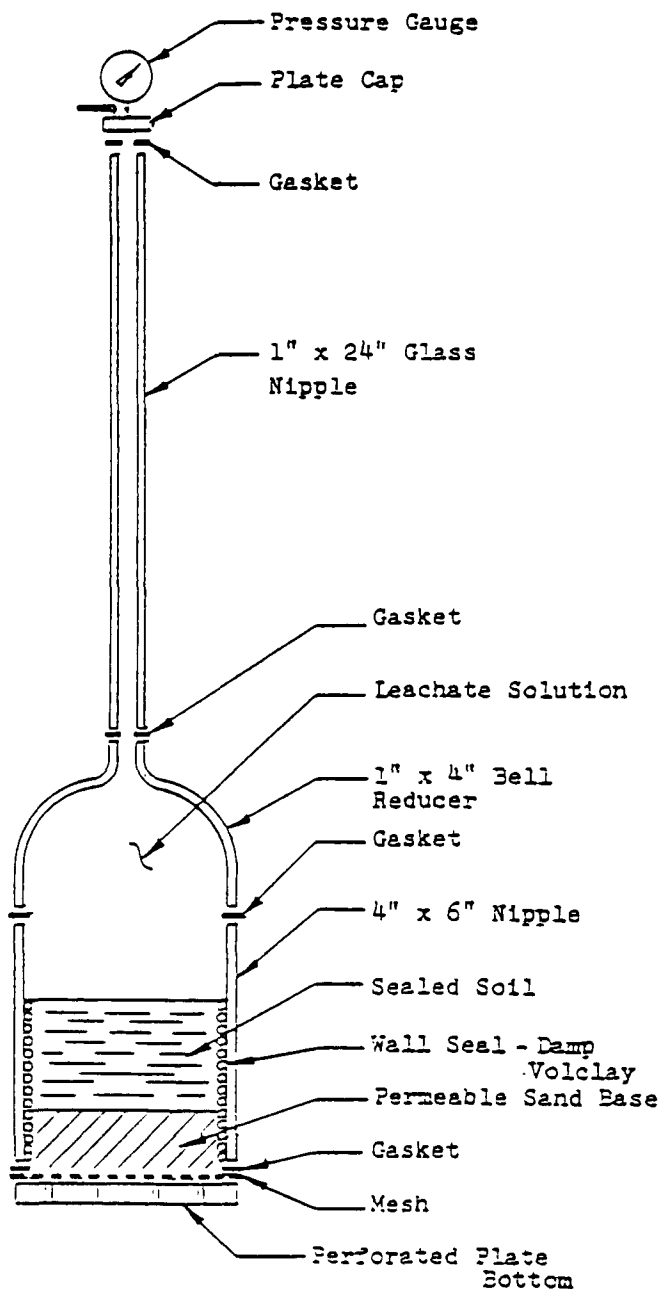


Figure 7.  
Fixed Wall Permeameter (from American Colloid Co.)

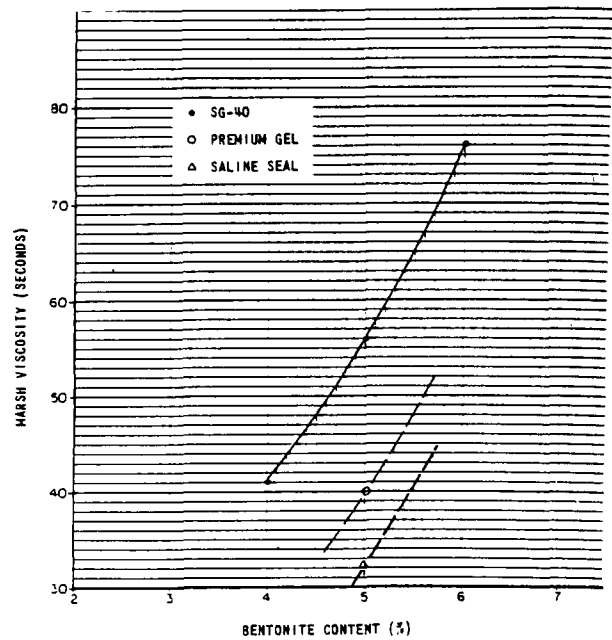


Figure 8.  
Marsh Viscosity vs. Bentonite Content

an indirect measure of the hydrated viscosity characteristics of the bentonite. Note that as bentonite content increases the Marsh viscosity increases (i.e., the slurry became thicker). Also note that the Marsh viscosity varies at a given bentonite content as the type of bentonite varies. The bentonite for these tests was hydrated utilizing water proposed for use during cutoff wall construction.

These examples are presented to show that the application of cutoff wall technology to waste containment requires analysis of the interaction between the bentonite, mixing water, backfill, and site groundwater/leachate. The long-term performance of a soil-bentonite cutoff wall for waste containment must be fully investigated.

Should a soil-bentonite slurry trench cutoff wall prove to be practicable, detailed construction specifications must be written. These specifications must include the source of the mixing water, required hydration time or slurry properties, allowable methods of mixing the bentonite slurry and the backfill, the bentonite-water viscosity and density limits, approved sources of the backfill, and allowable methods of backfill placement. An excellent treatment of slurry wall specifications has been written by Millet and Perez.<sup>14</sup>

Close construction control is required to ensure construction consistent with design assumptions and intent. A resident geotechnical engineer should document depth to key material, test the backfill and slurry, and provide on-site technical representation for the owner/engineer. Consideration must be given to the disposal of excavated soils should they be categorized as contaminated. Finally, proper planning for work safety is essential should a barrier wall be planned for containment of previously disposed wastes.

**Cement-Bentonite Slurry Trench Cutoff Walls:** As an alternative to soil-bentonite cut-off walls, cement-bentonite cutoff walls can be utilized. The trenches are excavated in a manner similar to soil-bentonite walls utilizing a slurry to maintain trench stability. However, in contrast to a soil-bentonite wall, the slurry consists of cement in addition to water and bentonite, and no backfill is added. The slurry is left in the trench and allowed to harden. A strength equivalent to stiff to very stiff clay can be obtained with the cement-bentonite slurry wall after a period of a month or so. Design considerations include the cement and bentonite content and type, and their relationship to the strength and permeability of the backfill. An example of the laboratory test

results investigating the strength of various mix designs is presented in Fig. 9.

Leachate compatibility tests must be conducted utilizing the site pollutant as permeant. The overall permeability of a cement-bentonite cutoff wall is generally higher than for soil-bentonite walls. Close control again must be given to the source of the mixing water.

**Vibrating Beam Slurry Walls:** Barriers to horizontal groundwater flow and contaminant migration have been designed and construction using the vibrating beam injection method (Fig. 10). This technique utilizes a vibratory-type pile driver to cause the penetration of a beam of specified dimensions to the design depth. Slurry is added through injection nozzles as the beam penetrates the subsurface soils and as the beam is withdrawn.

The slurry utilized with the vibrating beam technique is generally either of two types, cement-bentonite, or bituminous grout. Mix design considerations for cement-bentonite were previously discussed in this paper. Bituminous grouts are prepared as a homogeneous blend of asphalt emulsion, sand, portland cement and water. Flyash may also be included. It is reported that this bituminous grout can resist strong acids and high saline content wastes.

The engineer must be aware of the detailed aspects of thin slurry wall barriers installed by the vibrating beam technique in order to assure an adequate waste containment design and installation. The specification may include the slurry mix design, installation equipment requirements, batch mixing equipment requirements, verticality limits, injection pressure, overlap, depth, injection and extraction rates and procedures, and wall thickness.

Control of the beam tip location cannot be guaranteed, particularly with deep penetrations. For example, the presence of cobbles or boulders may cause a deflection of the tip. As in the case of conventional slurry walls, compatibility testing is necessary to investigate the slurry resistance to the contaminant being contained. A principal advantage of this technique is the elimination of the need to excavate potentially contaminated soils, possibly an important safety consideration for a barrier wall around active or retired facilities.

#### Bottom Seals (Liners)

In working with new facilities, or transferring existing contaminated materials to new impoundments, it is frequently necessary to design some sort of a liner system. The major function of a liner is to prevent leachate or waste from entering the groundwater regime. Liners, as with covers, can consist of native clays, processed clays, or polymeric membrane liners. It is important to note that under the recent "Interim Final Regulations",<sup>4</sup> the

USEPA considers a synthetic membrane liner best to "prevent" migration of wastes; whereas a clay liner will "minimize" migration of wastes. With all materials, compatibility testing is essential to determine the liner resistance to the waste or leachate to be contained.

The geotechnical considerations for the design and construction of liners include many of the same considerations discussed in the previous section discussing top seals. Only additional details unique to the use of natural clay, processed clay, and polymeric membranes as liners are discussed in the following subsections.

**Native Clay Liners:** The compatibility between the natural clays and the waste is an important design consideration for the use of natural clays as liners. It is important to ascertain the volume change and permeability change characteristics of the proposed clay liner material. The bulk transport of liquid waste must be precluded. Bulk transport of liquid through clay liners could occur due to differential settlement of the foundation materials. Tensile stresses within the liner could also result in cracking and subsequent bulk transport of liquid waste through the liner. Finally, and probably most importantly, physical-chemical stresses due to the pore-fluid-clay interaction could cause cracking.<sup>19</sup>

The determination of liner/waste compatibility requires site-specific studies. The compatibility is a function of both waste type and concentration. Studies of clay-waste compatibility conducted to date<sup>15,16,17,21,22</sup> have shed considerable light upon the subject. Despite these recent advances, laboratory tests under triaxial stress and gradient conditions can yield site-specific data from which to evaluate the suitability of a natural clay liner.

**Processed Clay Liners:** The unique geotechnical design and construction considerations for the use of processed clay for liners also relate to waste compatibility. The volume change characteristics of the processed clay are especially important. Generally, the processed clay is mixed with the subgrade material to form the impermeable liner. The impedance to groundwater flow is typically primarily by the processed clays, especially when the matrix soil is relatively free of natural fines. Hence, if the processed clay is subject to shrinkage upon exposure to the waste, large increases in permeability can occur. Even greater flow can occur if bulk transport of liquid waste occurs due to liner cracking. The hydration of a processed clay liner with uncontaminated water prior to waste disposal is recommended.<sup>23</sup>

**Polymeric Membrane Liners:** As with other liner types, waste compatibility (not a geotechnology problem) is the major design consideration. However, the permeability of a polymeric liner can increase with liner stretching. Thus, total and differential found-

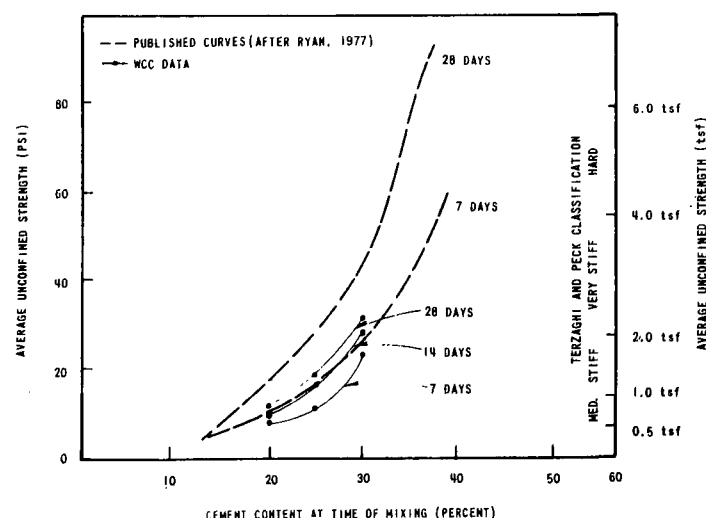


Figure 9.  
Strength vs. Cement Content  
Cement-Bentonite Slurry Trench Wall

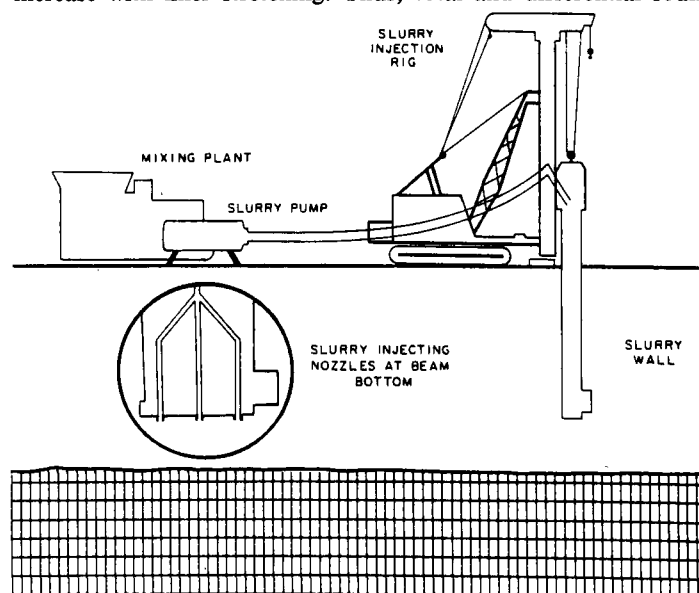


Figure 10.  
Schematic of Vibrating Beam Slurry Wall



dition settlement can impact the liner design. Close construction control is essential to the overall system performance. The "permeability" of an installed membrane liner system is generally a function of bulk transport through seam, joints, tears, holes and pinholes. Additional, typically non-geotechnical, aspects of polymeric membrane liners can be found elsewhere.<sup>24,25</sup>

## SUMMARY AND CONCLUSIONS

It is concluded that the application of conventional ground and surface water control techniques to waste containment systems requires special considerations beyond conventional design practices. Further, the application of geotechnology is essential to the adequate performance of these systems.

## ACKNOWLEDGEMENTS

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# COVERINGS FOR METAL CONTAMINATED LAND

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## INTRODUCTION

Metal contamination of land in Britain has arisen at all stages of metal utilization from the mining of metalliferous ores to the disposal of metal laden sewage sludges. Britain was one of the world's major non-ferrous metal ore producers from the late 17th century until the mid-19th century.<sup>1</sup> The major ores mined were those of lead, zinc, copper and tin. Ore extraction and processing produced large quantities of waste materials ranging from coarse waste rock, low in metal content, to very finely ground tailings.

During much of the period of maximum mining activity metal recovery techniques were poorly developed and the fine tailings frequently contained very high concentrations of heavy metals (up to 10% zinc, 3% lead and 400 µg/g of cadmium at some lead/zinc mines). These fine tailings were at first disposed of directly to water courses but 1876 legislation resulted in disposal in impoundments.<sup>2</sup> However, wind transport of these materials can affect soils for some distance downwind of abandoned mine sites,<sup>3</sup> while deposition of metal rich particulates during periods of flooding has caused severe contamination of agricultural land.<sup>4</sup> The total number of individual mine sites is high. For example, a survey of mines in Wales revealed a total of over 750 individual sites, mostly small in size but some containing over 20ha of contaminated land.<sup>5</sup>

Metal smelters have, in the past, been serious sources of land contamination through emissions from furnace stacks, dust blown from ore stockpiles and disposal of large quantities of waste slags containing high concentrations of metals. The major center of non-ferrous metal smelting in the U.K. from the 18th to the early 20th century was the Lower Swansea Valley in South Wales. Here 400ha of land was despoiled as a result of the activities of numerous metal smelting and refinery works from 1717 to 1974.<sup>6</sup> In common with most other derelict metal smelting and refinery sites the land involved is in an urban area, thus restoration and reuse is important.<sup>7</sup>

Other industries which have given rise to problems of metal contamination are foundries, scrap yards and metal reclaiming works, paint pigment works and acid manufacturing plants.

Sewage sludge, especially when derived from urban/industrial areas, can contain high concentrations of zinc, copper, tin, nickel, cadmium, lead and mercury.<sup>8</sup> Sewage sludge was formerly dumped on agricultural land known as sewage farms. These farms frequently encompass considerable areas and can be highly contaminated.<sup>9</sup> The metals tend to be very available and can become even more so as the sewage organic matter decomposes. Many of these sites are close to urban areas and are prime sites for redevelopment.

## COVERING LAYERS

There is thus a wide variety of metal contaminated land throughout Britain in both rural and urban situations. Its restoration is important for public health, pollution control, aesthetic and economic reasons. One of the most widely used restoration methods for these sites in the U.K. is to cover the contaminated material with "clean" imported soil in order to provide a rooting medium for plants and to isolate the potentially hazardous material from

human and animal contact. Such coverings can be simple layers of topsoil or suitable sub-soil placed directly over the contaminated materials, or some intermediate layer may be incorporated between the surface covering and the toxic substrate. These layers have been included in order to inhibit root growth into the contaminated soil and also as a result of concern over the possible failure of restoration schemes through the effects of upward migration of metal ions in capillary water during dry periods.<sup>10,11,12,13</sup>

These intermediate materials, frequently termed barrier layers, can be divided into three main types:

### •Impervious seals—

which are intended to prevent solute movement between contaminated material and topsoil by virtue of their impermeability. Included are heavy clay soils and artificial materials such as butyl rubber and high density polyethylene. These materials have been used on domestic refuse sites and sites containing organic contaminants.

### •Porous capillary breaks—

which are intended to prevent the upward movement of water by breaking the hydraulic conductivity between the topsoil and contaminated materials. Examples of materials used on metal contaminated sites include building rubble and limestone gravel.

### •Chemical barriers—

which are intended to chemically precipitate metals in solution at the waste/amendment interface. Ground limestone, pulverized fuel ash and Leblanc waste\* have been suggested as suitable materials.

\*Waste material from the old Leblanc process for sodium carbonate manufacture. It has a pH of 12 and consists largely of calcium sulphide and calcium hydroxide.

## RESEARCH PROGRAM

In order to investigate the long term effectiveness of surface covers on metal contaminated land the U.K. Dept. of the Environment have funded a research program whose prime aims are to assess:

- Under what circumstances and to what extent contamination of covering layers would occur under field conditions
- The extent of metal uptake into vegetation growing on covered, metal contaminated materials.

The research program consists of three main areas of work consisting of:

- Laboratory experiments
- Field experiments
- Survey of reclaimed sites

### Laboratory Experiments

Experiments incorporating a range of waste materials and barrier layers in artificial soil profiles have been constructed inside 300mm diameter PVC tubes. Details of the construction of these profiles were given in a previous paper.<sup>14</sup> A section through one of the columns is shown in Fig. 1.

The barrier layers used were estuarine clay, gravelly glacial clay, sea won sand, land won sand, pulverized fuel ash, building rubble

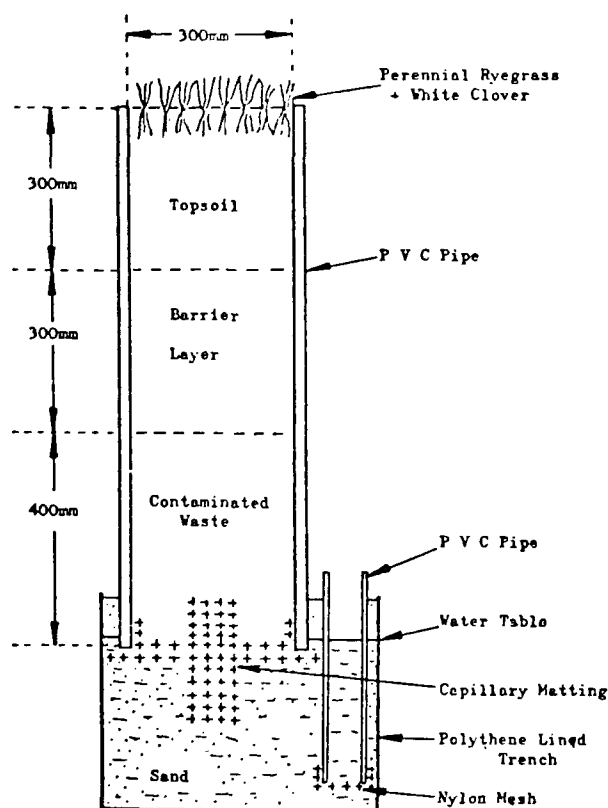


Figure 1.  
Section through soil column.

and ground limestone. Soil and vegetation samples from these profiles are collected at regular intervals and total metal concentrations determined.

To date, under extreme drought conditions, one of the barrier layer treatments, clay, has shown elevated metal concentrations in the supported vegetation. The reasons for this are being investigated in a further series of experiments.

### Field Experiments

A series of experimental plots has been constructed on metal contaminated material at a former munitions works. The treatments used duplicate those used in the laboratory experiments, but, under field conditions. The plots are described in a previous paper.<sup>13</sup>

Uptake of metals into vegetables grown on the plots has been minimal. Other experiments include an investigation of metal uptake by vegetables and fruits grown on top of covering layers on an old sewage farm.<sup>16</sup>

### Survey of Reclaimed Sites

A survey of sites in Britain where metal contaminated materials have been covered and vegetated is being carried out. Investigations at these sites consists of the collection of surface soil and vegetation samples, and extraction of cores through the covering layers into the original ground surface. Total metal concentrations in these samples are determined, analysis depending on the nature of the contamination at the site.

The sites which have been investigated are described in Table 1. The metals of biological significance most commonly encountered as contaminants are lead, zinc, copper (reflecting their industrial importance) and cadmium (also widely used but its presence on older contaminated sites is usually due to its strong association with zinc).

Table 1.  
Restored sites included in survey.

Site No.	Former use of site	Known Contaminants	Date Restored	Cover Materials	Present use
1	Lead/zinc mine 1855-1963	Pb, Zn, Cd	1977	200-400mm coarse shale quarry waste	Sheep grazing
2	Lead/zinc mine 1622-1921	Pb, Zn, Cd	1972	Varying depths of waste rock and sandy topsoil	Sheep grazing
3	Lead/zinc mine 1620-1901	Pb, Zn, Cd	1981	150-200mm stony subsoil over 150-350mm waste rock	Sheep grazing
4	Lead/zinc mine 1892-1920 1948-1956	Pb, Zn, Cd	1977	150-250mm coarse shale quarry waste	Sheep grazing
5	Lead/zinc mine 1710-1914	Pb, Zn, Cd	1975	150-900mm of various materials including topsoil, burnt and unburnt colliery spoil	Revegetation trial
6	Lead/zinc mine 1850-1920	Pb, Zn, Cd	1975	150-900mm of various materials including topsoil, burnt and unburnt colliery spoil	Revegetation trial
7	Lead Smelter 1805-1913	Pb, Cu	1971	100-200mm clay topsoil over 30-300mm clay subsoil	Public open space
8	Copper Smelter 1810-1924	Pb, Zn, Cd, Cu	1973	150mm clay loam topsoil over 300mm limestone gravel	School playing field
9	Copper/Arsenic Smelter 1866-1905	Pb, Zn, Cu, As	1964	150-300mm acid sandy-clay subsoil	Public open space
10	Steel Works 1839-1975	Zn	1980	150-250mm clay subsoil	Public open space
11	Chromate Works 1880-1968	Cr	1975	250-2000mm coarse sandy soil	Public open space
12	Chromate Works zinc smelter, Leblanc Works, Sulphuric acid works	Pb, Zn, Cd, Cr, As	1975	Varying depths of sand and top soil over 350mm Leblanc waste	Public open space and sports fields
13	Leblanc works, sulphuric acid plant 1847-1920	Pb, Zn, Cu, As	1975	100-200mm silty clay over 150-300mm railway ash	Public open space
14	Sewage Sludge disposal areas	Zn	1968 1979	Varying depths of topsoil over sand	Sheep grazing
15	Domestic refuse disposal area 1895-1950	Pb, Zn, Cd, Hg, As	1978	125mm topsoil and 25mm sand over 150mm flint gravel	Public open space and sports fields
16	Domestic refuse disposal area 1962-1974	Pb, Zn, Cd, Cu	1975	550-800mm clay gravel subsoil	Allotment gardens

The dates of restoration schemes are seen to be largely post 1970, although many of the sites had been disused and derelict for many years. This reflects the increasing public and official awareness of the necessity for restoration of these contaminated sites and derelict land in general during the 1960s. Local authorities were given powers to acquire derelict land in 1963, and from 1966 they have been eligible for generous grants to defray the costs of restoration. The actual level of grant varies from 50% to 100% depending on the area within which a site is situated.<sup>17</sup>

The choice of cover used has been largely based on local availability of materials since transport costs represent a major element in the total cost of a restoration scheme utilizing imported surface covers. In some cases decisions have also been based on preliminary experiments and/or scientific advice.

The covering systems used have varied from simple covers of subsoil to more complicated schemes involving intermediate barrier layers between the waste and the final surface cover. The materials used have encompassed the complete physical range from very

coarse waste rock through coarse gravel and sandy subsoils to heavy clays. Chemically the materials have ranged from highly alkaline chemical waste to acid sandy subsoil.

At some of the sites, covering of the contaminated material has been incomplete due to insufficient material being imported. At site 7 part of the area was left uncovered in order to preserve a series of smelter fume condensation flues of archaeological interest. As a result, materials containing very high metal concentrations were still present at the surface. Metal concentrations in the exposed contaminated materials compared with the restored areas of the sites are given in Table 2. This situation would clearly not be accepted at an intensively used site.

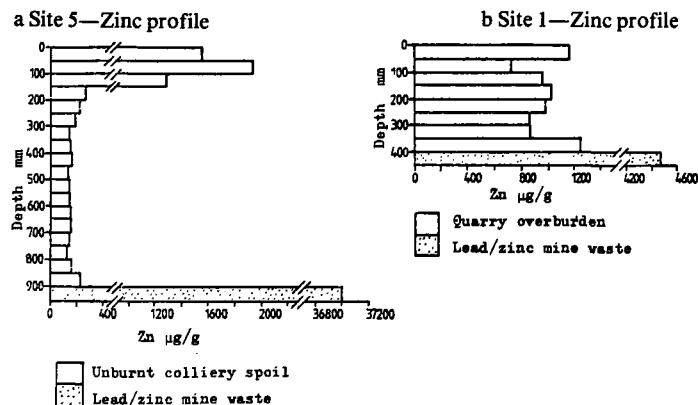
**Table 2.**  
**Sites with Incomplete Cover.**

**Metal concentrations in soils from covered and non-covered areas**

Metal concentrations  $\mu\text{g/g}$  dry wt.

Site number	Pb	Zn	Cd	Cu
1 covered	251	1140	4.5	—
non-covered	4460	20800	55.8	—
7 covered	160	183	0.5	43.7
non-covered	5280	512	0.6	386
9 covered	548	869	6.7	232
non-covered	1460	2350	54.0	67.2
"normal" unmineralized soil	2-200	10-300	0.1-2.0	2-100

At several sites, very coarse materials such as waste mine rock, quarry waste, and colliery spoil have been used as cover materials. Zinc concentrations are shown in Fig. 2a for a typical profile through such a material (placed over tailings containing high concentrations of lead and zinc sulphides) in revegetation trials at a derelict lead/zinc mine (site 5). There is no evidence of any increase in zinc concentrations in the cover materials beyond 50mm above the waste/amendment interface. The slightly elevated concentrations in the lowest sample of cover material was probably a result of physical incorporation of waste into the cover during restoration and also the difficulty of obtaining "clean" samples of this very coarse material in close proximity to the contaminated material. The very high concentrations of zinc in surface samples were due to contamination from adjacent exposed areas of mine waste.



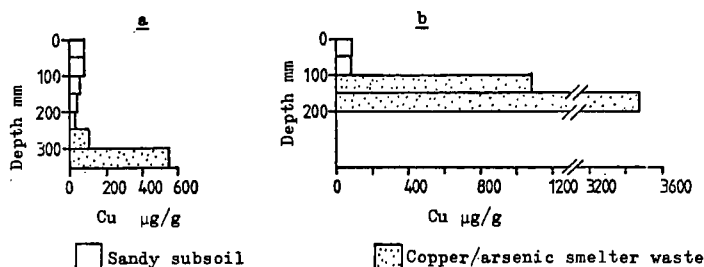
**Figure 2.**

The other metals determined in samples from this site (lead and cadmium) showed very similar vertical distributions with no evidence of contamination of the amendment by movement of metals from below. Of the three metals, zinc was most likely to show evi-

dence of any such movement since its sulphide, and its weathering product, zinc sulphate, are more soluble than the corresponding lead salts, and its concentration relative to that of cadmium is very great although their chemistry is similar.

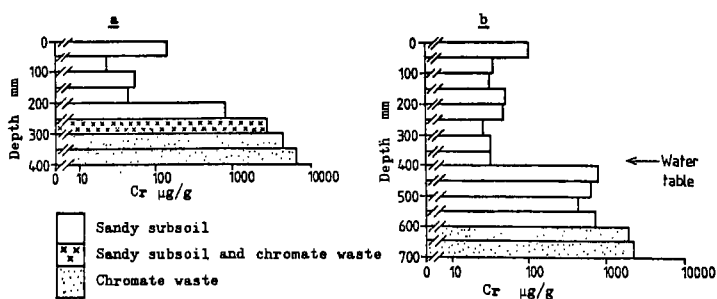
Burnt colliery spoil and alluvial sandy loam topsoil were also used in these revegetation trials. The metal profiles in these materials were very similar to those in unburnt colliery spoil. As a result of this trial and a similar series at site 6 a number of lead/zinc mines have been covered with porous materials similar to colliery spoils. Fig. 2b shows zinc concentrations in a typical profile through coarse quarry waste at site 1.

At site 9, an acid, coarse, sandy subsoil was used to cover the site of a former copper/arsenic smelter. Copper concentrations in a typical profile from this site are shown in Fig. 3a. There was no evidence of any movement of copper into the cover. The same is true for lead, zinc, cadmium and arsenic. Copper concentrations in a profile from the same site but in an area where vegetation showed signs of toxicity are given in Fig. 3b. This condition was simply due to an insufficient depth of cover above the toxic material. Similar effects due to shallow cover layers have been observed at other sites.



**Figure 3.**  
**Site 9 Copper profiles**

At site 11, a similar sandy subsoil was used to cover the site of a chromate smelter. Chromium concentrations in a typical profile from this site are shown in Fig. 4a. Some mixing of chromate waste into the cover had occurred during restoration resulting in the elevated concentrations in the lower horizons. Chromium concentrations in an area where a high water table was present within the cover are shown in Fig. 4b. This situation resulted in the contamination of the sandy subsoil with soluble chromium salts. The water table actually emerged at the surface in some areas of the site resulting in complete death of vegetation due to high chromium concentrations in the plant rooting zone.



**Figure 4.**  
**Site 11—Chromium profiles**

At site 12, a layer of Leblanc waste has been incorporated into the covering system as a chemical barrier between topsoil and chromate waste. The position of the barrier varied depending upon the requirements of landscaping. Chromium concentrations in a typical

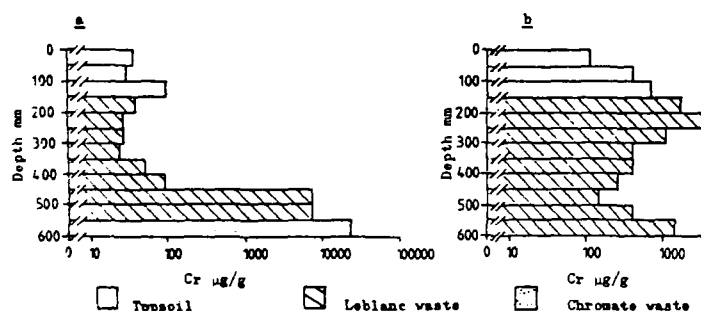


Figure 5.  
Site 12—Chromium profiles

core from this site are shown in Fig. 5a. There was evidence of a slight increase in chromium concentrations in the lower horizons of the barrier. Chromium concentrations in an area of the site where vegetation shows signs of toxicity are shown in Fig. 5b. They were elevated throughout the cover profile. This core was taken in an area at the base of a steep slope where water would be expected to emerge during wet weather.

Heavy clay soils have been used as cover material at three sites. These sites showed evidence of mixing of contaminated waste with the lowest cover horizons, but there was no evidence of any other contamination of the cover soils.

## CONCLUSIONS

The information derived from this project has shown that the measures used for restoration of metal contaminated land have been successful. In general, where covering has been carried out in accordance with recommendations there is no evidence that regression due to reappearance of toxicity will occur. Toxicity problems still exist at some sites due to areas of contaminated material remaining uncovered.

At some sites the provision of an insufficient depth of cover has resulted in toxic concentrations of metals within plant rooting zones causing adverse effects and in some cases, death of vegetation. These investigations at reclaimed sites have produced no evidence of upward migration of metals into covering layers through transport of metals in solution in capillary water under field conditions.

At some sites elevated metal concentrations in surface covers have occurred through physical incorporation of contaminated materials into the amendments during restoration work. At two sites where chromium is present in a soluble anionic form, contamination of the surface covers with resulting toxicity to vegetation has occurred where water enters waste mounds, becomes contaminated, and re-emerges through the covering layers at lower levels. At none of the sites was there any evidence of similar movement of cationic metal ions through soil covers.

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# SELECTION, INSTALLATION, AND POST-CLOSURE MONITORING OF A LOW PERMEABILITY COVER OVER A HAZARDOUS WASTE DISPOSAL FACILITY

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## INTRODUCTION

A closure plan, recently designed and implemented for a hazardous waste disposal facility, included the installation of a low-permeability cover over the wastes. This facility, located in western Pennsylvania, consisted of a lime neutralization plant and a 26-acre sludge impoundment. The facility started operations prior to the existence of strict hazardous waste disposal regulations and was not constructed with a liner system to protect groundwater.

As part of the closure requirements of the Pennsylvania Department of Environmental Resources (PADER), a low-permeability cover as well as a leachate collection and treatment system had to be installed. In addition, the facility owner is responsible for monitoring aquifers beneath the site to determine changes in water quality and the effectiveness of the liner. Presented here are the hydrogeologic conditions, the considerations that went into cover selection and design, the cover installation procedure and cost, and the groundwater monitoring plan.

## SITE CONDITIONS

The site is located in a sparsely populated area of farms and woodland. During the active life of the disposal facility, it received mostly acidic wastes from the regional steel industry for lime treatment and disposal. Prior to use as a treatment and disposal facility, the site was mined for the Pittsburgh Coal. Deep mining occurred first, starting just after 1910. Haulageways and rooms were left open beneath the surface from where the coal was retrieved. This mining method left coal in place to support the overlying rock. The amount left was sometimes up to 50% of what was originally there.

During several periods between 1930 and 1950, surface mining was performed to remove the remaining pillars of coal. Large equipment was used to excavate in successive cuts along the contour of the hillside, working deeper with each pass to reach the coal. Overburden was cast behind and downslope from each new cut.

After the last cut was made, a long open pit was left, with a highwall of in-place rock on the north side and mine spoil overburden piles on the south. No laws existing at that time required reclamation of the land.

This property was then purchased to utilize the open cut as a disposal lagoon. A treatment plan, consisting of several holding tanks and mixers, was constructed at one end of the abandoned strip cut. Once wastes were neutralized, they were discharged as a slurry. They flowed by gravity into the strip cut. The waste would then partially dewater and form a semi-solid sludge. The operation continued from 1953 until 1981, when the amount of wastes approached the capacity of the cut.

At that time, PADER gave standards for closure of this facility. The major concern was groundwater contamination.

To minimize leachate generation a low-permeability cover was required. In addition, a network of leachate collection drains along with a leachate treatment plant were required.

## GEOLOGIC SETTING

The site is located in the unglaciated portion (Kanawha Section) of the Appalachian Plateau Physiographic Province. The regional structure generally consists of subparallel anticlines and synclines trending northeast and plunging to the southwest.

Rocks exposed at the site are assigned to the Monongahela and Conemaugh Formations of the Pennsylvanian age. The base of the Pittsburgh Coal is the boundary between these formations. The rocks immediately underlying the base of sludge belong to the Conemaugh Formation. The lower portion of the Monongahela Formation is also present, but in much of the area these rocks have been removed by strip mining.

The rocks of the Monongahela Formation consist primarily of sandstone, shale, and limestone. The thickness of this unit varies from 50 to over 80 ft at this site.

The Conemaugh Formation consists of a very complex series of delta deposits. Most facies in the formation are lenticular, and the geology can vary significantly in the horizontal direction.

The study area has substantial mining history, because of the occurrence of the Pittsburgh Coal seam. The hill abutting the waste disposal site on the north was deep mined by the Pittsburgh Coal Company in the 1920s and 1930s. Mining was by the room and pillar technique, a common method at that time. Entries to the mine were at the area presently forming the northeast corner of the easternmost sludge pond. Surface mining took place in this area in the 1930s and early 1950s.

Mine maps show that deep mining operations extend through portions of the south-facing highwall. Mining also occurred through the center of the highwall where a depression extends to the north. Sludge filled this depression and formed a fingerlike configuration extending northward from the main sludge area.

The heavy metals in the waste sludge leach very little, most likely because the lime treated sludge has a pH of 8 to 10. Leachate testing has indicated that significant levels of  $\text{NH}_3\text{-N}$ ,  $\text{NO}_3\text{-N}$ , chloride and phenol are dissolved from the sludge.

Extensive sampling and analysis has been performed on the numerous seeps around the site. The seeps located upgradient from the site do not indicate any effect on groundwater quality from the disposal facility. Their water quality represents typical acid mine drainage water with low pH and high concentrations of Fe, Mn, and sulfate.

Seeps located along the south perimeter of the site downgradient indicate high concentrations of  $\text{NH}_3\text{-N}$ , chloride, phenol, and heavy metals (Al, Fe, Ni, Mn, Zn) where the overall quality has deteriorated with respect to pH. Mine waste leaching was suspended to contribute to low pH and increased metal concentrations.

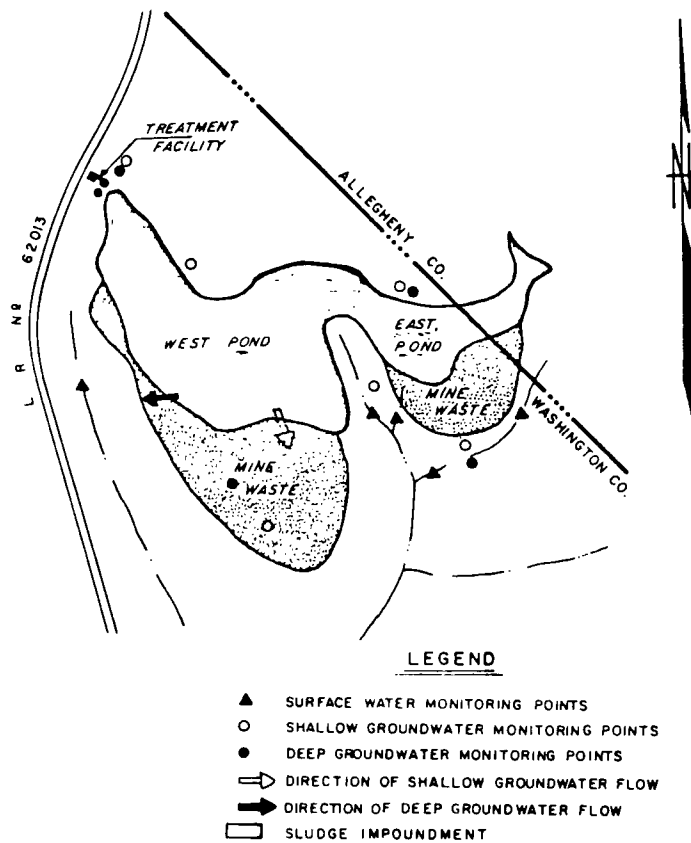
During facility operation, seepage originated from upslope runoff, direct rainfall, and free water from sludge deposition. The major portion of the water flowed southward and passed through the impoundment dikes. These waters continued their generally southward and downslope flow until reaching the perimeter of the

spoil areas, where considerable surface seeps appeared. These seeps then combined with two main water courses draining site.

The general geologic conditions at the site were determined by surface reconnaissance, mine maps, and investigation of highwall exposure in a strip cut on the opposite side of the south-facing highwall which formed the northern wall of the sludge pond.

### SUBSURFACE INVESTIGATION

The objective of the subsurface investigation was to define hydrogeologic conditions and determine the existence or probability of groundwater contamination. The hydrogeology was studied via 10 monitoring wells (Fig. 1). Six shallow monitoring wells and four deep monitoring wells have been installed. The wells monitor shallow and deep groundwater flow systems. Test borings were drilled using the rotary method with air or water. Roller bit or core samplers were used to obtain rock samples. After coring, each borehole was reamed with a 7.875 in roller bit, and 4 in. diameter PVC monitoring wells were installed. *In-situ* permeability tests were performed. Falling head or pressure tests were conducted, depending on the rock type being evaluated. A generalized geologic cross section is shown in Fig. 2.



LOCATION OF SAMPLING POINTS

Figure 1.  
Location of Sampling Points

Test borings through the Conemaugh Formation indicated that the geology of this formation can be divided into four units.

Unit I—0 to 100 ft below base of sludge. The uppermost unit is geologically the most complex. It consists primarily of claystone and siltstone, but contains numerous lenses of sandstone, shale, and limestone. At the northwest end of the site, claystones are very abundant in the lower part of this unit, but these often grade southeastward into sandstones. The sandstones are somewhat better developed in the southeast portion of the area. A continuous limestone layer was discerned in the uppermost part of this unit. This lenticular limestone bed is elongate in a northwesterly direction. The limestones are separated by siltstone and claystone.

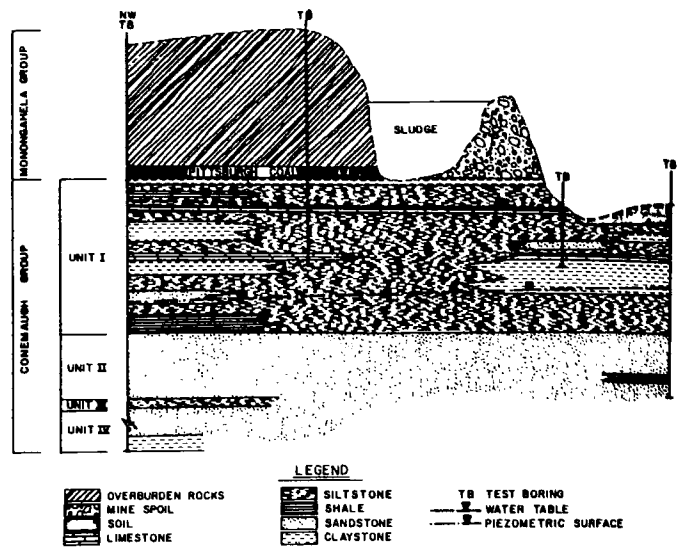


Figure 2.  
Generalized Geologic Cross-Section

The uppermost unit ranges from 85 to 100 ft thick where it has not been breached by erosion. The dip of this unit is northeastward.

Unit II—100 to approximately 130 ft below the base of sludge. The rocks underlying the uppermost unit consist mostly of the sandstone. Medium to medium-coarse grained argillaceous sandstone with abundant bituminous partings occur in the southeastern portion of the area. In the northwest portion of the area, it is a silty sandstone. It is 20 to 30 ft thick in the southeast and approximately 40 ft thick in the northwest.

Unit III—130 to 140 ft (approximately) below the base of sludge. Beneath the sandstone is an interlaminated unit of sandstone with black siltstone. It is 3 to 11 ft thick, with the greatest thickness occurring in the west.

Unit IV—140 to 215 ft (approximately) below the base of sludge. The interlaminated unit overlies the thick sandstone layer. It is approximately 75 ft thick, with some siltstone beds in the lower part. A claystone marks the base of the sandstone layer.

During this investigation, three principal water-bearing zones were identified. These are:

- A shallow groundwater flow system in the mine spoil, rock strata, and abandoned deep mines above the Pittsburgh Coal underclay and at the base of the sludge elevation
- An aquifer in the limestone layers beneath the Pittsburgh Coal, approximately 5 to 15 ft below the base of sludge
- A deeper aquifer in a sandstone unit of the Conemaugh Formation, approximately 140 to 160 ft below the base of the sludge.

The first aquifer is represented by the shallow groundwater flow system. This flow system occurs in bedrocks and mine spoil above the Pittsburgh Coal underclay and also in the abandoned deep mine. Water that infiltrates through this rock strata or mine spoil becomes perched on the Pittsburgh Coal underclay. Perched groundwater on the Pittsburgh Coal underclay is recharged from the north areas of the waste disposal site. This water flows beneath the existing sludge or at the interface between the sludge and mine spoil. Several seeps at the south perimeter of the site indicate this is the discharge area for this groundwater flow system.

The second principal aquifer occurs in the limestones from 5 to 15 ft below the base of sludge. These continuous and discontinuous limestone layers, although thin, appear to be good aquifers because of their high permeability. The limestone units represent a semi-confined aquifer. The flow is largely controlled by local topography but is generally southward. A swampy area southeast of the sludge impoundment may be the groundwater discharge area. This aquifer is separated from the underlying, deeper aquifer

by a continuous layer of the aquitardes and aquicludes. These layers consist mainly of claystone and siltstone.

Six shallow monitoring wells have been installed into this aquifer. Three are upgradient and three are downgradient wells.

The downgradient wells have consistently higher chloride,  $\text{NH}_4$ , and  $\text{NO}_3\text{-N}$ . This groundwater is found in close proximity to the cropline of the unit and travels a short distance before it is discharged.

The third aquifer at the site is a sandstone from 140 to 160 ft below the base of sludge. The thickness of this sandstone aquifer varies from 20 to 40 ft. This unit is particularly permeable at its top. However, it grades into a silty sandstone to the northwest; as it does so, it becomes less permeable. The most permeable zone occurs near its base. The groundwater flow direction is westward. This waterbearing stratum is a confined aquifer. Four monitoring wells have been emplaced into this aquifer.

The following observation was made during the drilling one of the monitoring wells. Water in the limestone aquifer was sealed off with casing and bentonite. As the rest of the hole was drilled, careful observations were made to detect water. The hole remained totally dry until a depth of 160 ft. The rocks below 160 ft, however, were saturated with water. This water is under pressure, as indicated by the fact that water level in the hole stands at 107 ft. The rock unit below the limestone aquifer can be attributed with being the confining layer which separates these two aquifers. The sandstone aquifer does not indicate any effect by leachate.

Since installation of the monitoring wells, water table measurements and samples have been periodically taken.

#### EVALUATION AND SELECTION OF COVER MATERIAL

The objective of the cover placement was to reduce or eliminate rainfall percolation through the sludge and consequently prevent leachate generation and contamination of groundwater. PADER required that the cover have a hydraulic conductivity of less than  $1 \times 10^{-7}$  cm/sec.

Cover options considered were: compacted local soil or mine soil, local soil with bentonite additives, bentonite or clay import or a synthetic membrane.

Compacted local soil or mine spoil. This option was considered as a result of the abundance of this material available due to the local strip mining. There were several problems which prevented its use. Much of this material was coarse. The amount of fines was relatively small, which would leave a significant amount of void space. Compaction could not be expected to overcome this problem because high densities could not be attained over the semi-solid sludge surface. In addition, some of this material consisted of carbonaceous shale fragments, which would produce an acidic leachate as rainfall infiltrated through the cover. This leachate would then flow through the sludge, releasing even more contaminants as a result of its increased acidity. The extraction of non-carbonaceous fines in suitable quantity from the local material for compaction over the sludge was considered technically and economically infeasible.

Bentonite additives to local soil. The high swelling characteristics of bentonite clay make it an effective soil sealer. The application rate is a function of the physical gradation and void ratio of the soil. The coarse nature of the local soil, with resultant high void ratio, required that high application rates be made to achieve low permeability. These application rates made this option economically infeasible.

Bentonite or clay import. A bentonite or clay import was considered. Bentonite could have been hauled in by rail from Wyoming; however, a supply adequate to cover 26 acres was relatively expensive. Other clays closer to the site did not possess the superior qualities of bentonite and would not have performed suitably as a cover.

Synthetic membrane. The use of a synthetic membrane was found to be the most economical cover option. The only other

practical option from a strictly technical viewpoint was the bentonite import, but it was too costly in this particular instance.

Under different circumstances, the synthetic membrane may not have been the option ultimately selected. If local soil had more fines, it may have been suitable for bentonite additives. Furthermore, if leachate collection and treatment was not part of the site closure and if the cover was the sole or primary protective feature to maintain groundwater quality, then questions relating to the life of the synthetic membrane may have resulted in selection of a bentonite cover.

#### FINAL COVER INSTALLATION

The final cover is a composite layer and consists of a local borrow material grade coarse, two layers of geotextile fabric, PVC membrane, and a vegetation and soil cover layer. Storm water runoff and seepage drainage systems are incorporated on and within the cover layer. A typical cross-section of the final cover is shown in Fig. 3.

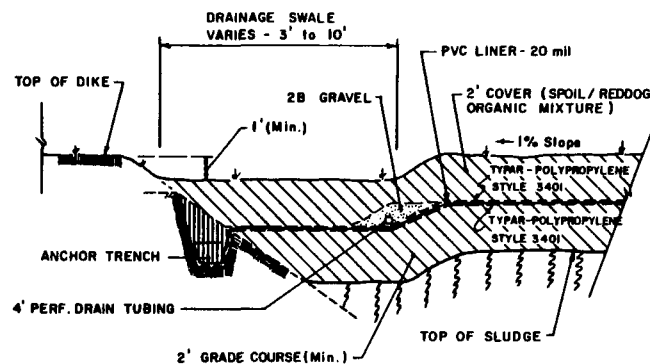


Figure 3.  
Detail of Low Permeability Cover

The cover surface was designed to slope at a minimum of 2% to achieve drainage of storm water runoff. Since the 30-acre sludge impoundment was developed in a contour strip mine, its shape is irregular and has a variably curved perimeter. Width of the impoundment ranged from 200 to 700 ft. This uncommon configuration necessitated a cover fill of varying thickness and grade to achieve conveyance and drainage of storm water runoff.

Material for the grade coarse fill was borrowed from local mine spoil and mine refuse piles to the south of the site. The mine spoil material is weathered rock overburden and soils from strip mining of the local coal seam in the 1920s and 1930s. The mine spoil was typically soft to hard shale and sandstone rock fragments from 0.5 to 24 in with little fine-grain particles. Mine refuse is the reject material from preparation of coal removed from deep mining of the same local coal seam in the 1920s. Mine refuse is typically more carbonaceous and acidic because of the higher percentage of coal and pyritic minerals. Under these conditions the mine refuse commonly oxidizes to form a hard, shale-like semi-fused mass, commonly called reddog. Reddog was present throughout the mine refuse deposits. Reddog is typically hard shale and sandstone fragments from 0.5 to 24 in with trace fine-grained particles.

The grade course fill ranged in thickness from 2 to 11 ft. Approximately 316,000 yd<sup>3</sup> of material was required. Self-loading scraper pans of 31 to 44 yd<sup>3</sup> capacity (Caterpillar 637 and 657) and 200 and 300 hp bulldozers (Caterpillar D7 and D8) were used to excavate and place the borrow material.

Prior to placement of the grade course fill on the sludge impoundment, a number of test fill ramps were constructed on the sludge surface to evaluate the bearing capacity of the sludge material. The semi-solid character of the sludge deposits raised the question of the feasibility of placing a cover fill with the heavy equipment.

*In-situ* sludge water contents were found to be 150 to 240% with a unit weight of 80 to 90 lb/ft<sup>3</sup>. The sludge is predominantly a silt-size material with a void ratio of approximately 8.0 and a com-



pression index from approximately 2 to 2.5. Natural soils with compression indices greater than about 0.4 are considered to have high compressibility, and few natural soils have compression indices greater than about 1.0. Therefore, the sludge was known to have a high compressibility and thought to possess a low bearing capacity.

The fact that the sludge surface would support a person indicated that the sludge possessed some shear strength and bearing capacity. The ground pressure of a 200 lb individual standing on the impoundment surface is estimated to be approximately 0.5 to 1.0 psi. This is considerably lower than the average ground pressure of 10 psi for a 300 hp bulldozer and up to 20 psi for a loaded scraper pan.

Since the sludge properties were found to vary with depth and areal extent, a field test fill was judged to be the most effective means to evaluate sludge bearing capacity for the covering operations.

The test fill was performed to determine the bearing strength of the sludge and the minimum cover fill thickness needed to support the proposed range of earthmoving equipment. A 4 to 5 ft layer of borrow material was placed on the impoundment by end dumping from the retaining dikes and pushing the material onto the sludge with the smallest available dozer. Initial results showed that the sludge would support 5 ft of cover material alone which indicated a minimum bearing capacity of approximately 4 psi.

The dozer then slowly extended the test fill out into the sludge to create a ramp approximately 25 ft wide. Since the sludge was demonstrated to support the dozer and 5 ft of cover material, the minimum suggested bearing capacity was increased to about 15 psi.

This procedure was continued with a series of test fill ramps across the thickest parts of the sludge. Equipment loadings were increased in increments up to a fully-loaded 44 yd<sup>3</sup> scraper pan without any failure in sludge shearing strength.

Once the supportability of the sludge impoundment was adequately demonstrated to the owner, engineer, contractor, and regulatory agency officials, the installation of the final cover was able to proceed.

The complete cover was installed on the sludge impoundment over a four month period, from July to Nov. 1981.

The grade course fill was placed on the sludge impoundment at the required final slopes for drainage of storm water and seepage. Since the grade course material included hard, angular, rock fragments, a protective, puncture resistant support layer was placed on the finished surface of the grade course to protect the PVC membrane. This support layer was a non-woven polypropylene fabric manufactured by DuPont (TYPAR 3401). The fabric was placed in 20 ft wide sections and overlapped a min of 6 in.

A 20 mil PVC membrane manufactured by B.F. Goodrich was placed directly on top of the geotextile support fabric. The membrane was delivered to the site in 100 ft wide by 200 or 300 ft long folded sections. An average field crew of 18 laborers and a foreman installed 1,140,000 ft<sup>2</sup> of membrane in 3.5 weeks.

Two technical representatives of the liner manufacturer were on-site full time to supervise liner installation. This supervision and final approval of installation was written into the project specifications and was considered a critical item in construction quality control.

The membrane was solvent bonded using an average 4 in overlap on each 100 ft section. Solvent was applied with a brush to the contact sides of each membrane piece. The seam was formed by pressing both solvent coated pieces together with a hand roller. Curing of each seam was completed in approximately 24 hr, depending on ambient air temperature.

Care was taken to avoid membrane installation at temperatures less than 40°F, since this would have an adverse effect on seam integrity.

The membrane was keyed along the impoundment perimeter using an average 1 ft deep, soil-backfilled, anchor trench. A perforated drainage pipe with a coarse aggregate backfill was placed continuously along the toe of the membrane to drain and convey water flowing on or near the membrane surface.

Another layer of geotextile fabric, identical to the fabric beneath the membrane, was placed directly on the membrane surface. This layer protects the membrane from puncture by angular rock fragments in the soil cover layer and additional dynamic stresses created by heavy equipment traffic.

Since the soil cover layer was required to support vegetation, a common borrow alone as used in the grade coarse fill was not acceptable. Soil cover layer specifications required a maximum 4 in. particle size, significant fine-grained soil fractions, and an organic soil supplement at an application rate sufficient to improve physical fertility for maintenance of good vegetative growth. Lime and fertilizer applications were also specified for seedbed preparation. The soil cover layer averaged 2 ft in thickness. Approximately 84,000 yd<sup>3</sup> of material was required.

Because the volume of soil cover was significantly less than the grade coarse fill, alternate borrow areas were investigated for a suitable material. Significant quantities of residual clay-silt soils and topsoil were found in undisturbed areas beyond the edge of the mine wastes. Organic silty soils were borrowed from the local stream beds as part of the foundation excavations for the sedimentation basin embankments.

The available amount of these soils was not sufficient to meet the required volume for the soil cover layer. It was decided to blend the organic fine-grained soils with mine spoil material less than 4 in in size to provide the final cover layer.

The mix ratio was approximately 2 parts mine spoil to 1 part organic-silt soil. Mixing was performed by the earthmoving equipment during material placement on the fabric-covered membrane. Care was taken not to operate equipment directly on the covered membrane. Cover materials were placed in lifts, with the initial 1 ft lift being mine spoil, and subsequent 6 in. lifts being mine spoil and organic silts. The placed cover layer was disced and sacrificed to complete mixing prior to hydroseeding of the lime, fertilizer, and soil-legume seed mix.

## COSTS

The total cost for placement of the impermeable cover over 26 acres was approximately \$2,030,000 (1981 costs). This converts to \$78,077/acre or approximately \$1.80/ft<sup>2</sup>.

This cost included the following items:

- Mobilization and site preparation
- Clearing and grubbing
- Sedimentation basins
- Excavation and fill
- Storm water drainage channels
- Underdrain
- PVC membrane and geotextile fabric
- Vegetation and mulch
- Supervision, field engineering, and general labor

## POST CLOSURE MONITORING

It is too early to determine the effect, if any, of the low-permeability cover on groundwater quality. Post-closure monitoring will include sampling of 11 surface water locations (seepage points and streams) and 10 monitoring wells. Samples are being analyzed for:

pH	Chloride
Free cyanide	Fluoride
Ammonia Nitrogen	Aluminum
Nitrate Nitrogen	Cadmium
Nitrite Nitrogen	Calcium
Phenols	Total Iron
Specific conductance	Manganese
Total dissolved solids	Lead
Hexavalent Chromium	Nickel
Mercury	Sodium
Zinc	Potassium

Sampling occurs on a monthly basis and is routinely reported to PADER. An on-going evaluation is underway to determine the long-term effectiveness of the cover.

# POLLUTION MIGRATION CUT-OFF USING SLURRY TRENCH CONSTRUCTION

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## INTRODUCTION

Over the last two decades, cut-off walls emplaced by slurry trenching have been installed at many solid and hazardous waste facilities. This paper presents the interim results of a project for USEPA's Office of Research and Development to develop a technical handbook on the use of slurry trenching techniques to control pollution migration.

Slurry trenching is a method by which a continuous trench is excavated (by backhoe or clam-shell grab) under a slurry of bentonite and water. This slurry, or more correctly, colloidal suspension, supports the trench walls and allows excavation to great depths with no other means of support. Once a trench has been excavated under slurry to the required depth and length, it is back-filled to form a continuous, nearly impermeable barrier, or cut-off wall, to groundwater flow.

In some cases, the slurry is a mixture of water, cement, and bentonite which hardens in place to form the final barrier. In other instances, this trenching technique is used to place soil-bentonite cut-off walls, where the backfill is composed of the excavated soil with small amounts (1 to 4%) of bentonite added.

In some instances, borrowed soil materials, such as additional fines, or gravel may have to be added to meet the requirements of lower permeability or higher strength. Another variation of this technique, seldom used for pollution migration control, is the use of pre-cast or cast-in-place concrete diaphragm walls, which are installed when both pollution migration cut-off and structural support are required.

## History

The use of bentonite slurries in trench excavation is an outgrowth of their use as drilling muds in petroleum exploration. In the late 1920s it was found that bentonite slurries aided drilling by lubricating the bit, removing the rock cuttings, and sealing the sides of the hole.<sup>1,2</sup> This use is reflected in the current bentonite classification system developed by the American Petroleum Institute (API). Under the API system, bentonites are rated by the number of barrels of drilling mud (of a given viscosity) that are obtainable from one ton to bentonite.

In Europe during the 1930s, it was found that borings and trenches can be kept open using these slurries and that the technique is well suited for use in restricted work areas and excavations in unstable materials.<sup>3</sup> The use of slurry walls for pollution cut-off began during the early 1970s and to date, many have been installed in the U.S.<sup>4</sup> Some typical wall installations for pollution control are listed in Table 1. Nonetheless, there are less than a dozen firms experienced with the construction technique, and only a few of those appear qualified to install slurry walls for pollution migration cut-off.

## SLURRY MATERIALS AND FUNCTION

The material used in the trenching slurry is a commercially available product called bentonite, sodium bentonite, or Wyoming bentonite. Bentonite is considered by many to be a clay but is, in fact, a rock composed mostly of the clay mineral montmorillonite, with smaller amounts of other clays and various metallic oxides. Montmorillonite crystals contain negative charges which attract and adsorb cations. In most bentonites, the montmorillonite is saturated with calcium ions; however, the products which are used for slurries and drilling muds are the Wyoming bentonites which contain more of the sodium saturated variety. This sodium bentonite is generally highly colloidal and plastic, and has the ability to swell many times its volume and to form thixotropic gels in water.<sup>2</sup>

Many commercially available bentonite products are highly modified by the addition of polymers, peptizers or other chemicals. This practice has been adopted in order to increase the API yield value of lower grade bentonite deposits, and in the case of polymer extended products, to increase piping resistance in liners. The remainder of this discussion assumes the use of "unaltered" high grade (i.e., high sodium montmorillonite content) bentonite.

The slurry used in trenching is composed of clean water mixed with from 5% to 7% bentonite by weight.<sup>5</sup> Clean water is used to

Table 1.  
Example Slurry Walls Installed for Pollution Control.

LOCATION	WALL COMPOSITION	SIZE* 1000 ft <sup>2</sup>	COST (\$/ft <sup>2</sup> )	POLLUTANT CONTAINED	STATUS
Indiana	Soil-Bentonite	500	3	Inorganics Ash Disposal	On-going
Illinois	Soil-Bentonite	13.5	4	Methane Gas	Completed
Louisiana	Soil-Bentonite	30	2.5	Ethylene Dichloride	Completed
Pennsylvania	Cement-Bentonite	1	2	PCB Oils	Completed
New York	Cement-Bentonite	77.3	5.5	Jet Fuels	Completed
New Hampshire	Soil-Bentonite	204	5	Mixed Organics	On-going
Wisconsin	Soil-Bentonite	98.4	2.8	Solid Waste Landfill Leachate	Completed
New Jersey	Soil-Bentonite	10	6	Phenols	Completed
Saskatchewan	Soil-Bentonite	53.4	4	Uranium Mill Tailings	Completed
Florida	Soil-Bentonite	58	2.6	Methane Gas Landfill Leachate	Completed
Ohio	Both Soil- & Cement Bentonite	25	10	Acid Mine Drainage	Completed
Florida	Cement-Bentonite	10	4	Radioactive Kerosene	Completed

\*These walls range from 2 to 4 ft in width & 15 to 100 ft in depth.

avoid chemical interactions which could hinder the performance of the slurry. When introduced into the trench, the slurry should be fully hydrated with an "apparent viscosity" of from 15 to 20 cp and a density of from 64 to 94 lb/ft<sup>3</sup><sup>6,7</sup> (1030 to 1500 kg/m<sup>3</sup>).

As stated earlier, the primary role of the slurry is to keep the trench open during excavation. A number of mechanisms have been suggested for trench support, including hydrostatic force exerted by the slurry, formation of a filter cake on the trench sides, and compaction of the earth on either side of the trench during excavation.<sup>8</sup> Of these three, the first two are the most important and are closely related.<sup>8,9</sup>

In order for the force exerted by the weight of the slurry to support the trench, the force must be exerted on the soil grains and not just on the soil pore fluids. The formation of a low permeability filter cake on the trench sides, caused by water loss from the slurry into the ground, eventually seals off the soil pores, allowing the hydrostatic force of the slurry to be transferred more directly to the sides. Filter cake formation a function of clay type, clay concentration in the slurry, and formation and pressure. Permeabilities of filter cakes have been measured as low as  $2.3 \times 10^{-8}$  cm/sec.<sup>5,9</sup> Additional trench support can be expected by the plastering effect of the filter cake holding the soil grains together, and by gelation of the slurry in the soil pores into which it infiltrates.<sup>8</sup> The contribution of the filter cake to the final cut-off wall is examined later in this paper.

### BACKFILL MATERIALS AND FUNCTION

As noted earlier, there are three major types of slurry trench backfill: soil-bentonite, cement-bentonite, and concrete. The choice of backfill is dependent on specific site characteristics and the requirements of the completed cut-off wall. Each of these is discussed below.

#### Soil-Bentonite Cut-Off Walls

Soil-bentonite (SB) cut-off walls are often backfilled using the soil materials excavated from the trench. These soils, or soils with more favorable properties borrowed from another source, are mixed with small amounts of slurry from the trench until they are a homogenous paste. The recommended consistency for the backfill is a mixture that will stand on a 10:1 slope (as measured by slump cone) with a water content of 25% to 35%. The minimum amount of bentonite in the backfill mixture will range from 0.5% to 2% depending on the initial water content of the excavated soil.<sup>5</sup>

The permeability of the backfill is very much dependent on the gradation of the soil used, as well as on the bentonite content and initial backfill water content. The lowest permeabilities are obtainable when the backfill is well graded and contains an appreciable amount of (i.e., 10-20% or more) of fines (particles passing a 200 mesh sieve) and especially plastic fines.<sup>5</sup> The extent to which

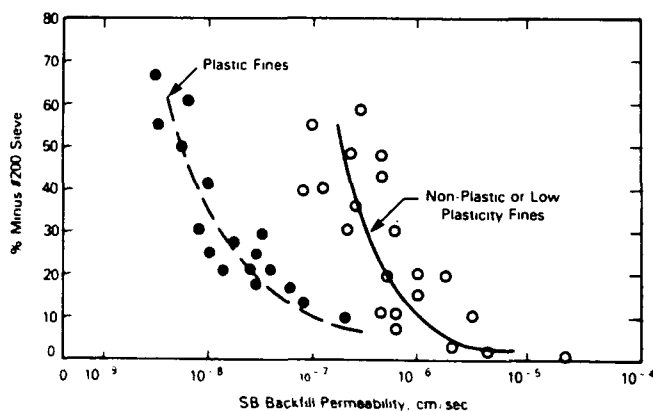


Figure 1.  
Permeability of Soil-Bentonite Backfill  
Related to Fines Content  
(After D'Appolonia and Ryan 1979)

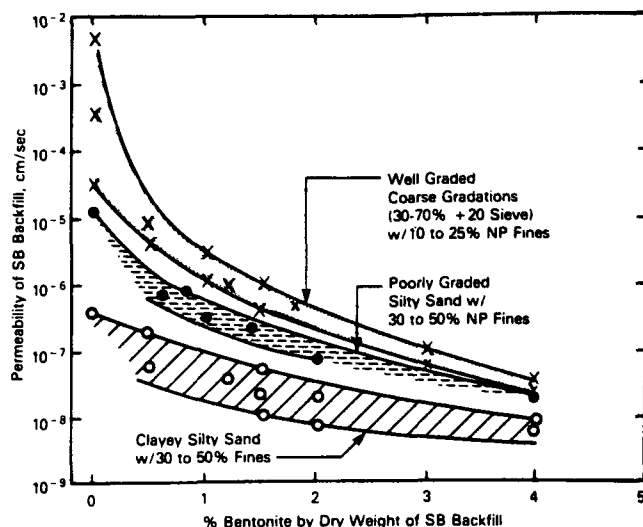


Figure 2.  
Relationship Between Permeability and  
Quantity of Bentonite Added to SB Backfill

(After D'Appolonia and Ryan 1979)

fines and plastic fines can affect backfill permeability is shown in Fig. 1 while the contribution of added bentonite to the permeability of the backfill is shown in Fig. 2.

In cases where the excavated soils are not well suited for backfill, borrowed soils may have to be added to meet the design criteria. For example, if low compressibility is called for in the design, and the trench materials lack coarser particles, additional sand and gravel may be needed. If low permeability is of greater concern

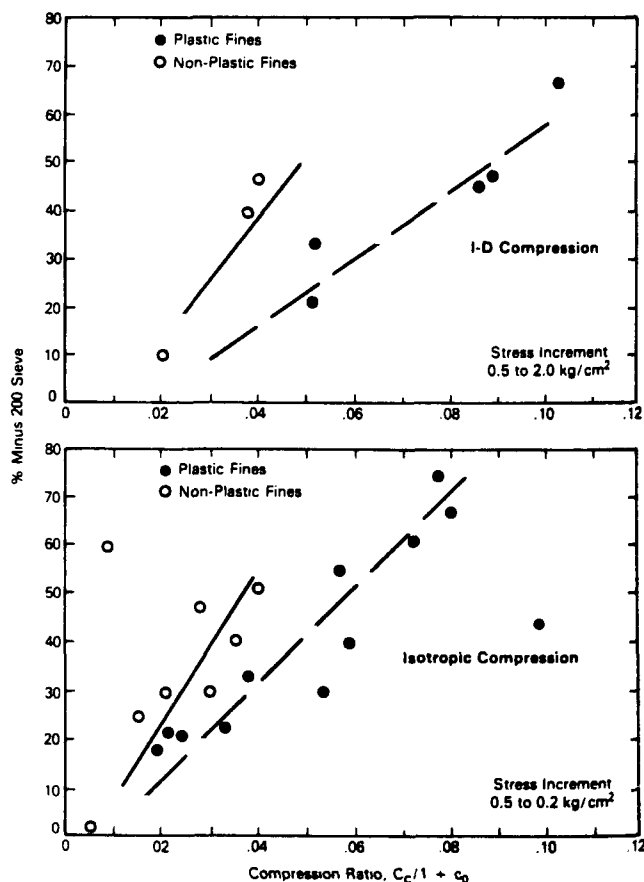


Figure 3.  
Compressibility of SB Backfill  
Related to Fines Content of Mix  
(After D'Appolonia, 1980)

than low compressibility, addition of borrowed coarser materials would be unnecessary. If fines are lacking in the trench soils, and low permeability backfill ( $\leq 1 \times 10^{-7}$  cm/sec) is called for, borrowed material could be required. Bentonite can make up only a portion of the plastic fines in the backfill mixture due to its high compressibility. In brief, gradation of the backfill is a trade off between permeability and compressibility as illustrated in Figs. 1 and 3.

The permeability of the final wall is a function of both the filter cake permeability and the backfill permeability. Because the backfill is less permeable than the surrounding soil it is possible that the downgradient filter cake is forced into the soil matrix under the hydraulic gradient across the wall. This gradient would act to force the upgradient filter cake into the backfill, but given proper backfill gradation (i.e., sufficient fines) it would remain intact.<sup>5</sup>

The relative contribution of the backfill and one filter cake to the final wall permeability is illustrated in Fig. 4. This figure also shows that the contribution of the filter cake is greater for more permeable backfill and vice versa. It also illustrates that, even with very permeable backfill, the maximum permeability of a SB cut-off wall will be on the order of  $1 \times 10^{-6}$  cm/sec due to the contribution of the filter cake.

### Cement-Bentonite Cut-Off Walls

Cement-bentonite (CB) cut-off walls are of two major types: (1) self hardening slurries, which both support the trench and are

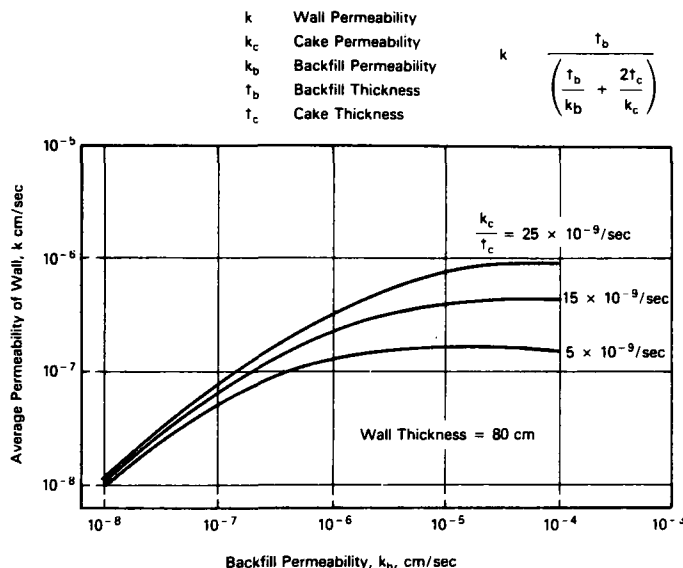


Figure 4.

Theoretical Relationship Between Wall Permeability and Permeability of the Filter Cake and Backfill

(After D'Appolonia and Ryan 1979)

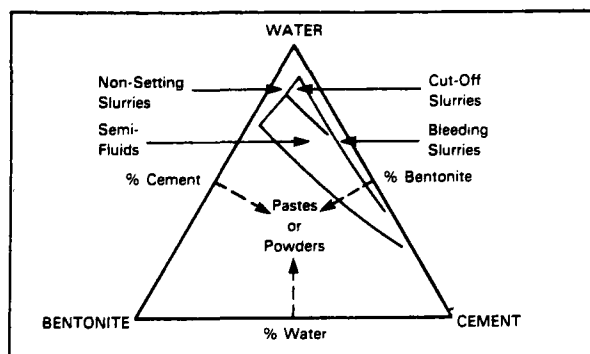


Figure 5.

Cement-Bentonite Slurry Compositions

(After Jefferis, 1981)

allowed to harden in-place, and (2) replacement slurries which are introduced into the trench following excavation using a bentonite-water slurry for trench support. Replacement slurries are used in very deep excavations or with time consuming rock key-ins where a normal CB slurry would thicken or set before excavation was complete. The self hardening slurries considered here are used in relatively shallow trenches ( $< 22$ m) where their rapid set would not interfere with excavation.

Typically, a CB slurry contains from 4 to 7% (by weight) bentonite, from 8 to 25% type I Portland Cement, and from 68 to 88% water.<sup>10</sup>

If too much bentonite and cement are used, the slurry may be too thick to work with. If too little cement is used, no set will be achieved; and if too little (or poor quality) bentonite is used, the cement will settle out of the slurry, causing excessive water bleeding. Typical CB slurry compositions are shown in Fig. 5. The actual composition of the slurry must be determined as part of the design phase.

At the time the CB slurry is introduced into the trench, it typically has a density of about  $1100 \text{ kg/m}^3$  and a Marsh viscosity ranging from 30 to 50 sec.<sup>10,15</sup> After excavation, but before set it can have densities of around  $1250 \text{ kg/m}^3$  and will be too viscous to pass a Marsh funnel.<sup>10</sup>

Filter cakes formed by CB slurries do not have the same properties as bentonite slurries, yet still serve to support the excavation. A CB filter cake can have a permeability orders of magnitude higher than bentonite (i.e.,  $1\text{--}4 \times 10^{-7}$  cm/sec), and filtrate losses around 20 times as large.<sup>10</sup> This condition is due to the calcium in the cement causing flocculation and aggregation of the bentonite. Excessive filter loss can cause problems with the excavation by thickening the slurry (by dewatering through filter loss) and by lowering the level of slurry in the trench.

Set times for the slurry can be controlled to some extent by controlling the amount of cement and through addition of additives. Rapid set times, however, are more easily achieved than retarded set times. The additives used most successfully are ground blast furnace slag and fly ash which replace a portion of the cement in the mixture. Slag has been shown to reduce cut-off permeability, bleed water, slurry shear strength, and set time. Fly ash can aid in resistance to chemical attack and can increase set time and bleed resistance.<sup>10</sup> Another method used to reduce bleed water from the curing slurry is to ensure that the slurry is mixed in a high shear mixer starting with a fully hydrated bentonite slurry.<sup>10</sup>

Self hardening (CB) slurries can offer a number of advantages in wall construction. This method is well suited for situations where the trenched material is unsuited for use as backfill or where there is insufficient area for SB backfill mixing. Also, because the slurry hardens in place, the wall can be built in sections or panels (by excavating a tie-in between completed sections). This method allows for more flexible construction schedules, and can be used in more extreme topography.<sup>11</sup> Some disadvantages of this method include the need for a greater amount of more expensive slurry, a relatively higher permeability than SB walls, less resistance to chemical attack, and in contaminated environments, the need to dispose of contaminated trench spoils.<sup>11</sup>

### Diaphragm Walls

Diaphragm walls are constructed of pre-cast or cast-in-place concrete panels using slurry trenching techniques, and are used in situations requiring great strength and relatively low permeability (Fig. 6). These are constructed by excavating a short, slurry supported trench section, using a clam-shell bucket. Upon completion of excavation, the trench section is filled with a pre-cast, reinforced concrete panel or tremied concrete around a reinforcement cage. Alternate or primary panels are installed first followed by the secondary panels. Joints between panels are formed using stop end tubes that are concreted after adjacent panels are complete.<sup>12</sup>

Another method involves using a CB slurry as the excavation fluid. The CB slurry, when set, forms the joint between panels.<sup>10</sup> Diaphragm walls can be expected to function much the same as

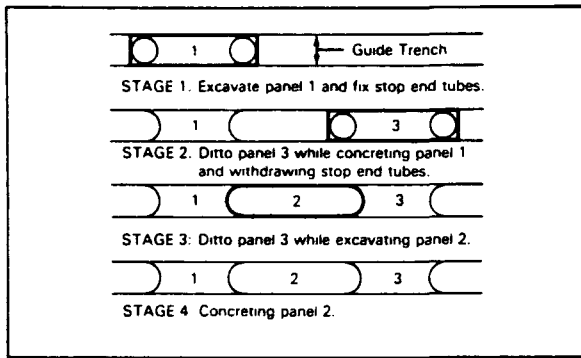


Figure 6.  
Typical Sequence Used in Construction of  
Diaphragm Walls (After Nash, 1974)

CB walls with respect to permeability and chemical resistance provided that the joints are sound. Since they are seldom used for pollution migration control, they are not considered further here.

### COMPATIBILITY

The presence of organic or inorganic compounds in the groundwater can have a detrimental effect on the bentonite slurry used during wall construction as well as the ability of the finished wall to contain pollutants. These chemicals can affect the physical/chemical properties of the bentonite and the backfill material, and can lead to failure of the wall either during construction or during its operational lifetime. Thus, before a slurry wall is considered as an appropriate remedial response, the effects of the leachate on the bentonite slurry and the finished wall must be determined. This testing procedure will provide the information that is necessary to properly select the grade of bentonite and the type of backfill material that should be used in the slurry wall construction.

Chemicals can affect the physical and chemical properties of the bentonite and backfill material, leading to:

- Flocculation of the slurry
- Reduction of the bentonite's swelling capacity
- Structural damage to the bentonite or backfill material

In general, flocculation of the bentonite slurry can be caused by chemicals, such as electrolytes and metals, that reduce the natural repulsive forces between the hydrated clay particles. From a practical standpoint, the exact mechanisms are unimportant. However, if the slurry in the trench flocculates, due to chemicals in the make-up water or the soil, it can lose its ability to support the trench, leading to collapse.<sup>13</sup> This problem can be avoided by adequate site investigation and testing.

Numerous organic and inorganic compounds can, through a variety of mechanisms, cause bentonite clay particles to shrink or swell. All of these mechanisms affect the quantity of water contained within the interspatial layers of the clay structure. Many chemicals can reduce the double layer of partially bound water surrounding the hydrated bentonite, thus reducing the effective size of the clay particles.<sup>14,15</sup> This effect can increase the permeability of the backfill. Proper testing and backfill composition, however, can prevent reduced swelling from having a detrimental effect on the final cut-off.<sup>14</sup>

Strong organic and inorganic acids and bases can dissolve or alter the bentonite or soil in the backfill material, leading to large permeability increases.<sup>14</sup> Aluminum and silica, two of the major components of bentonite, are readily dissolved by strong acids or bases, respectively. For example, when four types of clay were exposed to acetic acid, significant soil piping occurred due to the soil components being dissolved by the acid.<sup>16</sup> This condition leads to a significant increase in permeability in all of the clay types. Destruction of the proposed backfill mixture would be revealed during testing and could eliminate certain backfills from consideration.

Compatibility testing is done using actual site leachate or groundwater and the proposed slurry and backfill. The tests are not all

standardized or applied throughout the industry. In general, the tests include:

- Apparent slurry viscosity
- Filter press test
- Permeability

Viscosity testing indicates the ability or inability of the slurry to form a thixotropic gel in the presence of the contaminants. The filter press test gives a quick indication of the ability of the slurry to form a filter cake in a contaminated trench. Together, these tests can tell the design engineer whether problems with trench support might occur.

Permeameter tests of the proposed backfill mixture, using the site leachate as the permeant, are essential in determining the expected cut-off effectiveness. Following wall installation, permeability testing of actual backfill can be used to see if the design permeability was achieved. Care must be taken in collection of the leachate to ensure that the samples used in the tests are representative of the site conditions.

### SLURRY WALL APPLICATIONS

Slurry walls have been, and are being, applied to a variety of waste site situations. The composition, dimensions, and placement of the walls are, of course, designed on a site specific basis. As noted above, wall composition is dependent on a number of factors including site lay-out, site chemistry and strength requirements.

The dimensions of a slurry wall are essential design parameters, especially for depth and length. Wall width is largely a function of the excavation equipment used, and generally ranges from 0.6 to 1.6 m.<sup>14</sup> The depth of the wall is most dependent on the behavior of the contaminants and the site stratigraphy. In most situations, it is necessary to key the wall into a low permeability underlying strata (aquiclude) such as bedrock or a clay layer. In some cases, as with floating contaminants such as petroleum products, a so-called "hanging wall" can be used. Hanging walls are not keyed into an aquiclude but are placed only deep enough to intercept the top several meters of the water table, thereby allowing capture of floating contaminants.<sup>17</sup>

The length and shape (placement) of a slurry wall are largely dependent on the location of the pollution source and any resultant contamination plume, as well as the intended role of the wall. In general, a wall can be placed surrounding a source, or upgradient or downgradient from the source with respect to groundwater flow.

Upgradient placement can divert groundwater flow around a pollution source, thereby protecting that groundwater from contamination and reducing the amount and rate of leachate generation (Fig. 7). Care must be taken in the design to ensure that groundwater does not flow around the wall ends or rise to overtop the wall.

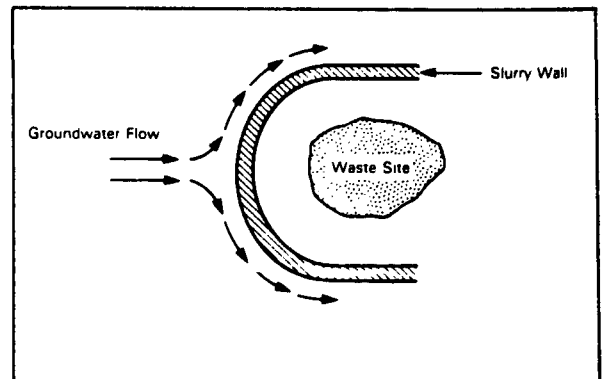


Figure 7.  
Upgradient Wall Placement

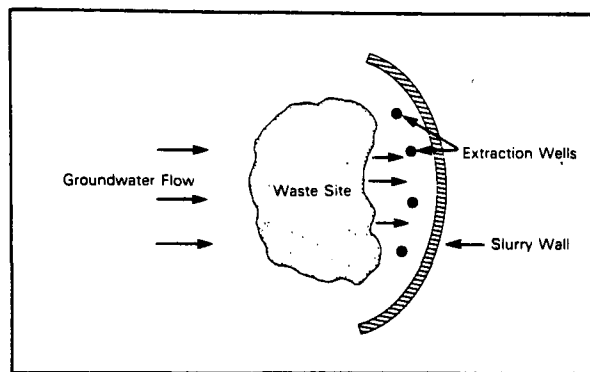


Figure 8.  
Downgradient Wall Placement

Downgradient placement, shown in fig. 8, can be used in situations where the amount of flow into a source is very low. In this practice, the slurry wall serves to capture the contamination plume so that it can be collected (by wells or drains) and treated. Care must be taken to ensure that contaminated water does not have a destructive effect on the wall (or is kept from contact with it), and that the contamination does not over top the wall.

Circumferential wall placement is employed in situations where most complete containment is desired. As shown in Fig. 9, the wall surrounds the source and prevents migration into and out of the site. Again, care must be taken to prevent wall destruction by thorough compatibility testing and/or by preventing contaminant-wall contact.

Slurry walls are rarely, however, the sole type of engineered remedial measure. Most often, additional measures such as extraction wells, leachate collectors, and surface seals are used in conjunction with slurry walls as part of the total remedial effort.

#### Site Characterization

In order to design and install a successful slurry wall, extensive site characterization, especially with respect to subsurface conditions, is necessary. Site investigations for construction projects are frequently accomplished in two phases, a preliminary phase, and a design phase. A preliminary investigation will reveal many of the physical constraints that would affect slurry trenching operations. Among the most important considerations are:

- Topographic restrictions
- Buried or overhead obstructions
- Equipment access
- Sufficient work area

These factors, and their interrelationships must be identified and considered very early in the design phase. Additional, general information will be collected on the subsurface conditions, which will allow the design engineer to select the most likely construction method(s).

The in-depth or design phase investigation will be more involved and more narrowly focused, centering on developing design parameters. For slurry walls, the principal focus will be on complete geologic and geohydrologic and, in some cases, geophysical characterization of the site. This is accomplished through a series of soil borings, initially general in nature and becoming more detailed as variability and anomalies are assessed. Among the most important parameters produced by this investigation are:

- Soil distribution and nature
- Aquifer geometry and gradients
- Groundwater and leachate chemistry

The accuracy and completeness of the design phase investigations are of prime importance to the success of a slurry wall project and should never be underestimated. Thorough site characterization

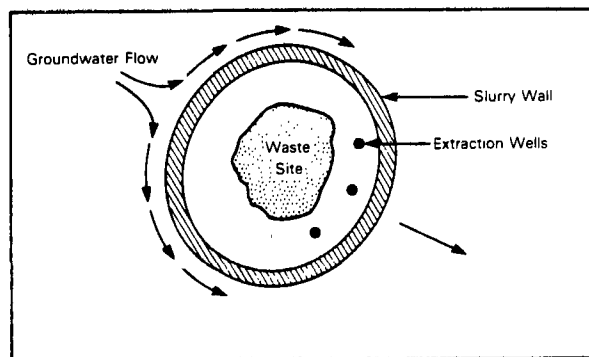


Figure 9.  
Circumferential Wall Placement

can allow problems to be anticipated and planned for before they become detrimental to the project.

#### SLURRY WALL CONSTRUCTION

The first phase of slurry wall construction is to prepare the site for work. This will vary considerably in nature and extent from site to site, but will involve such tasks as leveling the trench line, locating and/or moving overhead and underground obstructions, identifying storage areas and haul routes, and constructing impoundments for slurry hydration and storage. In cases where groundwater is very near the surface, a construction platform is often built along the trench so that the slurry can be kept well above the water table. Extra care in site preparation can help maintain construction schedules by identifying problems and planning for their resolution.

Excavation of the trench is accomplished using either a hydraulic backhoe or a cable or Kelly Bar mounted clam-shell grab. Backhoes are usually used for depths less than 16m; however, in recent years, modified or "extended stick" backhoes have reached 73 ft. Below these depths, clam-shell grabs have successfully installed walls over 94m.<sup>17</sup> If a linear wall is being installed, backfilling can begin as soon as excavation has reached the point beyond the calculated backfill slope (Fig. 10). For a continuous, circumferential wall, however, the entire trench is often excavated before backfilling is begun.

Slurry is usually prepared on the site as close as practical to the trench. The bentonite is weighed and mixed with water in a high shear mixer. From the mixer, it is pumped to a pond to hydrate fully under circulation. The hydration time is a function of bentonite quality, mixer shear, and pond circulation, and can vary considerably. From the hydration pond, the slurry is usually pumped to a storage pond before introduction into the trench. This procedure allows new slurry to be mixed and hydrated and provides a reserve supply of slurry in case the slurry level in the trench should drop suddenly when an unexpected previous zone is encountered.

All slurry trenching operations are accompanied by a simple mobile laboratory for testing new bentonite shipments, and for testing the slurry at various times during construction. The slurry is generally tested for viscosity (Marsh), density (mud balance), sand content, and pH. In many cases, filter loss and gel strength are also measures. The testing of the slurry is usually done after mixing, as it is introduced into the trench, and again as backfill is placed (a sample is taken from the trench bottom near the leading edge of the backfill). If the slurry in the trench is found to be too dense, additional new slurry is added to bring it back within specifications.

Backfill for a SB wall is usually mixed alongside the trench using a bulldozer. If additional soil or dry bentonite is needed it is spread evenly over the trench spoils and tracked and bladed with the bulldozer. During the mixing, slurry from the trench is added to the backfill mixture to form a homogenous, plastic paste. When the backfill has reached the specific composition and consistency, it is ready to be placed in the trench.





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# GELATINOUS SOIL BARRIER FOR REDUCING CONTAMINANT EMISSIONS AT WASTE DISPOSAL SITES

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## INTRODUCTION

The disposal of hazardous wastes, such as sanitary landfill leachate, chemical waste, or radioactive waste, is an increasing problem. Current practices call for waste disposal in earthen pits or repositories. However, these waste contaminants may eventually migrate so that potentially hazardous elements could be transported to the biosphere. Thus, reducing the transport of chemicals from waste disposal sites poses an immediate challenge.

Under sponsorship of the Department of Energy's Uranium Mill Tailings Remedial Action Program (UMTRAP), Pacific Northwest Laboratories (PNL) has investigated the use of engineered barriers for use as liners and covers for waste containment. A comparison of clay-soil mixtures and a gelatinous soil additive was performed to evaluate their use as a cover in reducing the escape of radioactive radon gas from abandoned uranium mill tailings piles. In addition, permeability measurements were performed to examine and compare the ability of gelatinous materials to reduce leachate movement and the migration of contaminants such as trace or heavy metals. The results of these studies led to the development of a low permeable, multilayer earthen barrier for effectively reducing contaminant emissions from waste disposal sites.

## COVER SCHEME

Every potential application of the gelatinous-soil material depends on site-specific conditions, such as the type of waste, remedial action requirements, and climatic conditions. However, using thinner but better engineered cover schemes (Fig. 1) can reduce the material costs that would be required to meet or exceed the expectations of currently proposed waste control strategies (i.e., 3 m or more thick).

The system consists of a capillary barrier and topsoil or overburden layer overlying the gel-soil mix barrier. The capillary barrier is comprised of a layer of crushed rock (minimum conditions) and

is used to isolate the moist gelatinous-soil barrier layer from a drier topsoil or overburden layer. By isolating the two layers, "wicking" from a moist layer to a dry layer is prevented, helping to maintain the moisture content of the gelatinous-soil layer. In areas with high rainfall, the capillary barrier may not be needed if the moisture content of the overburden layer is high enough to prevent wicking.

The topsoil or overburden layer is added: (1) for revegetative purposes, and (2) to prevent freezing and subsequent thawing of the gel-soil barrier layer. With selective revegetative efforts, control of the infiltration of moisture through the topsoil layer will be enhanced by evapotranspiration. Depending on the location of the waste site, the topsoil layer would be thick enough to ensure that the gelatinous-soil barrier is below the frost line of the area. This would eliminate the possibility of cracking due to freezing and thawing of the moist barrier layer.

Several factors control the movement of gases and/or liquids through porous geologic media: total porosity, air-filled porosity, moisture retention, bulk density, permeability (hydraulic conductivity) and gelatinous precipitants. For example, the total porosity of the gel cover ranges from 20 to 30%, as compared to 40% for clay. This reduction decreases the total amount of void space within the confining layer of the cover material available for gas or liquid movement. Similarly, the air-filled porosity of the gelatinous soil layer is near zero, limiting the space available for gas or liquid transport. In addition, the hygroscopic constituents within the gel cover layer retain moisture even at very high capillary pressures, thus assuring low gas transport even under relatively dry conditions.

Bulk densities greater than 2.1 g/cm<sup>3</sup> have been achieved in the field using standard road construction equipment to compact the gel layer. These density values increase structural stability and longevity. Gel-soil layer columns tested in the laboratory had permeabilities on the order of 10<sup>-8</sup> cm/sec with distilled water, thus allowing even lower flow rates than recommended by USEPA (less than 5 x 10<sup>-7</sup> cm/sec).

## RADON GAS ATTENUATION STUDY

During the normal operation of a uranium mine thousands of tons of uranium containing ore are processed daily. The extraction process, which is specific for the removal of uranium, does not alter the concentrations of the radioactive uranium daughter products which have come to equilibrium over many thousands of years. During the life of the mill, the concentration of these daughter products is constantly increasing as more and more of the spent feed material containing the members of uranium's decay chain are being expelled to the mill tailings disposal site.

Eventually, the concentration of the daughter products in the mill tailings is many times greater than the normal concentrations found in nature. As a result, the uranium mill tailings themselves could remain radioactive indefinitely due to the long lived uranium decay products such as <sup>230</sup>Th (half-life of 80,000 yr) and <sup>226</sup>Ra (half-life of 1,620 yr). Neither one of these isotopes is significantly

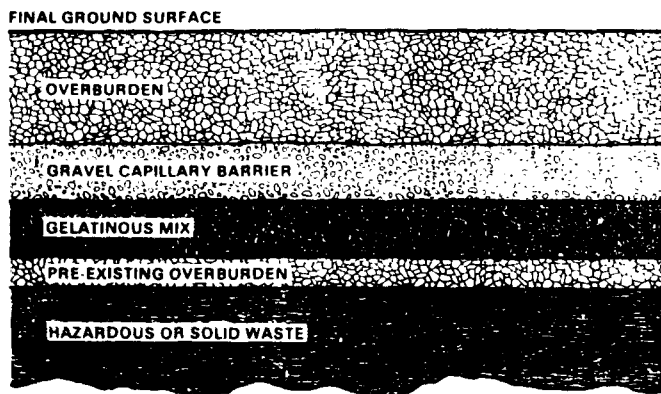


Figure 1.  
Multilayer Cover Scheme

removed during the uranium extraction process; in fact, greater than 90% of the radium content originally present in the ore goes to the uranium mill tailings. The  $^{238}\text{U}$  decay chain with the corresponding half lives and emissions down to stable  $^{206}\text{Pb}$  is shown in Fig. 2.

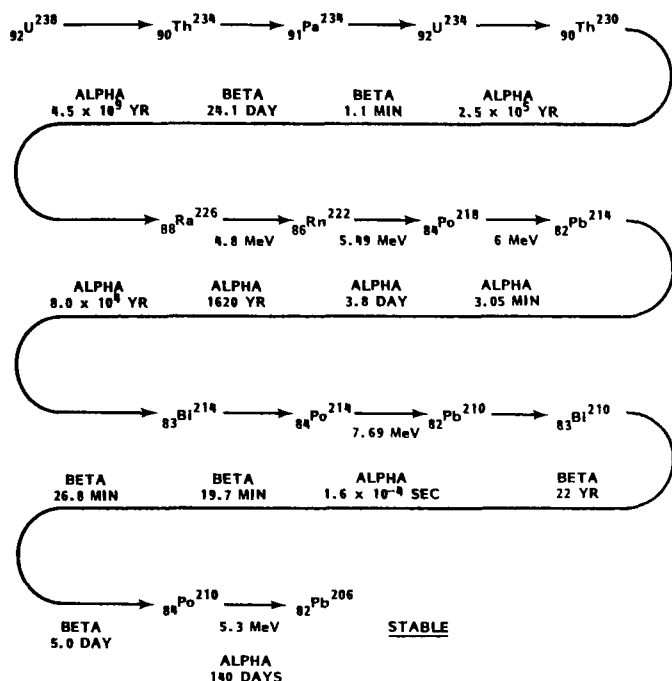


Figure 2.  
Uranium Decay Chain

Radium in trace amounts is found in all soils and water. Since there is such a high residual  $^{226}\text{Ra}$  content in the tailings, on the order of several hundred times the average background concentration, one of the major consequences associated with uranium mill tailings is the tailings pile acting as a source for the evolution of radioactive  $^{222}\text{Rn}$  gas.

Radon poses a serious environmental and health impact to populations acting as a source of radiation exposure. The immediate radioactive decay product of radon,  $^{218}\text{Po}$ , is a solid which can adhere to soil or aerosol particles. Upon inhalation these particles can remain lodged in the lungs and may be linked to pulmonary disorders or lung and respiratory cancer.

Realizing the health impacts of radiation exposure from uranium mill tailings piles, interim performance guidelines for management of uranium tailings were established by NRC in May of 1977. One of the performance objectives for post reclamation of a tailings disposal site was to reduce the radon flux from the tailings to about twice the flux in the surrounding environment. The current standard proposed by the USEPA will allow a tailings radon flux of not higher than 20 pCi/m<sup>2</sup>/sec. Therefore, the reduction and control of radon gas emission from a uranium mill tailings disposal site is an area of major concern in the mining and milling section of the nuclear industry.

Currently, general practice calls for earthen or other cover materials to control radon gas emissions. Much of the emphasis has been on earthen covers of the order of three or more meters thick to reduce emissions below the proposed 20 pCi/m<sup>2</sup>/sec standard set by the USEPA. Many of these proposed strategies for containing gases (i.e., synthetic covers, deep lake disposal, or thick earthen covers up to 10 m thick) have been either too expensive or difficult to install or lacking in long term stability.

The thinner covers offer the potential for significant savings in remedial actions with the possibility of improved long term radon control. However, the development and use of thinner engineered covers requires a better and more complete analysis capability.

Field tests of multilayer earthen covers for radon control have been conducted for the past 2 years at Grand Junction, Colorado. The initial tests conducted in 1980 used relatively thin (less than 20 cm) compacted layers of clay mixed with gravel to limit radon escape from tailings piles. Results indicated that compacted clay/gravel layers have been relatively effective in reducing radon fluxes (greater than 98% effective) but during the first year flux levels at all monitoring points were observed to exceed the USEPA limit then of 2 pCi m<sup>-2</sup> sec<sup>-1</sup>.

The 1981 field test was designed to test multilayer earthen systems that could reduce surface radon fluxes to less than 2 pCi m<sup>-2</sup> sec<sup>-1</sup>. The materials used were bentonite clay/gravel, bentonite/lime/gravel, and alum/lime/gravel mixes which were separately incorporated into the multilayer scheme shown in Fig. 1.

### Initial Radon Flux Measurements

Radon flux measurements were made using the aluminum tent system described by Hartley *et al.*<sup>10</sup> A pressure balanced system circulates air over the tailings surface and the radon is swept into an activated charcoal collector.

Tests were run to determine the effectiveness of activated charcoal as a radon trap at ambient temperatures. The results of those tests showed that using 400 g of an activated charcoal at a flow rate of 2 l/min through a 4.75 cm diameter convoluted steel tube, the activated charcoal was greater than 99.9% efficient in collecting radon at temperatures up to 50°C. Therefore, a radon measurement system was designed around a 2 l/min flow rate with 400 g of activated charcoal at ambient temperature (approximately 27°C).

The field radon measurements consisted of measuring the radon flux both before and after the multilayer barrier system was applied to the test area and consisted of the following steps:

- The tent was placed in the predetermined test spot and sealed to the surface by packing tailings or overburden around the edge of the lip of the tent dependent on whether pre- or post-application measurements were being made.
- The flow rate was adjusted to 2 l/min and the radon flux measurement was taken for 4 hr from the time the flow starts through the activated charcoal radon trap.
- After the measurement was taken, the activated charcoal was placed in 2.5 cm x 15 cm diameter petri dishes and subsequently counted using an intrinsic germanium diode or NaI detector and a multichannel analyzer. The count rate from the 609 Kev peak of Bi-214 was used in calculating the radon flux (J). The equation used was:

$$J \text{ (pCi m}^{-2} \text{ s}^{-1}) = \left( \frac{10^4}{3.7 \text{ E A}} \right) C \left( \frac{1}{1 - e^{-\lambda t_1}} \right) \left( \frac{1}{e^{-\lambda(t_2 - t_1)} - e^{-\lambda(t_3 - t_1)}} \right) \quad (1)$$

where

- E = counting efficiency of detector, count/disintegration
- A = cross sectional area of tent (cm<sup>2</sup>)
- C = net count rate of Bi-214 peak
- $\gamma$  = radon decay constant,  $2.09 \times 10^{-6}$  (sec<sup>-1</sup>)
- $t_1$  = exposure time
- $t_2$  = time from initial exposure to start of count
- $t_3$  = time from initial exposure to end of count

### Material Preparation

Several clay/gravel and gelatinous soil/gravel mixes were tested in 1981. The materials were loaded into a portable Calenco model 30 TP 14H pugmill rated at 300 t/hr which proportioned and mixed the radon barrier materials. The composition of the radon barriers are given in Table 1. Depending on the barrier materials being mixed, i.e., bentonite or the gelatinous mix, either water or aluminum sulfate (Alum) solution was required.

### Cover Application

Upon completion of the barrier materials mixing and stockpiling, a 11 m<sup>3</sup> paddle-wheel scraper self-loaded the material and transported it to the test plot. The scraper applied the material in

**Table 1.**  
**Gelatinous and Clay Mixtures Used as Radon Control Layers**  
**at the 1981 Grand Junction Field Test**

Plot	Material	Wt % (dry)
15 cm thick Gelatinous	1.9 cm minus roadbase	74.4
	topsoil	13.1
	lime	4.3
	alum	8.1
40 cm thick	1.9 cm minus roadbase	86
	bentonite (CS-50)*	12
	lime	2
30 cm thick	1.9 cm minus roadbase	88
	bentonite (CS-50)*	12

\* American Colloid, Skokie, IL.

layers ranging from 7 cm to 15 cm. Following application of each lift a Bomag model BW 210 PD vibratory tamping foot compactor made several passes to blend the added moisture and compact the barrier materials. A Bomag model BW 220A smooth drum compactor completed the compaction process.

The final compacted barrier thicknesses were: 15 cm for the gelatinous material, 30 cm for the bentonite/gravel mix and 40 cm for the bentonite/lime/gravel mix. Average compaction densities for the barriers were 1.96 g/cm<sup>3</sup> for the gelatinous mix, 1.96 g/cm<sup>3</sup> for the bentonite/gravel mix and 1.92 g/cm<sup>3</sup> for the bentonite/lime/gravel mix.

The final phase of the multilayer earthen cover included the capillary barrier and overburden application.

#### Post Cover Radon Measurements

Radon flux measurements after application of the barrier layers were made in the same manner as the initial measurements except the aluminum tests were sealed to the measurement site with the surrounding overburden material in place of tailings.

Results of the radon flux measurements show a substantial reduction in radon emanation. Values of 96% to greater than 99% reduction of radon gas from the tailings were achieved by the multilayer clay seal and the inorganic gelatinous soil barriers. The difference in effectiveness of the two types of barriers, clay based or gelatinous based, can be seen in the layer thickness required to achieve the results. The gelatinous soil barrier layers thickness was 15 cm thick while the bentonite and bentonite/lime based layers tested were 30 cm and 40 cm thick, respectively. For relatively identical radon flux reductions the gelatinous soil barrier required 50 to 60% less material dependent on which clay barrier is used for the comparison. Preapplication radon flux values and a number of post application radon flux values are shown in Table 2.

#### HYDRAULIC CONDUCTIVITY STUDIES

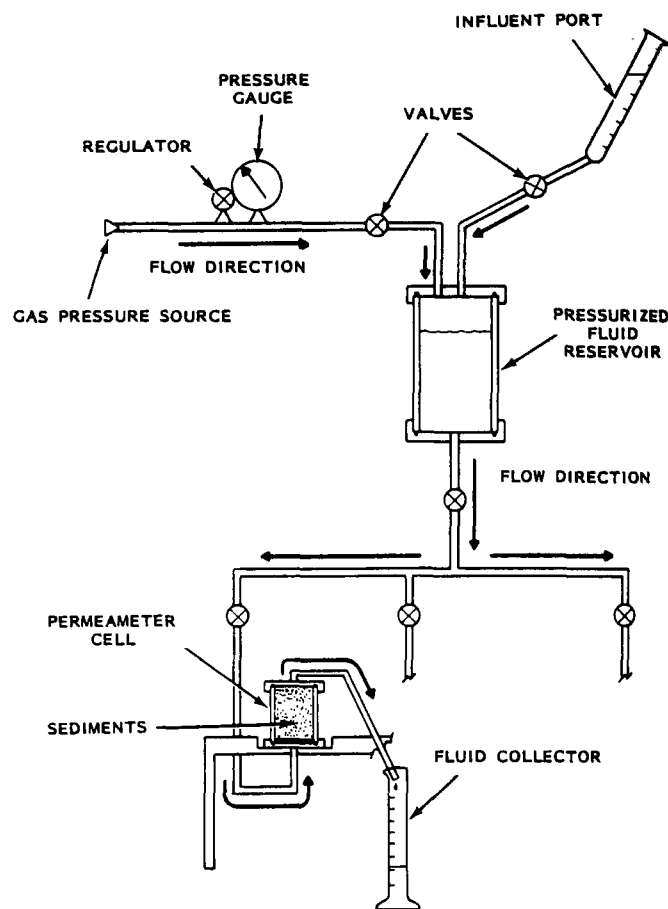
The hydraulic conductivity (K) is qualitatively defined as the ability of soil to transmit water. Column experiments used in determining hydraulic conductivity followed the ASTM method for determining constant head permeability with some minor modifications (Fig. 3). The flow of solution was from the bottom to the top to ensure saturated flow through the sediment.

These column experiments can be used in predicting the long-term effect of sediment-tailings solution interaction. The rate of flow is then monitored and hydraulic conductivity calculated using Eq. 2:

$$k \text{ (cm/sec)} = \frac{\Delta Q(\text{cm}^3) \times L(\text{cm})}{\Delta T \text{ (days)} \times A(\text{cm}^2) \times H(\text{cm}) \times 86,400 \text{ sec/day}} \quad (2)$$

where

- $\Delta Q$  = change in effluent  
 $L$  = length of the permeameter cell  
 $\Delta T$  = change in time  
 $A$  = cross-sectional area of the permeameter cell  
 $H$  = amount of head



**Figure 3.**  
**Illustration of the Apparatus Used for Determining Hydraulic Conductivity**

Three permeameter cells were packed with the gelatinous soil materials. The characteristics of each cell are listed in Table 3. The permeameter cells were then contacted with distilled water to acquire a constant hydraulic conductivity and to saturate the gelatinous material. Once saturated, they were transferred from one apparatus (Fig. 3) to a similar apparatus which contains tailings

**Table 2.**  
**Summary of Radon Flux Measurements Made at Grand Junction**  
**Before and After Cover Application (PNL Quarterly Report 9/82)**  
**pCi m-2 s-1**

Multilayer Barrier	Before	After Application			
	July 1981 Avg $\pm$ SD	Oct/Dec 1981 Avg $\pm$ SD	Feb 1982 Avg $\pm$ SD	July 1982 Avg $\pm$ SD	Average Flux Re- ductions
15 cm Gelatinous	367 $\pm$ 219	10 $\pm$ 11	12 $\pm$ 8	6 $\pm$ 5	96
30 cm Bentonite	175 $\pm$ 70	11 $\pm$ 8	38 $\pm$ 18	7 $\pm$ 4	92
40 cm Bentonite/lime	240 $\pm$ 179	11 $\pm$ 7	19 $\pm$ 8	8 $\pm$ 6	93

**Table 3.**  
**Characteristics Associated with the Permeameter Cells**

Cell No.	Dry Bulk Density (g/cm <sup>3</sup> )	Porosity	Pore Vol (ml)	Length (cm)	Diameter (cm)
A	1.96	0.26	25.08	4.97	4.97
F	1.92	0.28	18.72	3.0	5.37
G	1.88	0.29	19.75	3.0	5.37

solution. The chemical composition of the tailings solution is outlined in Table 4. Triplicate samples of tailings solutions were analyzed by Inductively Coupled Plasma (ICP) and Atomic Absorption Spectroscopy for major cations, Ion Chromatography (IC) for major anions and Intrinsic Germanium Detector for radionuclides.

The acidic tailings solution contains a large amount of total dissolved solids at a low pH (~1.9). There was a sharp decline in hydraulic conductivity in all three permeameter cells after contact with the tailings solution (Fig. 4). With the buffering of the acidic

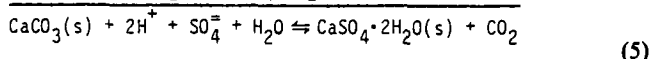
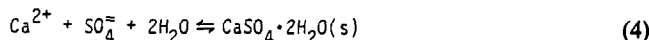
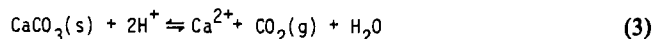
Table 4.  
Tailing Solution Characteristics (mg/l except as noted)

Parameters	Tailing Solution	Detection Limit
Al	721 ± 8	0.1
As(a)	0.54 ± 0.05	0.05
Ba	0.07 ± 0.01	0.05
Ca	557 ± 6	1.0
Cd(a)	0.12 ± 0.01	0.01
Co(a)	2.45 ± 0.2	0.05
Cr(a)	1.29 ± 0.2	0.05
Cu	21.1 ± 0.6	0.05
Fe	1974 ± 20	0.1
K	245 ± 15	0.2
Mg	1369 ± 13	0.5
Mn	1946 ± 18	0.1
Mo(a)	0.17 ± 0.01	0.05
Na	1073 ± 22	0.5
Pb(a)	1.62 ± 0.1	0.02
Se(a)	DL	0.15
Si	292 ± 3	0.1
Sn	11 ± 0.1	0.1
V(a)	2.99 ± 0.27	0.05
NH <sub>4</sub> <sup>+</sup> (b)	311 ± 11	5.0
F	210 ± 6	0.1
Cl	1064 ± 7.1	0.3
NO <sub>3</sub>	98 ± 0.7	0.3
SO <sub>4</sub>	22107 ± 323	0.3
U-238(c)	4466 ± 95	50
Ra-226(c)	1784 ± 48	50
Pb-210(c)	8665 ± 397	15
Th-230(c)	136705 ± 3001	400

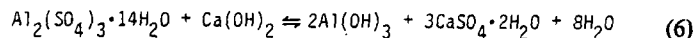
- (a) Analyses performed by Atomic Absorption Graphite Furnace  
 (b) Analyses performed by Nesslerization and Distillation  
 (c) Values in pCi/liter  
 DL = below detectable limits

tailings solution from approximately 1.9 to 9.2 and the reduction in total dissolved solids from 34.77 to 4.05 g/l, presents evidence that the reduction in hydraulic conductivity is due to the blocking of pore spaces by precipitants.

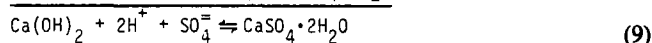
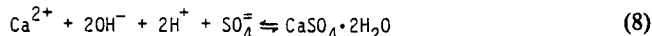
The reactions of importance involving the ability of a soil to neutralize a given solution is based on the buffering capacity of the sediment. Buffering capacity of a sediment is defined as the amount of solution which can be neutralized to a certain pH per gram of sediment. The calcium carbonate content of a soil gives an indication of the volume of solution which the sediment can neutralize. Calcium carbonate buffers the pH by dissolving the calcium carbonate in acid and forming carbon dioxide and water. The continued dissolution of calcium carbonate is driven by the mass action precipitation of calcium sulfate, the evolution of carbon dioxide gas, and the increasing hydrogen ion concentration as additional tailings solution migrates through the sediments. The reactions involved in this neutralization can be written simply in the following equations:



The slight excess of  $\text{Ca}(\text{OH})_2$  in the gelatinous material, used to ensure a complete reaction with the  $\text{Al}_2(\text{SO}_4)_3$  forming the gelatinous substance. The combination of the aluminum sulfate [ $\text{Al}_2(\text{SO}_4)_3$ ] and the calcium hydroxide [ $\text{Ca}(\text{OH})_2$ ] produce some insoluble gelatinous precipitates, aluminum hydroxide [ $\text{Al}(\text{OH})_3$ ] and calcium sulfate ( $\text{CaSO}_4$ ) as illustrated in Eq. 6:



thus enhancing the buffering capacity of the barrier. The following reaction occurs when contacted with the acidic tailings solutions:



The dissolution of calcium hydroxide aids in the neutralization by removing  $\text{H}^+$  ions from solution causing an increase in pH. Since the solubility of many of the tailings solution constituents are pH dependent, the change in hydrogen ion concentration causes precipitation reactions to occur resulting in a reduction of total dissolved solids content in the column effluent solutions.

## CONCLUSIONS

Based on the results of the cover study the gelatinous soil barrier and bentonite mixes reduced overall radon fluxes by greater than 90% over initial radon flux values. The gelatinous soil mix tested in the Grand Junction, Colorado field project was 15 cm in depth or approximately 50% to 60% less barrier material than the bentonite clay soil barriers tested. From an economic standpoint, this means less total material would be required to cover a waste site and could result in a substantial reduction in remedial action costs.

Hydraulic conductivity measurements on the gelatinous soil mixture show dramatic reductions in flow rates upon contact with the highly acidic uranium mill tailings liquor. Initial hydraulic conductivity values of  $5 \times 10^{-8}$  cm/s or less were achieved in laboratory experiments with distilled water. Upon contact with the acidic tailings solution flow was reduced by more than two orders of magnitude in flow reductions on 0.5 to 4 pore volumes of sediment solution interaction resulted in hydraulic conductivities on the order of  $5 \times 10^{-10}$  cm/s.

Some of the proposed strategies for controlling gas and leachate migration at waste disposal sites have been very expensive, difficult

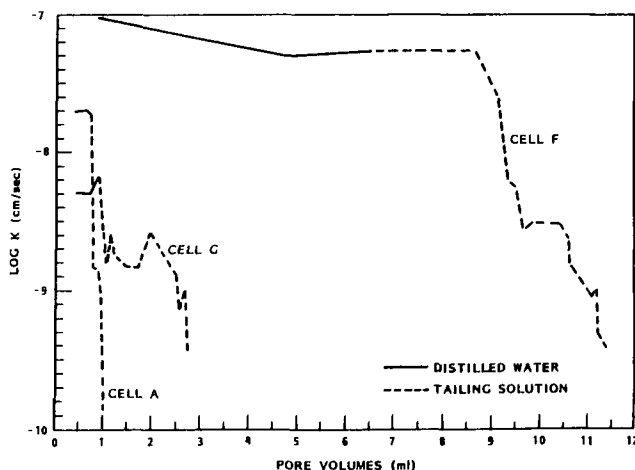


Figure 4.

Hydraulic Conductivity Versus Pore Volume of the Gelatinous Material

to install or lack long term stability. However, the use of the gelatinous-soil mixture as a cover or liner can reduce or eliminate some of these common problems associated with waste contaminants:

- Inaccessible materials. The main component in the multilayer scheme is comprised of 80 to 85% standard road base normally used in the construction of highways. The size distribution of the roadbase material varies somewhat from state to state but it is a material that is readily available throughout the country.
- Swelling and shrinking. As mentioned earlier, high bulk densities, low total porosities, and low permeabilities can be achieved whereas clays are extremely difficult to work with and require careful control of moisture content. As it swells, it will reduce the total porosity of the layer. When the moisture content is lower the clay shrinks and the porosity increases. The gel material being very hydrogropic entrains moisture into its pores and tends to maintain a consistent moisture content. This consistency eliminates any cyclic shrinking or swelling and gives a layer with very predictable properties.
- Ease of handling and application. In many cases, clay-soil materials must be mixed and applied at some moisture content less than optimum due to nonuniform wetting of the mix. Also, mixing clays at too high an initial moisture content causes the clays to adhere to the equipment being used. The gel material can be mixed at the optimum moisture content initially because of a more uniform moisture distribution. The gel material will not adhere to the machinery being used. Since the main component of the material is standard road base, large-scale application is achieved using standard road construction equipment.

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# TREATMENT OF HIGH STRENGTH LEACHATE FROM INDUSTRIAL LANDFILLS

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## INTRODUCTION

### Landfill Leachates

#### Definition

Landfill leachate is grossly polluted liquid, produced as rain, surface water and groundwater, remove various components from liquid and solid wastes. Depending on the wastes deposited at a landfill site, leachate may contain various synthetic and biogenic organic species, bacteria, viruses and toxic chemicals, including heavy metals and known or suspected carcinogens.<sup>1,2</sup> The water in the aqueous phase of leachate originates from groundwater infiltration into a landfill, surface water or precipitation seepage through the site, or may be inherently associated with wastes and decomposition processes.<sup>6</sup>

Leachate takes the character of a high strength wastewater similar to a concentrated industrial waste stream. Leachates generated from industrial and sanitary landfills display COD, TOC, SS, TDS and turbidity that exceed measurements of these common pollution parameters for municipal wastewater (Table 1). In addition to these high general contaminant values, levels of individual organic and inorganic contaminants are frequently very high.<sup>10</sup>

#### Hazardous Waste Disposal Sites

The USEPA has indicated there are over 32,000 sites nationwide that contain significant amounts of hazardous waste. As many as 2,000 of these landfills present imminent public health hazards.<sup>9</sup> Many of these hazardous waste disposal sites are located in the northeastern sector of the United States. In fact, nine of the 25 most dangerous are in New Jersey.<sup>13</sup>

The major concern with landfill leachate is surface or groundwater, with attendant public contact and possible impacts on sources of potable water. Recently, considerable attention has been paid to

actual and potential impacts on humans. Beck<sup>1</sup> points out that until the Love Canal incident, in which industrial toxic wastes literally drove people from their homes, the general public was not greatly concerned about landfill leachate and did not seek studies to monitor or treat it.

#### Detrimental Effects

There is the potential for severe effects of landfill leachates due to migration to municipal drinking water systems or to private wells. Although experts disagree on the toxic and/or carcinogenic effects of synthetic organic chemicals (SOC), they have concluded, based on animal tests, that organics must be kept below maximum safe levels in drinking water.<sup>7,8</sup>

Many SOC are chlorinated hydrocarbons or aromatics; in addition, many pesticides have given positive laboratory results and are possible carcinogenic substances. SOCs include: vinyl chloride, carbon tetrachloride, trichloroethylene, PCBs, benzene and trihalomethanes. Inorganic compounds pose a health threat, also. These include arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver.<sup>11</sup>

#### Renovation

There are processes available to treat leachates generated by industrial and chemical landfills. Most of the literature on treatment processes is based on industrial waste and sanitary landfill leachate treatment. Basically, hazardous waste treatment aims at ultimate disposal but may only accomplish one or more of the following:

- Detoxification
- Concentration of hazardous constituents in a reduced volume
- Fixation of the waste to inhibit leaching

The treatment approach chosen depends on waste characteristics and external factors that influence the degree of treatment necessary. The intent of this overall study is to evaluate and implement techniques of hazardous waste treatment.

In this paper, the authors describe examples of two very different and successful means of leachate renovation. These techniques are reverse osmosis and aerobic biodegradation; both requiring some pre-treatment.

#### PRETREATMENT

The high strength complex industrial landfill leachate used in this research study is the aqueous phase of bulk oil/water leachate mixtures. This material was provided by the USEPA Oil and Hazardous Materials Spill Branch. A Gravity Separator was used to remove much of the bulk oil, leaving some oil dispersed in the aqueous phase. Some bulk oil remained, however, floated on the surface of leachate samples. Leachates designated EPA-01, 02 and 03 were obtained at different points and times at the same landfill. Samples were stored at temperatures below 10 °C, to retard changes in composition during storage.

As received, samples of aqueous phase contain oil-in-water and water-in-oil-in-water emulsions and colloidal suspensions, as well

Table 1.  
Leachate Characteristics

Parameter	Leachates in this study**	Leachates* (Nat'l Sample)	Domestic Sewage* (med. conc'n)
pH	5.5-6.0	3.0-7.9	8.0
COD	23,000-29,000	25-41,000	500
TOC	8,000-11,000	11-8,700	200
TDS	16,000-25,000	1,450-15,700	500
Turbidity	75-150 NTU		
Color	Brown	Variable	Brown
Conductivity, $\mu\text{mhos/cm}$	13,000-18,000	800-2,000	700
Na	$1 \times 10^3$	5-1,350	150
Fe	$1 \times 10^4$	90-678,000	0.1
Mg	$1 \times 10^4$ - $1 \times 10^5$	25-453	30
Ca	$1 \times 10^3$	164-2,500	50

\*Taken from reports by Mikucki *et al.*<sup>6</sup>, Shuckrow *et al.*<sup>10</sup> and Clark *et al.*<sup>1</sup>

\*\*All values in mg/l unless otherwise noted.



as oil adsorbed on organic solids and clay particles that are difficult to settle. These dispersed oil phases are thermodynamically stable. Further, they interfere with any attempt to remove or convert dissolved inorganic salts and organic species. Activated carbon particles are wetted and macropores are sealed, reducing effective surface and adsorptive capacity to nil. Ultrafiltration and reverse osmosis membranes are fouled and blinded very rapidly. Fluxes quickly drop to zero. Cell suspensions are flocced and settled. The cell surface area available for substrate transfer is reduced by clumping and masked by adsorbed oil. Respiration and growth are severely retarded. Hence, pretreatment is necessary to eliminate turbidity due to dispersed oil.

A suitable scheme was developed and adopted as a standard for all samples and process research investigations. The pH of the aqueous phase of leachate samples was raised to 12 by addition of lime. Doses in excess of 6 gm/l may have been required. Slurries were centrifuged and/or settled for 10-20 hours and decanted. The supernatant flue was recarbonated to a pH between 7 and 8. Carbon dioxide was used to avoid air stripping and minimize anomalous volatilization. The recarbonation slurry was settled and decanted, yielding a second sludge. A final adjustment to a pH of 7 was made with concentrated sulfuric acid. A third settling step was usually required, to remove a small amount of calcium sulfate sludge.

Iron, magnesium and manganese were removed quantitatively by this pretreatment procedure. Turbidity reduction varied with settling time, but was never less than 95%. Dispersed oil was eliminated quantitatively, also. However, the oil was only a very small part of the initial TOC, i.e., 3-5%. After pretreatment, dispersed oil ceased to have any observable effect on subsequent treatment studies.

## REVERSE OSMOSIS

### General Description

Reverse osmosis is the separation of one or more solutes from solution by means of pressure exerted on the solution to force solvent through a semipermeable membrane. Most present work in reverse osmosis utilizes cellulose acetate membranes that sorb water preferentially to ionic species and dissolved matter. The treated water fraction is known as permeate; the reject species stream is termed the retentate.

Membrane pores of 5 to 20 Å in diameter are formed by the structure of the cellulose acetate matrix. Molecules that do not orient in a water-like crystalline structure are rejected by the membrane. In addition, the membrane pores exclude molecules with molecular weights greater than 200 by a simple sieve process, although this is not the mechanism of rejection. Because of preferential sorption of water and rejection of ions and most organic molecules, water of extremely high quality can be produced.

Normal osmosis occurs when water passes from a less concentrated solution to a more concentrated solution through a semipermeable membrane. Potential energy exists between the two solutions across the semipermeable membrane. Water flows, due to this energy difference, from the less concentrated to the more concentrated solution until the system is in equilibrium. Pressure on the concentrated solution will stop transport of water across the semipermeable membrane, when the applied pressure equals the apparent osmotic pressure between the two solutions. The latter is a measure of the potential energy difference between the solutions.

As additional pressure is applied to the more concentrated solution, water will begin to flow from the concentrated solution to the less concentrated solution. The rate of transport is a function of pressure applied to the concentrated solution, the difference in the absolute osmotic pressure of each solution, and the membrane area pressurized. The absolute osmotic pressure is the potential energy between the solution and pure water.

### Membrane Performance Parameters

Effectiveness of reverse osmosis in treatment of high strength industrial wastewater is determined by several process and solution

parameters. Organic removal and membrane fouling are important features of membrane performance.

Parameters used to measure the efficiency of membrane separation include ionic strength, conductivity, total dissolved solids, chemical oxygen demand, and total organic carbon. These parameters indirectly reflect inorganic ions, dissolved solids and organic matter removed. The efficiency of operation can be defined as the percent rejection of these quantities, by comparison of raw waste to permeate.

### Membrane Fouling

In membrane separation of high strength wastewater, the quantity and quality of permeate may deteriorate due to membrane fouling.<sup>2,4</sup> Eykamp defines fouling as a condition in which a membrane undergoes plugging or coating, by some element in the waste stream being treated, such that flux is reduced and a buildup on the membrane surface commences.

Foulants can be classified as sparingly soluble inorganic compounds, colloidal or particulate matter and dissolved organics. Ultimately, if fouling is allowed to continue, effective membrane service life is diminished rapidly. Therefore, pretreatment processes must be utilized in high strength complex wastewater treatment.

### Equipment

In this study, the authors employed a tubular cellulose acetate reverse osmosis membrane, manufactured by Abroc, Inc. (Wilmington, Mass.). The membrane was 5 ft long and 0.5 in. in diameter, with a net surface area of 0.65 ft<sup>2</sup>. The reverse osmosis system could operate in steady-state (complete recycle) and unsteady-state modes. Most data were collected in the steady-state mode; permeate and retentate are recirculated back to the feed container. This procedure allowed sampling at all points to quantify operational effectiveness, but did not diminish the quantity of experimental wastewater; the retentate stream and feed were identical. The system was operational basically in an unsteady-state mode. Permeate and retentate were separated and collected; the retentate was concentrated in rejected species. The system was equipped with a 55 gal, water-cooled feed tank and several staging tanks, including a pretreatment system.

### Procedure and Results

In Experiment 3 EPA-02 leachate pretreated with the standard lime pretreatment process was used. This experiment was performed at steady-state, with recirculation of permeate and retentate to the feed tank. This simulates operation in the unsteady mode when the concentration of the retentate does not change significantly in response to changes in raw waste concentration. Operation was continued for approximately one week to evaluate flux and separation efficiency. Separation effectiveness was observed as TDS and conductivity reductions over the period of the run. TOC and COD assays were performed to evaluate removal of dissolved organics. Experiment 4 was a continuation of the previous test. The system was switched to unsteady operation. Changes in system parameters were observed and compared to steady-state performance.

In Experiment 3, 40 gal of leachate with the following characteristics were used: 17830 micro-mhu/cm conductivity, 4.9 pH, 16,400 mg/l TDS, 27,120 mg/l COD and 8,120 mg/l TOC. Process operating parameters throughout 142 hr of steady-state operation were: pressure, 400 psig, temperature, 21.6°C, and flow rate, 1 gal/min. Salt rejection averaged 95%, reducing raw feed conductivity to 890 micro-mhu/cm. Permeate ionic strength decreased slightly after start-up, but leveled off quickly (Fig. 1). Total dissolved solids removed was greater than ion rejection, displaying 97.9% reduction. Dissolved solids were reduced from 16,400 mg/l to an average of 340 mg/l.

The permeate was colorless, clear and waterlike, with a slight odor of the parent waste. Feed solids, after evaporation, appeared brown, whereas permeate solids showed a trace of yellowish brown. Permeate dissolved solids decreased only slightly, in time. The feed

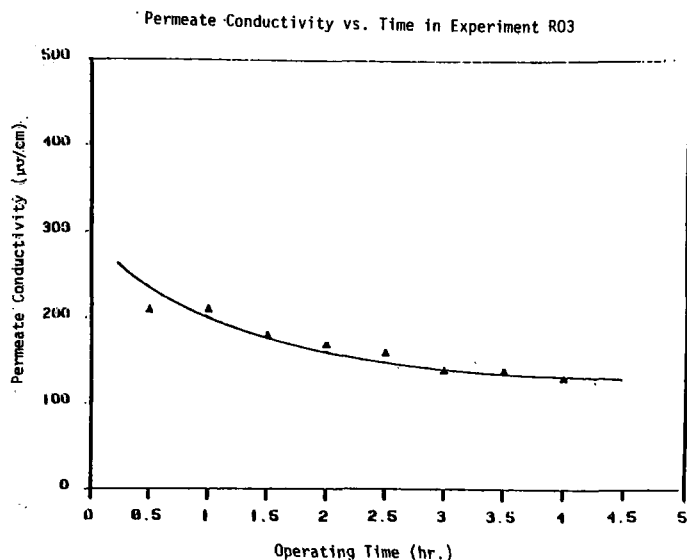


Figure 1.  
Permeate Conductivity vs. Time in Experiment R03

pH of 4.9 decreased to a pH of 3.3. Thus, the ionic species that passed the cellulose acetate membrane are highly acidic in character. The flux did not change appreciably during 142 hr of continuous operation. Permeate flux averaged 4.4 gal/day/ft<sup>2</sup> with a recovery of 0.20%.

Pretreated leachate feed COD, with an average value of 26,400 mg/l, was reduced by 68%. A permeate COD of 8,570 mg/l was produced by reverse osmosis. Approximately 3% of the TDS and one third of the organic matter in the leachate feed can permeate the membrane. TOC, COD and TDS are interactive. However, solutes that pass the membrane are more organic in character than solutes in the bulk of the leachate. TOC results support these observations; 50% of the TOC was removed from a feed with an average TOC of 8,480 mg/l, yielding a permeate TOC of 3,440 mg/l. Slight reductions in permeate COD and TOC may be due to a non-fouling gel layer formed on the interior membrane surface, augmenting organic separation.

In Experiment 4, a continuation of Experiment 3, the unsteady-state mode was used for an additional week of operation. An electrical outage midway through the run caused the system to be inoperative for several hours, leading to slight loss in pressure. Overall performance in this study suggested that, as the concentration of the reject species in the feed increased, concentration in the permeate increased, also. This result follows the basic theory of membrane concentration gradients. Ion rejection decreased from 95%, at the start of the unsteady operation, to 91% after 116 hr. Both feed and permeate conductivities increased, reaching 27,620 and 2,490 micro-mhu/cm, respectively. TDS followed conductivity, with solids rejection decreasing from 98 to 96% over the span of operation. The dissolved solids concentration of the feed increased 40%, to 22,280 mg/l, while the permeate concentration was close to 1,000 mg/l in the final hour. Considering the volume of permeate, this was not significant. Forty percent of the permeate was obtained from feed. Flux rate decreased only slightly to 3.5 gal/day/ft<sup>2</sup>.

### Summary

Reverse osmosis proved capable of processing pretreated leachate, EPA-02, reducing TDS of 16,400 mg/l by 98% and ionic strength by 95%. Reverse osmosis separated this waste into a clear, colorless permeate, with some odor. Also, it reduced the COD and TOC of the leachate by over one-half; rejections were 68 and 59%, respectively. Although solids removal was high, much of the solids permeating the membrane were organic in character.

Degenerative fouling of the membrane did not pose a problem. Over 250 hr of continuous, steady-state and unsteady-state leachate

operation did not disclose a fouling problem. This was also the case with high strength simple salt and binary salt and carbon solute mixtures.

Reverse osmosis process effectiveness with high strength wastewaters is affected by several operating and solution variables. The most important of these is pressure. An increase in pressure increases permeate flux rate and the separation efficiencies for some solutes. An increase in temperature improves flux and rejection slightly, not significantly. The effect of wastewater pH on membrane performance is slight. In a binary salt and carbon system, the removal efficiency improves slightly with increasing pH.

## AEROBIC BIODEGRADATION

### General

The study of bacterial metabolism of synthetic organic chemicals can use one of several approaches. Investigations of pure compound utilization by selected microbial strains are common. The effects of a single SOC on mixed microbial populations, such as activated sludge systems, are of great interest. Such experiments are essential to avoidance of upsets in wastewater treatment plants. The extreme complexity of potential substrates in landfill leachate mandates the approach in the present case. It is not to be expected that one or a limited number of microbial species have or can acquire the enzyme systems requisite to fully utilize this diversity of carbon sources.

Aerobic biodegradation studies have concentrated on the use of sewage organisms. Secondary sludge is taken from an activated sludge plant with substantial industrial inflows and cultured in the laboratory to prepare a master batch of seed for comparative respiration and growth experiments. The medium is due to Krishnar and Gaudy (1977) and includes:

Glucose	1 g/l
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	500 mg/l
MgSO <sub>4</sub> · 7H <sub>2</sub> O	100 mg/l
FeCl <sub>3</sub> · 6H <sub>2</sub> O	500 mg/l

pH is buffered with 1M K<sub>2</sub>HPO<sub>4</sub> solution. The master batch is grown to a nominal concentration of 10 g/l of total solids. It is then separated into 20 or more seed aliquots for the 100-200 ml Erlenmeyer flasks used in shake aeration studies.

Control flasks combine sludge seed, glucose medium and distilled water to volume. The desired sludge solids level is 2.5 g/l. Test flasks receive the seed aliquot, glucose and/or leachate carbon, and nutrient medium. Replicate control and test flask sets are sacrificed at preselected times after inoculation. The progress of the experiment is monitored by one or more of the following variables:

- Respiration Rate—specimens to Gibson or Warburg respirometer
- Volatile Suspended Solids, Total Suspended Solids, Total Solids, Protein, Optical Density—surrogates for cell mass
- TOC—total organic carbon in system—suspended solids, adsorbed carbon and medium
- Glucose—preferred substrate

Various experimental series were designed to test the utility of sludge acclimation, cometabolism and supplementary glucose addition. Measurements were intended to compare respiratory assimilation and cell mass or growth rate, as well as test for cellular adsorption or cellular uptake and storage without metabolism.

### Experiment 120281

This experiment was intended to compare respiration and organic carbon utilization, with and without leachate carbon at a concentration approximating the initial glucose carbon. Glucose concentrations were measured for samples taken during the initial 12 hr, from both test and control flasks. Optical density, DIC and respiration rates were monitored for almost 4 days.

## Experimental Scheme

Control	Test
1.5 g/l glucose	1.5 g/l glucose
2.5 g/l sludge solids	2.5 g/l sludge solids
nutrient medium	2.0 g/l leachate DOC
	nutrient medium

## Glucose Uptake

Glucose uptake in control flasks was rapid and complete in the 12 hr observation period. Glucose was taken up by the flasks with leachate added after substantial delay. Measurement after 24 hr found glucose had disappeared completely from test flasks.

## Respiration

Respiration rates of control flasks samples exceeded those of test flask specimens, during glucose uptake by the former, at 0 and 5 hr. By 12 hr, test flask rates were seven-fold greater than control flasks, although control flasks respiration did not display an effect of substrate depletion (Table 2). Respiration in the test flask remained higher for the rest of the experimental period. In addition, respirometer measurements were linear and very reproducible. Oxygen uptake data taken at 36 hr is plotted in Fig. 2. Average respiration rates for the entire experiment are described in Fig. 3.

Table 2.  
Biogradation of Leachate

Time (hr)	Volatile Solids (mg/l)		Glucose in Solution (g/l)		Respiration Rate ( $\mu$ l/min)	
	Control	Test	Control	Test	Control	Test
0	1310	1310	1.36	1.30	1.60	0.77
1	--	--	--	--	--	--
2	--	--	1.08	1.26	--	--
4	--	--	0.84	1.47	--	--
5	--	--	--	--	3.92	1.53
6	--	--	0.65	1.23	--	--
8	--	--	0.98	1.43	--	--
10	--	--	0.04	1.20	--	--
12	2621	1755	0.00	1.13	1.33	9.73

## Biodegradation

Samples were taken from test and control flasks at 12 and 24 hr intervals, over a period of 84 hr. Volatile solids (determined by optical density) increased in both control and test flasks, but increased much more for the test flasks (Table 3). Optical density appears to give better estimates of cell mass than direct volatile solids measurements, probably because there is negligible interference of dissolved leachate solids with the measurement.

Soluble TOC showed an overall decrease of 72% between 24 hr to 84 hr. From time zero, a decrease of 85% was observed. The TOC of the control remained constant at zero, except at 48 and 84 hr. This result is due possibly to lysis of cells and release of cell matter into solution. This corresponds to a decrease in volatile solids between hours 36 and 84; refer to Table 3, also.

## Comment

A lag in glucose uptake accompanied the presence of leachate carbon. Degradation of leachate appeared to take place in this case, however. This is suggested by increased respiration rates of test over control flasks, a large increase in cell mass in the test flasks, and a large decrease in soluble TOC in the test flasks. It is not clear whether the TOC removed from solution was oxidized fully or used in cell growth. It was not determined whether leachate carbon is adsorbed onto cell surfaces, or taken up and dissolved in cellular fatty structures.

O<sub>2</sub> UPTAKE VS. TIME IN EXPERIMENT 120281

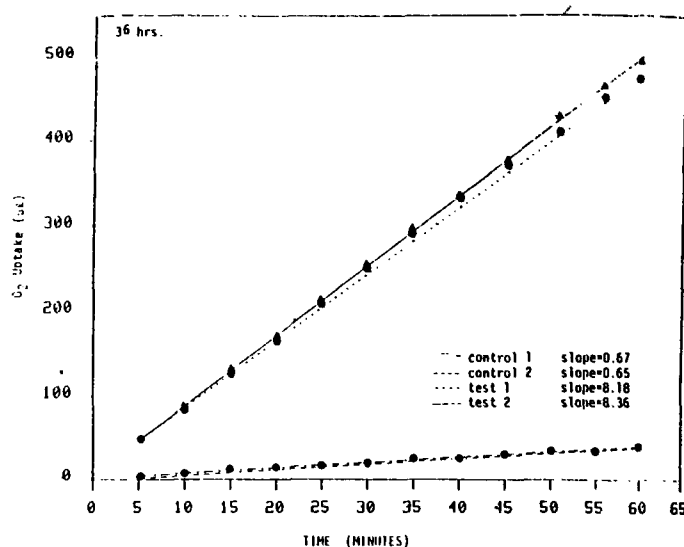


Figure 2.  
O<sub>2</sub> Uptake vs. Time in Experiment 120281

RESPIRATION RATE VS. TIME IN EXPERIMENT 120281

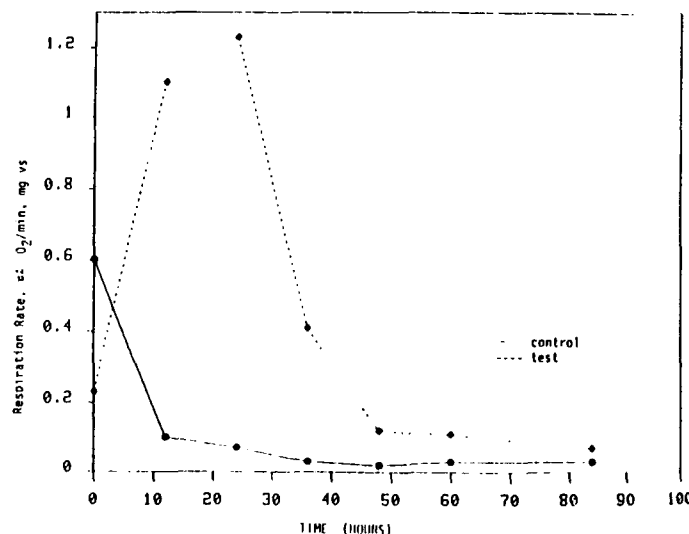


Figure 3.  
Respiration Rate vs. Time in Experiment 120281

Table 3.  
Biodegradation of Leachate—Experiment 120281

Time (hrs)	Volatile Solids** mg/l		Soluble TOC mg/l		Respiration Rate $\mu$ l/min/mg vs	
	Control	Test	Control	Test	Control	Test
0	1310	1310	*	2600†	0.60	0.23
12	2620	1760	*	*	0.10	1.10
24	2330	1950	0	1120	0.07	1.23
36	2860	4000	0	510	0.03	0.41
48	2790	4440	10	410	0.02	0.12
60	2540	5720	0	310	0.03	0.11
84	2480	4700	210	310	0.03	0.07

\*not measured

†approximate value

\*\*approximated by optical density measurements

## Experiment 022882

## Experimental Scheme

Control Flasks	Test Flasks
400 mg/l DOC as glucose	400 mg/l DOC as glucose
2000 mg/l DOC as sucrose	2000 mg/l DOC as leachate
suspended solids ~2500 mg/l	suspended solids ~2500 mg/l

The growth and respiration rates of an activated sludge culture containing leachate and glucose, as carbon sources, were compared with the rates of the same culture using glucose and sucrose, with sucrose contributing DOC equivalent to that of the leachate. The experimental period was 84 hours, nutrient medium was added to test and control flasks.

## Glucose Depletion Study

Glucose uptake was measured from hours 0 through 12, at 2 hr intervals. The test flasks showed uptake rates similar to previous experiments. However, the control flasks showed a high level of glucose present throughout the 12 hours, probably due to hydrolysis of sucrose to its monomers fructose and glucose. Respiration was measured after 0, 6 and 12 hr; the overall rate of the test flasks was slightly lower than the control flasks. Refer to Fig. 4 and Table 4.

## Biodegradation

After the glucose depletion study, respiration was measured at 12 hr intervals. The overall rates for the test flasks were higher than for the control flasks (Fig. 4). Since the test and control flasks contained equal amounts of DOC, as leachate and sucrose, respectively, this may indicate that leachate is preferred over sucrose as an energy source, by the activated sludge, rather than as a carbon growth source. This is further suggested by the higher values of suspended and volatile suspended solids in the control flasks relative to the test flasks. DOC reduction in test flasks, over the 84 hr period, averaged 82%, a value similar to data from previous experiments. The DOC reduction for the control flasks averaged 93% (Fig. 5).

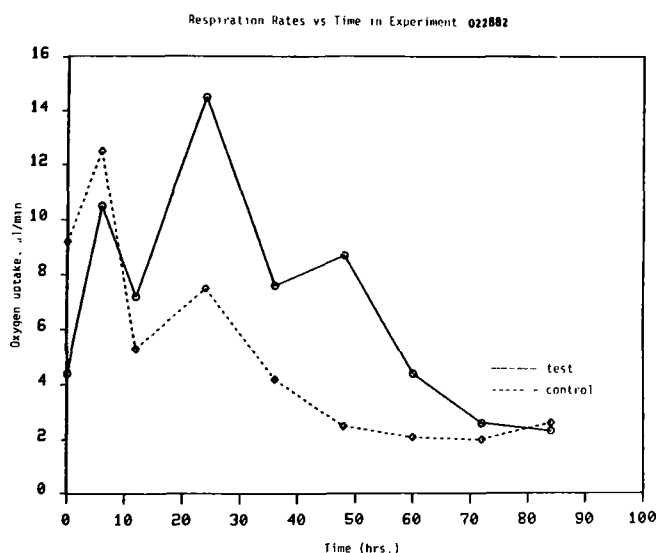


Figure 4.  
Respiration Rates vs Time in Experiment 022882

Table 4.  
Biodegradation of Leachate—Data for Experiment 022882

Time (hrs)	Suspended Solids (mg/l)		Vol. Suspended Solids (mg/l)		DOC (mg/l)		Respiration $\mu\text{l/min/mg/vss}$	
	Control	Test	Control	Test	Control	Test	Control	Test
0	2500	2500	---	---	2400	2400	---	---
12	3760	3570	3260	2110	1040	1470	0.328	0.683
24	4990	3530	4620	2330	400	1210	0.320	1.284
36	5510	5540	4610	4060	140	1050	0.182	0.377
48	5040	4930	4021	3100	140	890	0.124	0.564
60	4500	3930	4130	2590	135	740	0.106	0.312
72	4710	5110	3850	3110	150	560	0.104	0.160
84	4870	4350	4270	3540	180	130	0.116	0.131

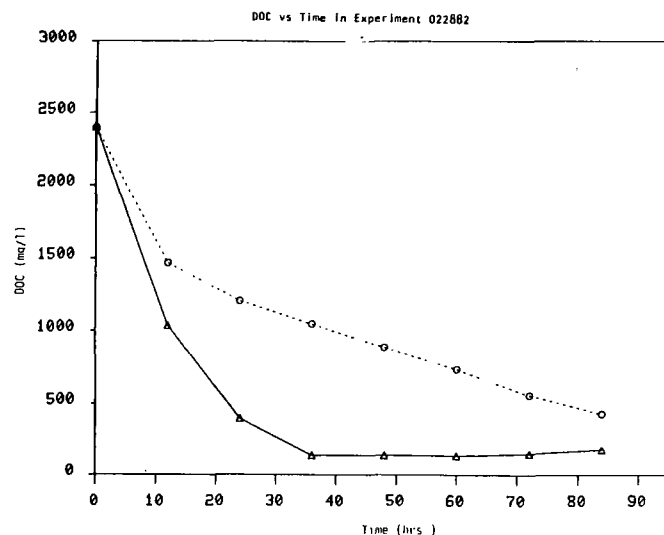


Figure 5.  
DOC vs Time in Experiment 022882

Apparently, leachate serves as both an energy source and a carbon growth source for the activated sludge seed. Respiration rates are higher and growth rates are lower than rates observed with sucrose, a readily available carbon source.

## CONCLUSIONS

Pretreated industrial landfill leachate can be renovated by reverse osmosis, without degenerative membrane fouling. Greater than 95% of the inorganic species and 50% of the organic species present in the leachate can be removed.

Subsequent to acclimation in the presence of glucose, sewage organisms degrade leachate under aerobic conditions. Respiration rates are enhanced substantially in the presence of leachate.

## DISCLAIMER

Reference to commercial products or processes in this paper does not constitute endorsement by Rutgers University of by the U.S. Environmental Protection Agency.

## ACKNOWLEDGEMENTS

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# TREATMENT OF TNT AND RDX CONTAMINATED SOILS BY COMPOSTING

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## INTRODUCTION

The manufacture and handling of TNT and RDX, major explosives used in conventional weaponry by the United States, has resulted in contamination of soils and sediments at facilities carrying out these operations. Because of the recalcitrant nature of these compounds, the contamination of soil and sediment around these facilities has increased over a period of years.

A number of investigators have studied biodegradation of RDX under aerobic and anaerobic conditions. Sikka *et al.*<sup>1</sup> reported that aerobic biodegradation of RDX occurs very slowly only in the presence of sediments. Under anaerobic conditions, they found that RDX was degraded in few in the presence of yeast extract. McCormick *et al.*<sup>2</sup> evaluated the biodegradability of  $^{14}\text{C}$ -RDX and observed that degradation occurred only under anaerobic conditions. Rapid disappearance of  $^{14}\text{C}$ -RDX in static cultures was observed although little of the initial label was trapped as  $^{14}\text{C}$ -labeled gas. Most of the label remained in the aqueous fraction. Several byproducts of anaerobic degradation of RDX have been tentatively identified as formaldehyde, nitrosotriazine, hydrazine, dimethyl-hydrazine and methanol.<sup>2</sup>

In the environment, the nitro groups of TNT are reduced in a step wise fashion to amino groups. The intermediates in this reduction scheme may condense to form dimers, and subsequent reduction and condensation reactions can lead to the formation of complex polar polymers.<sup>3</sup> Major transformation products have been identified as monoaminodinitrotoluenes and tetranitroazoxytoluene. No evidence for ring cleavage in soil or fresh water environments has been found.<sup>3,4</sup>

The fate of TNT in soil amended with nutrients was studied by Osmon and Andrews.<sup>5</sup> The amendments did not alter the reductive transformations observed to occur in unamended soils. A preliminary study on composting of TNT by these investigators indicated that composting resulted in a rapid decrease in TNT concentration. The usual transformation products were not detected as products of TNT composting. In this paper, the authors describe the results of laboratory and greenhouse scale studies on composting for cleanup of TNT and RDX contaminated lagoon sediment.

## MATERIALS AND METHODS

All composts were composed of 45% chopped alfalfa hay (*Medicago sativa*), 45% Purina Sweetena horse feed and 10% soil [air dried, sieved (2 mm) Lakeland sand (typic quartzipsamments), thermic coated)] contaminated with either TNT or RDX. Additionally, a small quantity of active uncontaminated compost was used to seed each compost. The laboratory bench-scale composts were 50 g (dry weight) with sufficient distilled water added to bring the moisture level up to 60% (wet weight basis). Test composts were spiked with either 1.0  $\mu\text{Ci}$  of  $^{14}\text{C}$ -TNT or 0.72  $\mu\text{Ci}$  of  $^{14}\text{C}$ -RDX. Both radiolabeled compounds were uniformly ring labeled with radiocarbon purities of 96 and 97% for  $^{14}\text{C}$ -TNT and  $^{14}\text{C}$ -RDX, respectively. Control composts contained no  $^{14}\text{C}$  tracers. The final concentration of explosive on both test and control composts was 10,000  $\mu\text{g/g}$  (1% by weight).

Test composts that were not immediately sacrificed were placed in the aeration and gas trapping apparatus illustrated in Fig. 1. Each compost was incubated at 55°C and continuously aerated with humidified, warm,  $\text{CO}_2$ -free air. Off-gases from each compost were

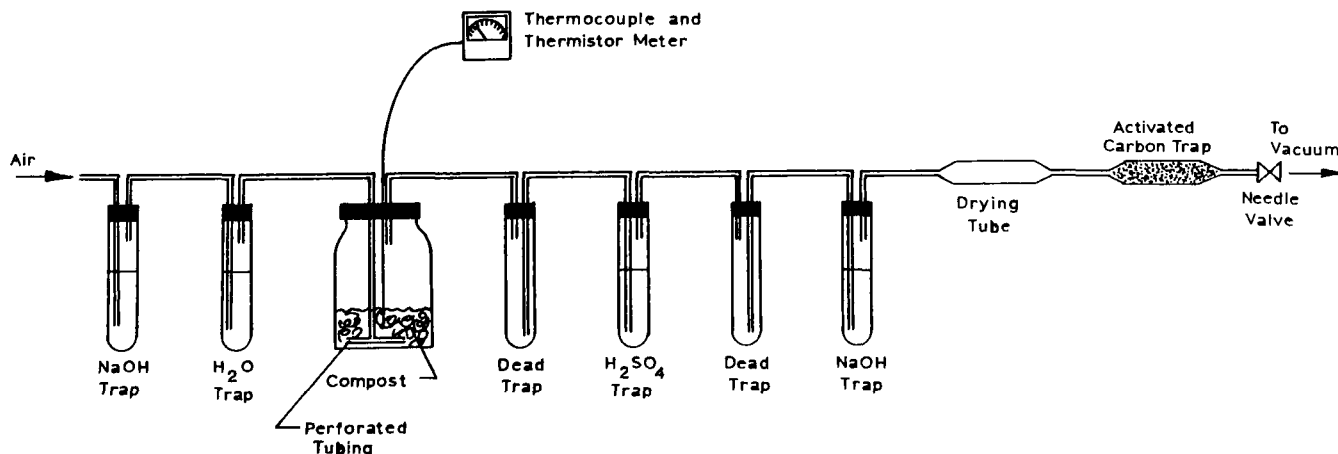


Figure 1.  
Laboratory Compost Aeration Apparatus

individually scrubbed through concentrated  $\text{H}_2\text{SO}_4$  and 5 N NaOH, and then dried and passed through activated carbon to remove any volatile  $^{14}\text{C}$  compounds emitted from the composts. The NaOH traps were replaced weekly or more often to avoid  $\text{CO}_2$  saturation of the trap. The  $\text{H}_2\text{SO}_4$  traps were replaced after three weeks. Subsamples of the liquid traps were assayed for  $^{14}\text{C}$ -activity by liquid scintillation counting. At the conclusion of the experiment, the carbon traps were crushed to a fine powder and subsamples were combusted ( $850^\circ\text{C}$ ) for 30 min. A 1:5 (v/v) mixture of  $\text{CuO}$  and  $\text{Al}_2\text{O}_3$  was used as a catalyst. The  $^{14}\text{CO}_2$  released was collected in Carbosorb and quantified by liquid scintillation counting.

Control composts were incubated and aerated as described for the test composts, but the off-gases were not scrubbed. Weekly air samples were removed from the control composts and analyzed by gas chromatography for  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2$ , and  $\text{O}_2$  (Varian 3700 gas chromatograph; 6 ft CTR column from Alltech, thermal conductivity detector).

After 0, 3 and 6 weeks of composting, both control and test composts were sacrificed for analysis. At each time interval, three replicate test composts for each explosive were sacrificed. Each compost was extracted three times with 160 ml of appropriate solvent(s). The  $^{14}\text{C}$ -RDX composts were extracted with acetone. The  $^{14}\text{C}$ -TNT composts were extracted once with methanol/benzene (40:120) and then re-extracted twice with benzene. All extractions were carried out at  $37^\circ\text{C}$ . Extracts for each individual compost were combined and subsamples were counted by liquid scintillation counting to quantify the total extractable  $^{14}\text{C}$ .

A portion of each extract was concentrated by rotary evaporation and then analyzed by thin layer chromatography (TLC). The TLC development was in a saturated atmosphere using silica gel 60 F-254 TLC plates. The developing solvents used were cyclohexanone for RDX and petroleum ether:ethyl acetate:hexanes (160:80:25) and benzene:hexanes:pentane:acetone (50:40:10:3) for

TNT. The TNT TLC plates were developed in two directions. The separation of major TNT transformation products on a two dimensional TLC plate is illustrated in Fig. 2. Radiolabeled compounds on the TLC were located by autoradiography and were identified by comparing  $R_f$  values with authentic standards. Each  $^{14}\text{C}$  labeled spot was scraped from the TLC plates and counted by liquid scintillation counting to determine its activity. Following solvent extraction, the compost solids were freeze dried, weighed, and ground to a powder. Subsamples of the powder were combusted as previously described to determine residual  $^{14}\text{C}$  activity.

One RDX control and one TNT control compost were sacrificed at time 0 and duplicate samples were sacrificed for the 3 and 6 week composts. These samples were assayed for percent moisture ( $80^\circ\text{C}$  for 24 hours), pH (approximately 1:9 solid to water ratio), total Kjeldahl nitrogen content (6) and total carbon content. The total carbon was determined by combustion with the  $\text{CO}_2$  being trapped by NaOH solution, which was then titrated to the phenolphthalein end point.

All liquid scintillation counting was performed on a Beckman LS-7500. Samples were counted in the 300-655 window with automatic quench correction to adjust the window appropriately for varying levels of quench. Samples were corrected for quench from a standard quench curve using Beckman's H number as a measure of quench.

Greenhouse scale composts were 10 kg (dry weight) in size. The composting chambers were 38 x 56 x 46 cm wooden boxes sealed with varnish. Each chamber had a removable lid, which did not form an air tight seal when in place and was insulated on all sides to reduce heat loss from the compost. The composts were aerated by intermittently drawing fresh air from the top of each chamber down through the compost. The length of time the composts were aerated in a 10 min cycle was adjusted to control the temperature of the composts. Three thermocouples were placed in each compost and temperatures were recorded daily.

Duplicate composts containing 20,000  $\mu\text{g/g}$  (2% by weight) of TNT and duplicate composts containing 10,000  $\mu\text{g/g}$  (1% by weight) of RDX were prepared as previously described. In a preliminary study, it was determined that four replicate 50 g (wet weight) subsamples were adequate to estimate the explosive concentration in compost. The TNT composts were subsampled after 0, 3 and 4 weeks of composting. The RDX compost was subsampled after 0, 3 and 6 weeks of composting. An uncontaminated control compost was subsampled after 0, 3, 4 and 6 weeks of composting. The subsamples were extracted as described for the laboratory composts and TNT and RDX concentrations were determined by gas chromatography. For TNT analysis a 2 mm ID by 6 ft glass column packed with 1.57, OV17/1.95% OV210 on 80/100 Anakrom Q was used. The GC oven temperature was  $180^\circ\text{C}$  and the injection port was maintained at  $210^\circ\text{C}$ . The carrier gas was nitrogen at a flow rate of  $28\text{ cm}^3/\text{min}$ . The RDX concentrations were determined with a 2 ft glass column packed with 10% SE30 on 80/100 Supelcoport. The oven temperature was programmed from 180 to  $210^\circ\text{C}$  at  $10^\circ\text{C}$  per minute, the injection port was maintained at  $210^\circ\text{C}$  and the carrier gas ( $\text{N}_2$ ) flow rate was  $30\text{ cm}^3/\text{min}$ . Both TNT and RDX concentrations at the termination of the experiment were corrected for changes in the mass of the compost.

The  $^{14}\text{C}$  data from the laboratory study was subjected to statistical analysis. The percent recovery of  $^{14}\text{C}$  for each parameter was analyzed separately in a one-way analysis of variance to test for differences in recoveries with respect to length of time composting. Statistical evaluation of the recovery of TNT transformation products was not performed because of the low quantities of these materials isolated from the composts. Where statistical significance was indicated by the analysis of variance, the Student-Newman-Keul multiple range test was employed to compare means. All testing was done at the 5% level of significance.

## RESULTS AND DISCUSSION

### TNT Experiments

Composting in laboratory studies was successful in rapidly reducing TNT levels. Recovery of  $^{14}\text{C}$  as the parent TNT molecule

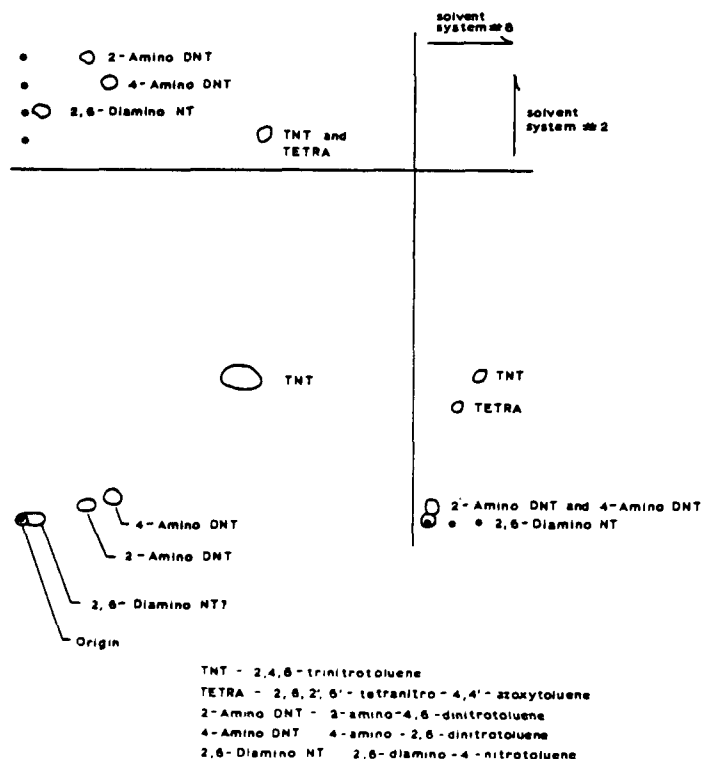


Figure 2.

Two Dimensional Thin Layer Chromatograph of a Six-Week TNT Compost Extract Including Metabolite Standards

TNT—2,4,6-trinitrotoluene; TETRA—2,6,2',6'-tetranitro-4,4'-azoxytoluene;  
2-Amino DNT—2-amino-4,6-dinitrotoluene; 4-Amino DNT—4-amino-2,6-dinitrotoluene;  
2,6-Diamino NT—2,6-diamino-4-nitrotoluene



was reduced from an average of 93.5% at time zero to 46.6 and 16.6% respectively after 3 and 6 weeks of composting, respectively (Table 1). Despite this substantial loss of TNT, only insignificant quantities of  $^{14}\text{C}$  were trapped as  $^{14}\text{CO}_2$  (Table 2) suggesting that cleavage of the TNT ring did not occur to any appreciable extent. Other volatile losses of  $^{14}\text{C}$  from the TNT composts (in  $\text{H}_2\text{SO}_4$  and carbon traps) were insignificant. Transformation of TNT through the reduction of nitro groups to amines, as reported in earlier work,<sup>3,4</sup> did not appear to be a primary mechanism of TNT loss during composting. No  $^{14}\text{C}$ -labeled amino derivatives of TNT were detected in the compost extract after 3 weeks of composting. After 6 weeks of composting only small quantities of 2-amino-2,4-dinitrotoluene and 4-amino-2,6-dinitrotoluene were found in the extract of one of three replicate composts. Negligible quantities of 2,6-diamino-4-nitrotoluene may have been present in the 6 week composts but the presence of polar materials in the solvent extract interfered with the identification and quantification of this compound.

The reduction of TNT levels in the compost was correlated to a reduction in the solvent extractable  $^{14}\text{C}$  ( $R=0.9997$ ) and was paralleled by a significant increase in residual  $^{14}\text{C}$  activity ( $R=0.9835$ ). The composting process apparently altered TNT to form products which are insoluble in benzene and/or are very strongly sorbed to the compost materials.

Analysis of the control composts indicated that the C/N ratio and percent moisture did not limit microbial activity (Table 3). Air

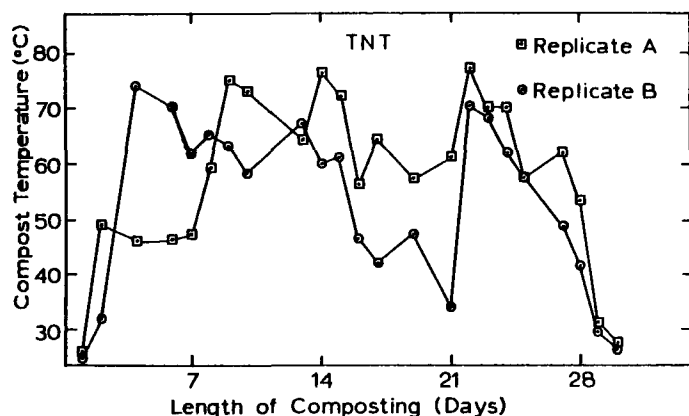


Figure 3.

Temperature Profiles for TNT Greenhouse Composts

Table 1.

 $^{14}\text{C}$  Recovery from TNT Laboratory Compost Extracts  
% of total  $^{14}\text{C}$ 

Length of Composting (wks)	Replicate	TNT	A†	B	C	D	E
0	A	89.8	---	---	---	---	---
3	B	88.8	---	---	---	---	---
	C	101.8	---	---	---	---	---
3	A	44.5	---	---	---	1.5	---
	B	48.9	---	---	---	1.0	---
	C	46.5	---	---	---	0.9	---
6	A	---	---	---	0.1	1.0	0.6*
	B	37.0	---	---	1.1	2.0	---
	C	12.9	0.6	1.1	0.8	0.9	---

A†—2-amino-2,4-dinitrotoluene

B—4-amino-2,6-dinitrotoluene

C—this was not a discrete spot on any chromatograph but an area that would contain 2,6-diamino-4-nitrotoluene if it were present

D—origin

E—other unidentified  $^{14}\text{C}$ -compounds†—no  $^{14}\text{C}$ -activity detected

\*—present in two spots

Table 2.  
 $^{14}\text{C}$  Recovered from Uniformly Ring-Labeled  $^{14}\text{C}$ -TNT Composted 0, 3 and 6 Weeks in the Laboratory  
% Recovery of  $^{14}\text{C}$

Length of Composting-Weeks	$^{14}\text{CO}_2$	$\text{H}_2\text{SO}_4$ trap	Carbon trap	Solvent extract	Residual $^{14}\text{C}$	Total
0	0.0 b†	0.0 a	0.0 a	93.5 a	1.7 c	95.2
3	0.2 b	0.0 a	0.0 a	47.8 b	37.8 b	85.8
6	0.5 a	0.0 a	0.0 a	19.3 c	66.5 a	86.3

†Values in a column not followed by the same letter are significantly different at the 5% level of probability according to the Student-Newman-Kuel multiple range test.

Table 3.  
The pH, Moisture Content and C/N of the Laboratory Control TNT Composts

Length of Composting	pH	Moisture (%)	C/N
0 wks	5.9	60.0	15.6
3 wks	8.1	58.8	14.9
3 wks	6.0	59.7	17.7
6 wks	8.0	61.9	13.4
6 wks	4.7	56.3	20.6

analyses of the compost atmospheres showed that the compost remained aerobic throughout the experiment.

Analysis of the extracts from the greenhouse scale composts confirmed the rapid disappearance of TNT observed in the laboratory scale composts. TNT levels were reduced by more than 99%, below the detection limit of  $16.9 \mu\text{g/g}$ , within three weeks (Table 4). The greenhouse composts maintained temperatures between 55 and  $75^\circ\text{C}$  with no external heat applied (Fig. 3). The elevated temperatures of the greenhouse compost evidently increased the efficiency of TNT transformation over that observed in the laboratory study.

## RDX

Laboratory studies demonstrated that RDX is rapidly metabolized in compost. The  $^{14}\text{C}$  recovered as RDX accounted for 112.3, 68.9 and 21.6% of the  $^{14}\text{C}$  initially added to the composts after 0, 3 and 6 weeks of composting, respectively (Table 5). Thin layer

Table 4.  
TNT Concentrations in Greenhouse Compost Material  
TNT ( $\mu\text{g/g}$ )

Sample	0 Week	3 Week	4 Week
Box 1 (control)	<17 †	<17	<17
Box 4	19,678	<17	<17
Box 5	20,404	<17	<17

†Detection limit for quantification of TNT from compost was  $19.6 \mu\text{g/g}$

Table 5.  
 $^{14}\text{C}$  Recovered from  $^{14}\text{C}$ -RDX Laboratory Composts at 0, 3 and 6 Weeks.

Length of Composting	$^{14}\text{CO}_2$	$\text{H}_2\text{SO}_4$ trap	Carbon trap	Solvent extract †	Residual $^{14}\text{C}$	Total
0 wks	0.0 c ‡	0.0 b	0.0	112.3 a	6.1 b	118.4
3 wks	19.6 b	0.3 a b	0.0	68.9 b	13.5 a	102.3
6 wks	55.8 a	0.7 a	0.0	21.6 c	16.1 a	94.2

† $^{14}\text{C}$ -RDX was the only detectable  $^{14}\text{C}$  component of the solvent extract

‡Values in a column not followed by the same letter are significantly different at the 5% level of probability according to the Student-Newman-Kuel multiple range test.

chromatographic analysis of the compost extracts indicated that RDX was the only  $^{14}\text{C}$  containing compound present in the extracts. No byproducts of RDX degradation were detected.

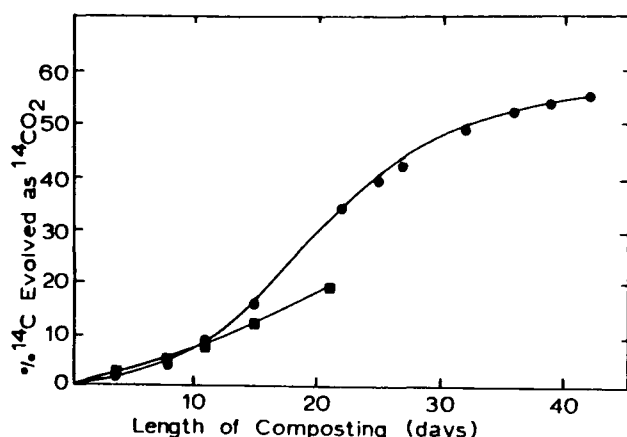


Figure 4.  
Cumulative Percent  $^{14}\text{C}$  Recovered as  $^{14}\text{CO}_2$  From  $^{14}\text{C}$ -Labeled RDX in Compost

Significant quantities of  $^{14}\text{C}$  were volatilized from the composts as  $^{14}\text{CO}_2$ . The cumulative average recovery of  $^{14}\text{CO}_2$  with length of composting is presented in Fig. 4. The rapid loss of  $^{14}\text{C}$ -RDX with the concurrent evolution of  $^{14}\text{CO}_2$  suggests that the RDX molecule is very quickly metabolized with a substantial portion of the carbon being released as  $\text{CO}_2$ . The breakdown products of RDX appear to be assimilated into the microbial biomass as quickly as they are produced. Initial losses of  $^{14}\text{C}$  as  $\text{CO}_2$  are therefore presumed to reflect the rate of RDX breakdown. However, as composting proceeded, increased amounts of  $^{14}\text{C}$  would be incorporated into the biomass resulting in additional  $^{14}\text{CO}_2$  losses through secondary metabolism.

On this basis, the  $^{14}\text{CO}_2$  recoveries can be used to estimate the breakdown of RDX with length of composting. Recovery of  $^{14}\text{CO}_2$  during the first four days of incubation showed that RDX degradation began shortly after compost initiation. The rate of RDX breakdown increased during the first two weeks of composting before reaching a maximum rate which was maintained for an additional week. During the last three weeks of the experiment, the rate of  $^{14}\text{CO}_2$  evolution declined. Depletion of RDX readily available for microbial attack, shifts in the microbial populations or decreased activities of select group(s) of compost organisms could be responsible for this decline.  $^{14}\text{CO}_2$  resulting from secondary metabolism probably constituted a significant portion of the  $^{14}\text{CO}_2$  recovery during the last two weeks of the study. Recovery of residual- $^{14}\text{CO}_2$  showed a statistically significant increase during the first three weeks of composting as a fraction of the carbon from RDX metabolism was incorporated into the microbial biomass. There was no substantial change in residual  $^{14}\text{C}$  between the three and six week composts presumably due to secondary metabolism of the  $^{14}\text{C}$  in the biomass with resultant  $^{14}\text{CO}_2$  evolution.

Analyses of the controls indicated that the composts were not limited by aeration, water or C/N ratio (Table 6).

Table 6.  
Moisture Content, pH and C/N of Laboratory RDX Control Composts

Sample	pH	% Moisture	C/N
0 week	5.9	60.0	14.8
3 week	8.3	66.3	13.4
3 week	4.8	53.1	19.0
6 week	8.5	64.5	11.4
6 week	8.5	70.1	12.7

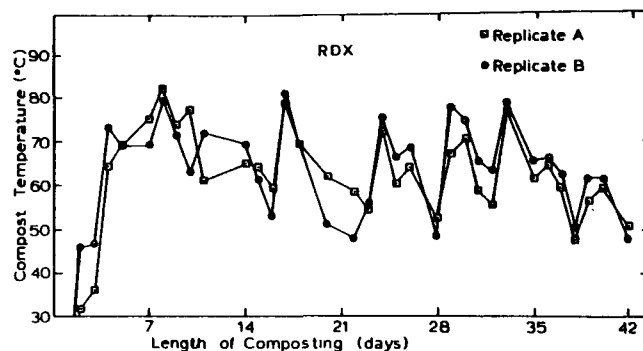


Figure 5.  
RDX Greenhouse Temperature Profiles

Breakdown of RDX in the greenhouse scale composts was initially more rapid than that observed in the laboratory (Table 7). After three weeks of composting, 55% of the RDX was degraded in the greenhouse composts compared to a 31% reduction in the laboratory composts. As with TNT, the temperature of the greenhouse composts was significantly higher than that of the laboratory composts (Fig. 5) and the increased rate of breakdown could have resulted from the elevated temperatures. The six week old composts from both greenhouse and laboratory experiments had approximately the same level of residual RDX (22% laboratory and 24% greenhouse). The increased temperatures and higher levels of microbial activity of the greenhouse composts were not more effective than the laboratory composts in reducing RDX over an extended period of composting.

Table 7.  
RDX Concentration in Greenhouse Compost Material  
μg/g in Compost

Compost	T <sub>0</sub> Week	T <sub>3</sub> Week	T <sub>6</sub> Week
Control	ND †	ND	ND
RDX	9,240	3,284	3,142
RDX	9,414	5,093	1,277

†Detection limit for quantification of RDX from compost was 794.7 μg/g

## CONCLUSIONS

TNT rapidly disappeared in both the 50 g laboratory and the 10 kg greenhouse scale composts. The rate of disappearance was much greater in greenhouse scale composts. It is assumed that the increased rates of disappearance are related to the higher temperatures and greater microbial activity of the larger scale composts. Recovery of  $^{14}\text{CO}_2$  from the laboratory composts was negligible suggesting that the benzene ring in TNT is not cleaved during composting. The recovery of very small quantities of  $^{14}\text{CO}$ -TNT reduction products in relation to the large disappearance of TNT suggests that the biotransformation pathway involving reduction of the nitro groups and subsequent polymerization<sup>3,4</sup> is not a primary route of TNT loss from the compost. It is hypothesized that a mechanism of TNT transformation unique to composting is responsible for incorporating the TNT ring structure into solvent insoluble residue in the compost.

Composting is an effective method for degrading RDX. A large portion of the ring carbon ( $^{14}\text{C}$ -labeled) was evolved as  $^{14}\text{CO}_2$  during six weeks of composting. The pattern of  $^{14}\text{CO}_2$  evolution indicated that RDX metabolism begins very quickly after composting is initiated and that the rate of degradation increases during the first two weeks of composting.  $^{14}\text{C}$ -labeled byproducts of RDX breakdown were not detected in acetone extracts of the composts at

any of the sampling times. Probably the RDX molecule is largely destroyed in the compost. After 6 weeks of composting 22 to 24% of the parent RDX molecule remained in both laboratory and greenhouse scale composts. No explanation for the relatively high levels of RDX remaining in both the laboratory scale and greenhouse scale composts after six weeks is apparent from the data. A build up of a substance(s) that inhibits or blocks RDX metabolism is possible. The consistency of the levels of residual RDX could be explained if this inhibitory material is synthesized either directly or indirectly as the result of RDX breakdown. Other possible phenomena that could have contributed to a high level of residual RDX include shifts in the compost microbial population as the compost ages, a general decrease in the microbial activity of the compost, and a bonding or adsorption of RDX to the compost materials thus reducing RDX susceptibility to microbial attack.

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# HAZARDOUS WASTE INCINERATION: CURRENT/FUTURE PROFILE

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## INTRODUCTION

The control of hazardous waste is one of USEPA's highest priorities for the 1980s. EPA estimates that 57 million tons of organic hazardous wastes are generated annually in the United States.<sup>1</sup> Approximately 70 percent of this waste could be disposed of by using thermal destruction technologies. USEPA regards incineration as a principal technology candidate for destroying hazardous waste. Since the Congress enacted the Resource Conservation and Recovery Act of 1976 (RCRA), incineration has been included among those hazardous waste disposal technologies that are regulated by the Agency.

The objective of the authors is to discuss: (1) the extent to which incinerators are currently being used in industry for the disposal of hazardous waste, (2) the basic characteristics of such incinerators, and (3) innovative technologies which are currently under investigation for possible future applications. Since incineration can serve as an alternate to land disposal for many hazardous wastes, this paper will assist those interested in uncontrolled waste site cleanup.

In 1980 EPA promulgated regulations requiring every facility which is treating, storing or disposing of hazardous waste to file Part A of the RCRA permit application form<sup>2</sup> under OMB permit No. 158-ROOXX. The data submitted on these forms was stored in a computer information system entitled "Hazardous Waste Data Management System" (MWDMS) which is operated in each of the 10 EPA Regions.

The Incineration Research Branch of USEPA's Industrial Environmental Research Laboratory in Cincinnati has expanded HWDMS and is developing the Hazardous Waste Control Technology Data Base (HWCTDB) to manage detailed incineration engineering data, trial burn data and related information.

The information presented in this paper is based on part of the data assembled for the HWCTDB project. The topics to be discussed include conventional incinerators, innovative technologies, a profile of existing incinerator facilities and a profile of incinerator manufacturers.

## CONVENTIONAL INCINERATORS

### Liquid Injection Incinerators

Liquid injection incinerators are currently the most commonly used type of incinerator for hazardous waste disposal. A wide variety of units is marketed today, with the two major types being horizontally- and vertically-fired units. A less common unit is the tangentially-fired vortex combustor.

As the name implies, the use of the liquid injection incinerator is confined to hazardous liquids, slurries and sludges with a viscosity value of 10,000 SSU or less. The reason for this limitation is that a liquid waste must be converted to a gas prior to combustion. An ideal size droplet is 40 microns or less, and is attainable mechanically using rotary cup or pressure atomization, or via gas-fluid nozzles and high pressure air or steam.

The key to efficient destruction of liquid hazardous wastes lies in minimizing unevaporated droplets and unreacted vapors. Typical combustion chamber residence time and temperature ranges are 0.5 to 2 sec and 1300°F to 3000°F, respectively. Liquid injection incinerators are variable dimensionally, and have feed rates up to

5,600 lb/hr.

The combustion chamber is a refractory-lined cylinder. Burners are normally located in the chamber so that the flames do not impinge on the refractory walls. The combustion chamber can be actively cooled by process air prior to its entry into the combustion zone, thus preheating the air to between 300°F and 700°F.

### Rotary Kilns

Rotary kiln incinerators are generally refractory-lined cylindrical shells mounted at a slight incline from the horizontal plane. The speed of rotation may be used to control the residence time and mixing with combustion air. They are generally used by industry, the military and municipalities to degrade solid and liquid combustible wastes, but combustible gases may also be oxidized. Recently, rotary kiln incinerators have been used to successfully dispose of obsolete chemical warfare agents and munitions.

Two types of rotary kilns are currently being manufactured in the United States: (1) cocurrent, with the burner at the front end with the waste feed, and (2) countercurrent, with the burner at the back end. Optimal length to diameter (L/D) ratios range from 2 to 10, and rotational speeds of 1 to 5 ft/min at the kiln periphery are common, depending on the nature of the waste. Residence times vary from a few seconds for a highly combustible gas, to a few hours for a low combustible solid waste. A typical feed capacity range is 1300 lb/hr to 4500 lb/hr for solids, and 630 lb/hr to 2250 lb/hr for liquids at temperatures ranging from 1475°F to 2900°F.

### Fluidized Beds

Fluidized bed incinerators are vessels containing a bed of inert granular material, usually sand, which is kept at temperatures in a range from 850°F to 1550°F.

Fluidizing air is passed through a distributor plate below the bed and agitates the heated granular material. Hazardous waste material and auxiliary fuel are injected radially in proportionately small amounts and mixed with the bed material which transfers heat to the waste. The waste in turn combusts and returns energy to the bed.

The reactor vessel is commonly about 20 to 25 ft in diameter and 30 ft high. Bed depths are typically 3 ft while at rest and 6 ft during operation. Variations in the depth affect both residence time and pressure drop, resulting in a compromised depth which optimizes residence time and excess air to ensure complete combustion.

### Multiple Hearths

A typical multiple hearth furnace includes a refractory-lined steel shell, a central shaft that rotates, and a series of rabble arms with teeth for each hearth. Sludge and/or granulated solid combustible waste is fed through the furnace roof by a screw feeder or belt and flapgate. The rotating air-cooled central shaft with air-cooled rabble arms and teeth distributes the waste material across the top hearth to drop holes. The waste falls to the next hearth and then the next and so on until discharged as ash at the bottom. The rabble arms also agitate the waste as it moves across the hearth to continually expose fresh surfaces to the hot gases.

## INNOVATIVE TECHNOLOGIES

### Molten Salt

Molten salt destruction<sup>3</sup> is a method of combusting organic material while, at the same time, scrubbing *in-situ*, any objectionable by-products of the combustion and thus preventing their emission in the effluent gas stream. This process of simultaneous combustion and scrubbing is accomplished by injecting the material to be burned with air, or oxygen enriched air, under the surface of a pool of molten sodium carbonate. The melt is maintained at approximately 1650 °F; at this temperature the organic hydrocarbons are immediately oxidized to carbon dioxide and water. Halogens in the waste form halide salts while phosphorus, sulfur, arsenic or silicon (from glass or ash in the waste) form oxygenated salts such as sodium phosphate, sulfate, arsenate or silicate. These products are retained in the melt as inorganic salts rather than released to the atmosphere as volatile gases.

In 1981, under contract to USEPA, Rockwell International tested hexachlorobenzene and chlordane in their pilot-scale molten salt reactor. The results show that the destruction and removal efficiency of their molten salt reactor exceeds 99.99% for these chemicals.

### High Temperature Fluid Wall

The high temperature fluid wall (HTFW) process is a high temperature process for quickly reducing organic wastes to their elemental state.<sup>4</sup> A cross-section of a typical high-temperature fluid-wall reactor is shown in Fig. 1. The reduction is carried out in a reactor which consists of a tubular core of porous refractory material capable of emitting sufficient radiant energy to activate reactants fed into the tubular space. The core material is designed to be of uniform porosity to allow the permeation of a radiation-transparent gas through the core wall into the interior. The core is completely jacketed and insulated in a fluid-tight pressure vessel. Electrodes located in the annular space between jacket and core provide the energy required to heat the core to radiant temperatures around 4000 °F.

During operation, the waste material to be pyrolyzed is finely ground to a 20 mesh and introduced into the top of the reactor. As the material falls through the tubular space it is exposed through radiative coupling to power densities of over 1200 watts/in<sup>2</sup>. The finely divided reactants are heated through the direct impingement of electromagnetic radiation.

Through a cooperative agreement between USEPA and the State of California, the developer of HTFW, Thalgard Inc., will test their 3 in. diameter reactor in late 1982 in California.

### Wet Air Oxidation

Wet air oxidation (WAD) is the aqueous phase oxidation of dissolved or suspended organic substances at elevated temperatures and pressures.<sup>5</sup> Water, which makes up the bulk of the aqueous phase, aids in catalyses to the oxidation reactions proceed at relatively low temperatures, 350 °F to 650 °F, and at the same time the water moderates the oxidation rates removing excess heat by evaporation. Water also provides an excellent heat transfer medium enabling the WAD process to be thermally self-sustaining with relatively low organic feed concentrations.

The oxygen required for the reactions is provided by an oxygen-containing gas, usually air, bubbled through the liquid phase in a reactor used to contain the process; this then is the derivation of the commonly used term "wet air oxidation." The process pressure is maintained at a level high enough to prevent excessive evaporation of the liquid phase, i.e. 200 to 3,000 psi.

Through a cooperative agreement between USEPA and the State of California, Casmalia Resource Management Inc. in California is in the process of installing a reactor in the Casmalia industrial dump site to detoxify wastes in the site. The manufacturer of the reactor, Zimpro Inc., will test other compounds of interest in the reactor in addition to the wastes at the site.

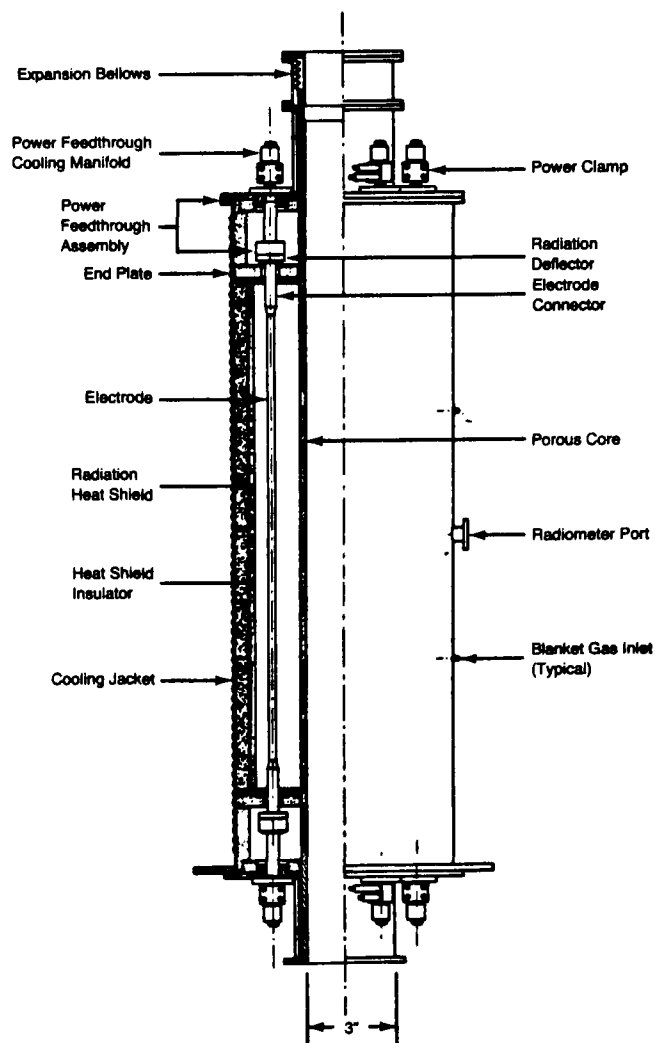


Figure 1.  
Cross-section of a typical high-temperature fluid-wall reactor

### Plasma Reactor

Plasma have been referred to as the fourth state of matter since they do not always behave as a solid, liquid or gas. A plasma may be defined as consisting of charged and neutral particles, having an overall charge of approximately zero, all exhibiting collective behavior.

The most common method of plasma generation is electrical discharge through a gas.<sup>6</sup> A typical plasma reaction vessel schematic is shown in Fig. 2. The plasma, when applied to waste disposal, can best be understood by thinking of it as an energy conversion and transfer device. A low pressure gas is used as a medium through which an electrical current is passed. The type of gas used is relatively unimportant in creating the discharge, but will ultimately affect the products formed. In passing through the gas, electrical energy is converted to thermal energy by absorption by the gas molecules, which are activated into ionized atomic states, losing electrons in the process. Arc temperatures up to 50,000 °C can be achieved along the centerline recirculation vortex. Ultra-violet radiation is emitted when molecules or atoms relax from the highly activated states to lower energy levels. Waste materials are atomized, ionized, and finally destroyed as they interact with the decaying plasma species. The products which result are simple because their activated states are atomic.

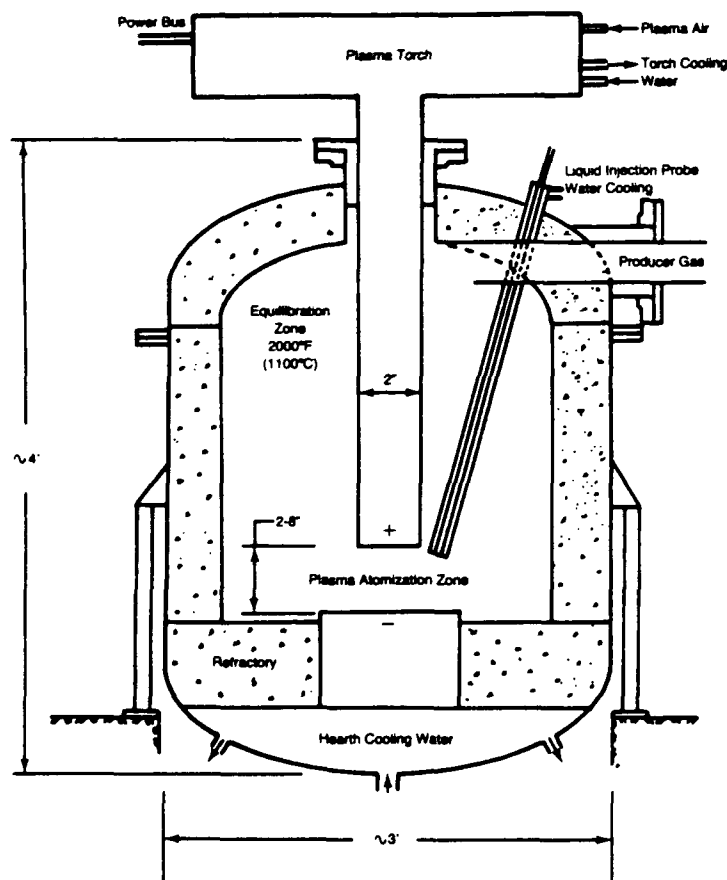


Figure 2.  
Plasma reaction vessel schematic

USEPA and the State of New York are currently in negotiations to form a cooperative agreement to build a mobile plasma reactor with a capacity of 50 gal/hr. The objective is to destroy sludges from the Love Canal treatment facilities.

### PROFILE OF EXISTING INCINERATION FACILITIES

The existing facilities data discussed in this paper were assembled in support of the Regulatory Impact Analysis Program for hazardous waste incineration. The approach to the data assembly began with preparation of a list of all known facilities which might have one or more operational hazardous waste incinerators. As of the Nov. 30, 1981 cutoff date established for this list, 612 such facilities were identified. The HWDMS contained 566 of these and 46 were identified from other sources. However, at that time, it was known that some of the Part A applications had not yet been entered into HWDMS. Based on later information obtained from HWDMS in July 1982 (estimated 100% complete), it was calculated that the list of 612 facilities was approximately 90% complete.

Initial telephone contacts with many of these facilities revealed that a significant number did not have an operational hazardous waste incinerator. Of the 612 facilities, a total of 537 facility spokesmen indicated whether or not their facility had an operational hazardous waste incinerator and provided varying amounts of additional information. The summary findings discussed here are based on the information verified by these 537 facilities.

The hazardous waste incineration status of these 537 facilities divided by USEPA regions is shown in Table 1. A total of 284 operational HW incinerators were identified at 219 facilities. Thus only 40.8% of the facilities contacted verified having an operational HW incinerator. Inspection of the list of facilities in the HWDMS data base in July 1982 showed that there were 128 facilities not previously contacted during the telephone campaign. If it is assumed that these facilities have the same verification rate as those contacted earlier, then an additional 52 facilities should

have 68 operational HW incinerators. Therefore, there are approximately 350 operational HW incinerators at 270 facilities in the United States.

The number of operational HW incinerators by type is shown in Table 2. Of the 264 incinerators whose type was specified, 208 (79%) are capable of burning liquids by injection. Twenty-nine units (11%) are capable of burning bulk wastes (solids or liquids). The remaining types are mostly special purpose units such as steel drum reconditioning burners or military ammunition disposal units.

Table 1.  
Status of Hazardous Waste Incineration Facilities  
in Each EPA Region\*

Region	Operational Facil.	Operational Incin.	No. Operational HWI	Under Constr	Status Unknown	Sample Size
I	10	12	34	3	1	48
II	22	28	46	4	1	73
III	23	30	48	5	0	76
IV	46	59	52	6†	0	102
V	29	31	44	3	0	76
VI	62	95	28	4†	0	93
VII	8	8	11	3	0	22
VIII	5	5	9	1	1	16
IX	14	16	14	3	0	31
X	0	0	0	0†	0	0
Total	219	284	286	32†	3	537

\*Information obtained from an estimated 81% of the HWI facility population.

†3 facilities have both an operational unit and a unit under construction; 2 in Region IV and 1 in Region VI.

Table 2.  
Type and Number of Operational HW Incinerators\*

Type	Number	% of Total Specified
Liquid Injection	136	51
Hearth with Liquid Injection	33	12
Fume with Liquid Injection	24	9
Rotary Kiln with Liquid Injection	10	4
Combination System†	5	2
Rotary Kiln (Solids Only)	1	1
Hearth (Solids Only)	23	9
Ammunition and Explosives	12	5
Drum Burner	7	3
Other‡	13	5
Total Specified	264	100
Type not Specified	20	
Total	284	

\*Information obtained from an estimated 81% of the HWI facility population.

†Includes interconnected multiple units (e.g., rotary kiln in series with liquid injection unit).

‡Includes such items as fluidized bed incinerators.

The design capacities of operational HW incinerators are shown in Table 3. Design capacities were reported for 180 incinerators burning liquids and 44 incinerators burning solids. The median design capacity of incinerators burning liquids is 150 gal/hr with most units (86%) not exceeding 1000 gal/hr. Incinerators burning solids tend to have similar capacities with the median being approximately 650 lb/hr (equivalent to 78 gal of water).

The temperature and gaseous residence time for operational HW incinerators is shown in Table 4. Combustion temperatures were reported for 173 incinerators. Gaseous residence times were reported for 104 incinerators. The median combustion temperature was approximately 1800 °F, and median gaseous residence time was slightly under 2 sec.

Table 3.

## Design Capacity of Operational Hazardous Waste Incinerators\*

Incinerators Burning Liquids				Incinerators Burning Solids			
Capacity (gal/hr)	No.	% of Total Specified		Capacity (lb/hr)	No.	% of Total Specified	
0- 50	48	27		0- 100	4	9	
51- 100	28	16		101- 300	5	11	
101- 200	22	12		301- 500	12	27	
201- 300	22	7		501- 1,000	6	14	
301- 500	23	13		2,001- 5,000	7	16	
1000- 2,000	17	9		5,001-10,000	1	2	
2001-10,000	8	4		10,001-20,000	2	5	
Total Specified	180	100		Total Specified	44	100	
Unspecified	28			Unspecified	17		
Total	208			Total	61		

\*Information obtained from an estimated 81% of the HWI facility population.

Table 4.

## Temperature and Gaseous Residence Time for Operational Hazardous Waste Incinerators\*

Maximum Temperature						
Residence Time	<1600 °F	1600 °F -1900 °F	1901 °F -2200 °F	>2200 °F	Not Specified	Total
<1.0 sec	7	2	0	4	1	14
1.0-1.9 sec	8	17	6	5	4	40
≥2.0 sec	8	3	32	7	0	50
Not Specified	13	42	12	7	106	180
Total	36	64	50	23	111	284

\*Information obtained from an estimated 81% of the HWI facility population.

The major wastes burned and the number of facilities reporting these wastes are shown in Table 5. Most of the wastes reported are liquids, principally spent non-halogenated solvents and aqueous solutions of corrosives, reactives or ignitables. About 600,000 tons per year of wastes were actually weak aqueous solutions containing only a few percent of the hazardous substance reported. These solutions accounted for 59% by weight of all wastes reported. The most frequently reported waste was the non-listed ignitable waste with high heat content ( $\approx 6000$  Btu/lb). This waste was reported for 69 incinerators. The largest single category of waste by weight was

non-halogenated solvents (USEPA Code F003) accounting for 233,000 tons per year at 18 incinerators.

## PROFILE OF THE HAZARDOUS WASTE INCINERATOR MANUFACTURING INDUSTRY

During February and March 1981, incinerator manufacturers were contacted in order to determine those marketing hazardous waste units. Four directories were used to provide names, addresses and some telephone numbers of manufacturers:

- 1981 Chemical Engineering Catalog
- February 1981 Buyer's Guide, Pollution Equipment News
- 1981 Catalog and Buyer's Guide, Pollution Equipment News
- 1980-81 Directory and Resource Book, Air Pollution Control Association

Hazardous waste incinerator manufacturers were asked to voluntarily provide information about the types of incinerators manufactured, the approximate number of units sold between 1969 and 1981, and design and operation information. 1969 was selected as a cutoff date based upon several manufacturers' estimates that 12 years of useful service may be expected from a hazardous waste incinerator. A summary of the number of manufacturing companies and the number of incinerators in service classified by type is presented in Table 6.

Liquid injection incinerators are most prevalent with 64.0% of the market, hearth incinerators comprise 20.8% of the units sold, and 12.3% of the incinerators are rotary kilns. These three types account for 97% of the units manufactured.

Of the 57 companies identified as marketing hazardous waste incinerators, 28 have sold no units in the United States. Apparently many of the companies that have not sold an incinerator are anticipating a large market growth. Of the 23 companies marketing liquid injection incinerators, eight have sold none to date; eight of the 17 companies offering rotary kiln incinerators have sold none to date; and five of the nine companies offering fluidized bed incinerators have sold none to date. All hearth incinerator manufacturers have sold at least one unit. Most of the companies offering innovative incineration technology have not sold any units to date.

Incinerator capacities may be rated by the thermal input or the mass input to the combustion chambers. The ranges and typical values of the capacities of the major types of incinerators are given in Table 7. Hearth incinerators generally have the smallest capacity of the major types, although rotary hearths can be constructed with

Table 5.

## Number of NW Incinerators Reporting Major Wastes and Quantity Burned\*

			Number of Incinerators Reporting		
EPA	Description	Waste	Quantity	Quantity Short Tons/Yr	
D001	Ignitables (High Btu, High HW)†	69	60	39,578	
D001	Ignitables (Low Btu, Low HW)	19	17	140,015	
D001	Ignitables (High Btu, Low HW)	6	3	5,870	
D001	Ignitables (Waste Light Oils)	3	2	1,610	
D001	Ignitables (Unspecified)	7	5	21,190	
D002, D003	Corrosives and Reactives	32	30	191,895	
F001, F002	Spent Halogenated Solvents	18	11	17,945	
F003	Spent Non-Halogenated Solvents	22	18	233,120	
F005	Spent Non-Halogenated Solvents	24	21	18,253	
K011	Acrylonitrile Production Bottoms	3	3	120,000	
K016-K020	Hvy. Ends, C1 Chemical Production	10	10	38,165	
K049	Slop Oil Solids, Petroleum Ref.	1	1	5,000	
P063	Discarded Hydrocyanic Acid	6	5	135,325	
U220	Discarded Toluene	3	3	10,801	

\*Information obtained from an estimated 81% of the HWI facility population.

†High Btu = 6000 Btu per pound

High HW = major portion of waste is hazardous (e.g., organic liquids)

Low HW = major portion of waste is non-hazardous (e.g., contaminated water)



capacities up to 170 million Btu/hr. Typical rotary kiln and liquid injection incinerators have approximately the same capacity. Although the largest incinerator listed in Table 7 has a capacity of 150 million Btu/hr, some manufacturers have received requests to bid on facilities as large as 300 million Btu/hr.

**Table 6.**  
**Number of Hazardous Waste Incinerators Sold in the United States**

Type of Incinerator	No. of Mfg Co	HW Incin Sold	% of Total
Liquid Injection	23	219	64.0
Fixed Hearth	12	59	17.3
Rotary Kiln	17	42*†	12.3
Fluidized Bed	9	9	2.6
Multiple Chamber Hearth	2	7	2.0
Pulse Hearth	1	2	0.6
Rotary Hearth	1	2‡	0.6
Salt Bath	2	0	---
Induction Heating	1	0	---
Reciprocating Grate	1	1	0.3
Infrared Heating	1	1‡	0.3
Open Drum	1	0	---
Total		342	100.0

\*Includes five units in construction

†Includes one oscillating kiln

‡One unit is in construction

and the waste characteristics. The most important operating conditions are the combustion zone temperature, combustion gas residence time at elevated temperature, and excess air usage. Typical operating conditions are summarized in Table 8. Hazardous waste incinerators may be designed to operate outside the ranges of these typical values. These data are obtained from a relatively small sampling of incinerator manufacturers and may not be indicative of the entire industry. Incinerator manufacturers often determine operating conditions from trial burns or a customer's waste.

#### COMPARISON OF OPERATIONAL DATA WITH MANUFACTURERS' DATA

A comparison of the number of HW incinerators reported by manufacturers and existing HW facilities is made in Table 9. A total of 284 operational HW incinerators were identified at 219 facilities. If a projection of these facility figures is made to account for the estimated 128 facilities from which data were not obtained, the total operational HW incinerator population would be approximately 350 at 270 facilities. This figure agrees very well with the 335 operational units reported by manufacturers. In contrast, existing facilities reported 32 units under construction which is much higher than the 7 reported by the manufacturers.

A comparison of the types of operational HW incinerators reported by manufacturers and HW facilities is made in Table 10. The manufacturers' data and the projected total existing population agree extremely well for the liquid injection and hearth type incinerators. However, the rotary kiln population reported by manufacturers is more than double the number reported by

**Table 7.**  
**Design Capacities of Hazardous Waste Incinerator Types**  
**(From Manufacturers' Data)**

Incinerator Type	Range (lb/hr)	Mass Capacity		Range (10 <sup>6</sup> Btu/hr)	Thermal Capacity	
		Statistical Value and Population	Typical Value (lb/hr)		Statistical Value and Population	Typical Value (10 <sup>6</sup> Btu/hr)
Liquid Injection	30-24,500	Median 43	1,600	0.125-130	Median 50	8
Hearth	25- 2,500	Average 48	810	3- 9	Average 4	4.9
Rotary Kiln	1200- 2,080	Average 2	1,600	1-150	Median 34	10.3
Fluidized Bed	--	-- 1	31,000	8.5- 67	Average 5	45.5

In addition to the refractory lined combustion chamber, hazardous waste incinerators may be equipped with automated loading and ash removal systems, energy recovery equipment and air pollution control equipment. The most prevalent energy recovery equipment is a firetube or watertube boiler generating steam. Air pollution control equipment is located downstream of the combustion chamber and energy recovery equipment. It may consist of one or more of the following components:

- Quench chamber to cool combustion gases
- Particulate collection device
  - Venturi scrubber
  - Baghouse
  - Electrostatic precipitator
  - Cyclone
  - Ionizing wet scrubber
- Gas absorbing device
  - Packed tower scrubber
  - Plate or tray scrubber
  - Spray tower scrubber
  - Ionizing wet scrubber

Most hazardous waste incinerator manufacturers buy energy recovery and air pollution control equipment from vendors rather than manufacture the equipment.

Incinerator manufacturers design hazardous waste units to operate at specific conditions depending on the type of incinerator

**Table 8.**  
**Ranges of Incinerator Operating Conditions**  
**(From Manufacturers' Data)**

Incinerator Type	Combustn Zone Temp (°F)	Combustion Gas Residence Time (sec)	Excess Air (% stoichiometric)
Liquid Injection	1800-3000	0.3-2.0	120-250
Rotary Kiln	1200-2300	2 hr (solids)	50-250
Afterburner	2000-2500	1.0-3.0	120-200
Hearth			
Primary Chamber	1200-1800	---	30-200
Secondary Chamber	1400-2200	1.5-2.5	200-400
Fluidized Bed	1400-2000	1.0-5.0	100-150

facilities. Reasons for the discrepancies may include: some of the units sold since 1969 may no longer be in use or may now burn non-hazardous wastes; some manufacturers might not have been given enough information to know whether the customer's wastes are hazardous; or, some manufacturers may not know if the customer's wastes are regulated under RCRA or the Toxic Substances Control Act. All of these may cause high or low estimates of the number of incinerators.

**Table 9.**  
**Comparison of Number of HW Incinerators Reported by**  
**Manufacturers and HWI Facilities**

	Reported by HWI Facilities Contacted		
	Actual No. Reported	Proj. for Total Popula.	Rep'd by Mfr's
Operational Incinerators	284	350	335
Units Under Construction	32	40	7
Total Reported	316	390	342

**Table 10.**  
**Comparison of the Types of Operational HW Incinerators**  
**Reported by Manufacturers and HWI Facilities**

	Reported by HWI Facilities Contacted		
	Actual No. Rep'd	Proj. for Total Popula.	Rep'd by Mfr
Liquid Injection	160*	213	219
Hearths	56†	75	70
Rotary Kiln	13† ‡	17	37
Fluidized Bed	4	5	9
Others	31**	42	††
Types Not Specified	20	0	††
Total Opera- tional	284	352	335

\*Includes fume/liquid units

†Includes units both with and without liquid injection

‡Includes 2 rotary kilns in combination units

\*\*Includes 3 combination units not having a rotary kiln

††This category not obtained from manufacturers

## CONCLUSIONS

In this paper the authors have presented a brief discussion of hazardous waste incineration, including: (1) the technologies, (2) existing facilities, and (3) incinerator manufacturing. A wide variety of incinerators were shown to be in operation throughout the nation.

In addition, new processes offer promise for improvement in the capability for more complete hazardous waste destruction and extension of this capability to cover a wider range of wastes. It is becoming increasingly undesirable to select untreated landfilling as the method for disposal of hazardous wastes. Many other options are preferable.

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# THE USE OF GROUT CHEMISTRY AND TECHNOLOGY IN THE CONTAINMENT OF HAZARDOUS WASTES

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## INTRODUCTION

Uncontrolled hazardous waste sites include a wide variety of waste disposal locations where toxic wastes from manufacturing or mining activities have been discarded or dumped in a manner that poses a threat to human health and the environment. The potential pollutants vary from highly toxic organics to inorganic weathering products from mine spoils. In the superfund list of 160 problem sites, 134 sites involve significant pollution from toxic organics and 26 involved inorganic industrial wastes (such as battery or plating wastes), mine tailings or mine drainage or slag. The wastes at the disposal sites can be in tanks, lagoons, drummed storage or waste piles. In most cases, soil and groundwater contamination from leakage or intentional discharge is already evident. Remedial actions at the sites usually take the form of removing waste to a safer location and/or developing a strategy for on-site containment by installing barriers to control waste movement or by immobilizing toxic constituents in place.

In this paper, the authors discuss grouting technology and grouting equipment in remedial actions other than diversion of un-contaminated groundwater. While grouts have long been used to stabilize soils for foundations or to produce barriers to control groundwater movement in tunnelling or excavation, there are other aspects of grout chemistry that can be used to directly restrict chemical transport from waste materials.

## GROUTS AND GROUTING METHODS

Grouting involves the injection of liquid solution or suspensions into granular materials to fill voids and cement the particles together

so as to restrict fluid flow in the media or improve its strength or bearing capacity.<sup>1,2</sup> Two classes of grouting materials are generally recognized: (1) particulate grouts and, (2) chemical grouts (Table 1). The particulate grouts are generally Portland cement and blends of clay and Portland cement. The chemical grouts are solutions or emulsions of various types that "gel" or polymerize after injection. Table 1 includes data on some of the types of chemical grouts that are currently available and are potentially of use.<sup>3</sup> These materials have very little in common except that each can be made into a low viscosity, injectable liquid that will "gell" or polymerize to form a solid or highly viscous fluid within a particulate medium.

Typically, grouts are injected into sediments using a perforated pipe with expandable packers to restrict the movement of grout in the boring. The pressures used during injection are relatively low, being not more than 1 psi for each foot of overburden. Excessive pressures can cause the porous medium to be fractured or wedged open. Natural planes of weakness or porous zones in an alluvial unit will accept more grout. By using expandable packers in a boring, grout can be restricted to specific horizons and each horizon can be grouted to capacity. A typical grouting setup includes a mixer, an agitator; a pressure pump and an injection system (Fig. 1).

Grouts are typically injected by pumping the grout into sections of a prepared boring. In alluvial material, it is necessary to inject an annular layer of grout into the boring to hold it open for introduction of more grout at each horizon. The annular grout is fractured by pressure during subsequent grout injection. Second phase injection grouts the porous units further out from the borehole.

Table 1.  
Examples of Grouts Potentially Useful in Waste Immobilization<sup>(1-6)</sup>

Group	Type	Gelling System	Special Characteristics
Particulate	Clay-Cement	Solidification of Portland cement.	Clay can be selected to bind specific metals.
Particulate	Clay	Swelling and gelation of expanding clays.	Clay can be selected for particular chemical properties.
Chemical	Sodium Silicate	Polymerization to form silica gel on mixing with salts or acids.	Reaction is known to bind heavy metals. System is highly alkaline.
Chemical	Cationic Asphalt Emulsion	Emulsion is broken by adding hydrated lime slurry.	System is highly alkaline, material remains pliable after gelation; coating of mineral grains occurs.
Chemical	Resorcinol	Polymer is formed with formaldehyde. Reaction is catalysed with hydrochloric acid.	System is acidic at gelation. pH 1.5-2.5.
Chemical	Polyurethane	Polymer is formed by combination of polyisocyanates with polyols, polyethers, glycols or castor oil. Reaction is catalysed with tertiary amines and tin salts.	System will polymerize at a wide range of pH's.

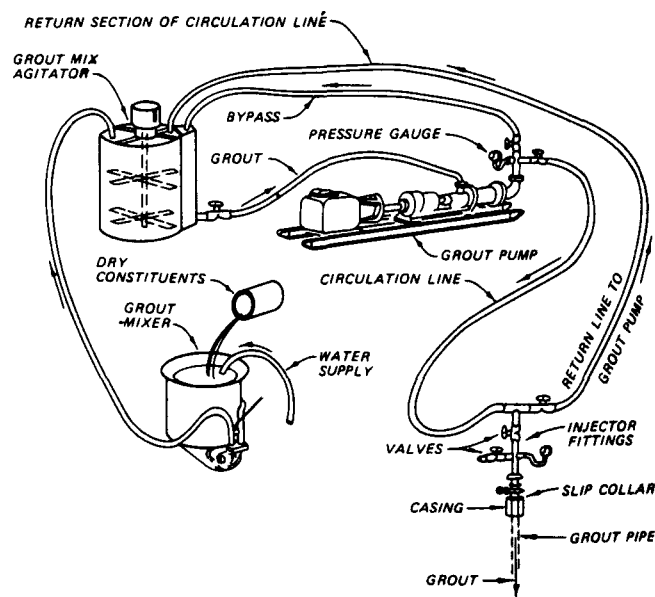


Figure 1.  
Example of a typical grouting setup for a recirculating system.<sup>(1,2)</sup>

The grouts are typically mixed by the batch method using a highshear mixer and the prepared grout is pumped into an agitator that keeps the material mixed during injection. Set time or gelling time is regulated by mixing in gelling accelerators or retardants. A positive pressure pump is used to move the grout into the bore hole. Pressures are regulated using the pump in conjunction with a system of valves and bypass lines.

Where chemical grouts are used, specialized equipment is added to meter the components of the grout and stationary inline mixers can be used for blending. Often, care must be taken to use non-corroding, non-reactive materials in pumps and piping.

### APPLICATION OF GROUTING AT WASTE SITES

Grouting technology can potentially be used in a variety of ways to provide better waste containment at a disposal site (Fig. 2). Shallow grouting can be employed to improve the cover over a waste site by employing closely-spaced, shallow grout injections to develop a nearly impervious layer in the existing cover. Closely-spaced, shallow grouting could also be employed to prevent the dispersal of contaminated soils (or mine spills) at a disposal site and to reduce infiltration and transport of toxic contaminant to the water table. The viscosity and particle size of a grouting material generally restricts the type of sediment or alluvium that a grout can penetrate. For chemical grouts, the lower the viscosity, the finer the grain size of the sediment that can be penetrated.

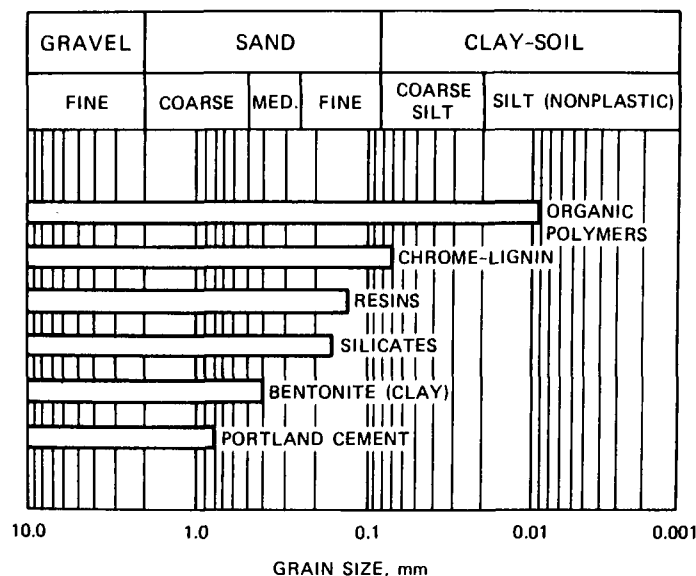


Figure 3.  
Grouts typically used in different soil types.<sup>(1)</sup>

a continuous seal is developed. Grout is normally injected as bulbs of material and care would have to be taken in planning injection holes to assure that the bulbs of grout merge to form a continuous bottom seal.

An optional strategy would involve grouting back up into the waste and producing a solidified waste mass. This approach would require much more grout and would involve injecting into wastes that frequently are fine-grained (clay-sized) materials.<sup>8</sup> This technique involves some uncertainty with regard to the completeness of the treatment. If the grout can restrict contaminant movement because it alters the pH or bonds the toxic materials chemically, even partial grouting may reduce the rate of escape of contaminants.

Complete waste solidification could be assured if the waste were pumped or dug out and mixed into the grout and pumped into a second storage site to gel or set (Fig. 2). This approach of combining the waste directly with a grout has been used successfully with radioactive waste where the material was immobilized and injected into geologic strata with very low permeability.<sup>9</sup>

The four basic approaches to using grout chemistry and technology in remedial action can be combined a variety of ways to improve waste containment. In most cases, the same material and equipment could be employed. It would be possible to bottom seal, top seal and solidify surrounding contaminated soils using very similar mixers, pumps and injection equipment.

### Waste/Grout Interactions

Most grout formulations used in foundation and construction applications are tolerant systems that set under adverse conditions; but chemical waste may contain materials that can prevent a set or degrade the grout. The usefulness of the grouts in waste containment can be improved by selecting grouts or adding materials that bind or sorb specific contaminants.

Cement and silicate grouts are alkaline systems and the high pH's produced in a waste generally reduce the mobility of toxic metals. Clay grout with specific absorption characteristics can be employed to retain toxic metals.

As a group, organic pollutants may be the least easily retained wastes.<sup>10</sup> The use of specific sorbents for organics may be helpful in improving containment.

Problems related to compatibility and chemisorptive properties are illustrated in Table 2. Fillers can be added to many grouts to increase absorption. For example, clays, diatomaceous earth, and fly ash are common fillers in cement grouts. Organophilic materials as fillers in grout may enhance adsorption and allow the grouts to be used as chemical barriers to toxic organics.

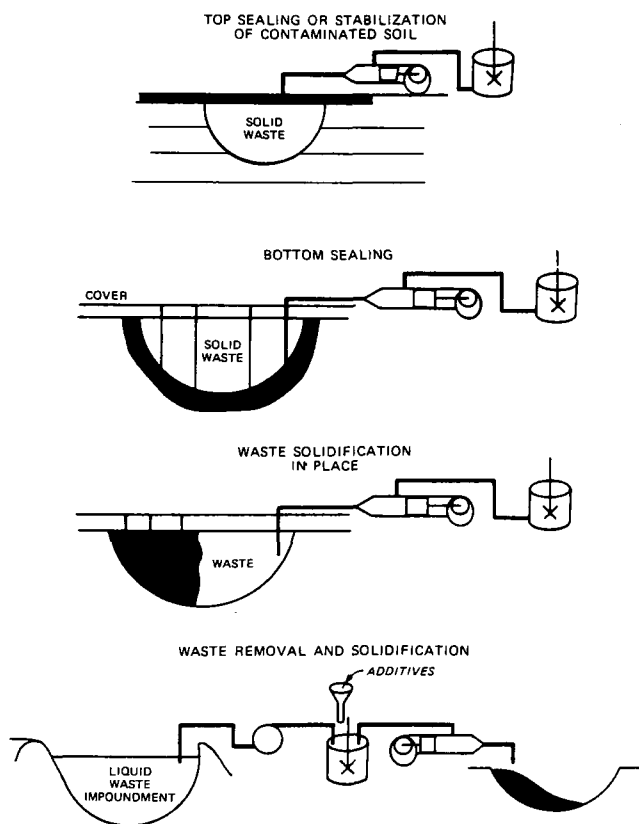


Figure 2.  
Techniques for employing grouts in hazardous waste containment.

In particulate grouts, the grain size of the grout is the limiting factor. Particulate grouts are generally restricted to materials that have an average grain size of medium sand or greater (Fig. 3). The organic polymer grouts can be used in materials as fine as a medium silt. Organic polymer grouts also have more closely regulated setting times; a characteristic that is very necessary when silts are being injected.

Bottom sealing involves injecting grout into granular material below the waste. This approach has been suggested by Tolman.<sup>7</sup> The major difficulty in employing grout in this way is assuring that

**Table 2.**  
**Compatibility and Chemisorptive Properties**  
**for Selected Types of Grout**

Grout Type	Materials known to cause set retardation or degradation	Materials known to be chemisorbed
Clay or Cement/Clay	High concentrations of metal salts or some organics prevent setting. Smectite clays are adversely affected by many organics.	Metals may be selectively sorb on some clays.
Sodium Silicate	Presence of acids or concentrated salts can cause early gelation.	Silica gels trap divalent and trivalent metals.
Cationic Asphalt Emulsion	Organic solvents especially hydrocarbons can soften asphalts.	---
Resorcinol	Presence of strong bases can retard set.	---
Polyurethane	Ammonia or ammonium hydroxide inhibit gel formation. Strong bases cause swelling.	Foam is used as a sorbent for benzene, kerosene, n-butylaldehyde, and phenol.

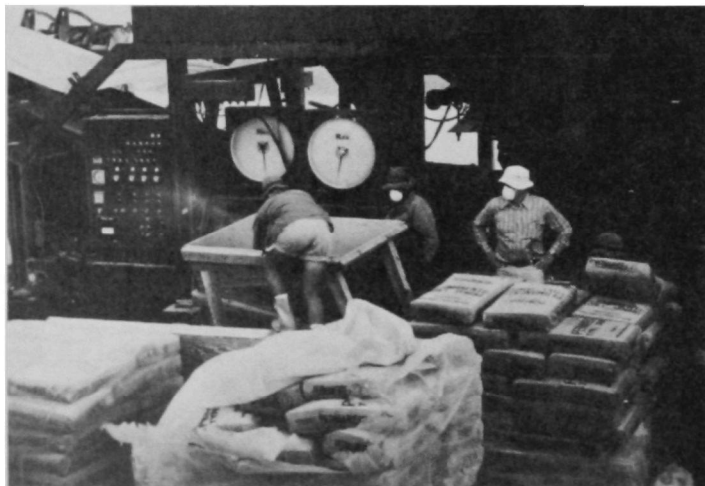
## EXAMPLES OF GROUTING IN WASTE CONTAINMENT

### Madawaska Uranium Mine, Bancroft, Ontario

The mine used an acid leaching process to remove uranium from ore. The tailings were placed in a disposal area surrounded by a tailings dam. The mine water contained approximately 35 picocuries/liter of radium-226.<sup>11</sup>

There was particular concern that mine water was seeping through the mine tailings and into a recreational lake near the mill site. Canadian regulations require that all discharge water contain less than 3 picocuries/liter.

Grout mixtures of illite, smectite, and bravaisite clays (a mixed clay) and cement were prepared and pumped into a triple line of bore holes placed between the lake and the tailings pond. Even before the project was complete, the amount of dissolved radium in water collected below the barrier showed a definite decline. The clay/cement slurries adsorbed the radium from the seepage water, creating a chemical barrier for the radium, but water still moved through the barrier. Approximately 2,600 tons of grout were placed in the grout curtain. It has been estimated that the amount of clay involved is sufficient to adsorb the radium escaping from the pond for thousands of years.



**Figure 4.**  
Batch plant used for the preparation of grout/waste mixtures at Runit Island, Eniwetok Atoll.

### Runit Island, Eniwetok Atoll Test Site

In 1978, an effort was undertaken by the U.S. Army Corps of Engineers to decontaminate areas on several islands associated with the hydrogen bomb testing in the 1950s. Several areas of contaminated coral sand were to be contained. A grout batch plant (Fig. 4) was fabricated on the site and the waste was mixed directly into a Portland cement grout and pumped into a large blast crater on the island. The batch plant separated the coral sand fines in a screening operation and mixed them with Portland cement and an attapulgite-based suspending agent and sea water.

The grout was pumped approximately 300 ft and laid down in bottom of a blast crater (Fig. 5). The grout was designed to set up under salt water and contain a minimum amount of cement with the maximum amount of waste. Formulation for lowest cement content grout proposed consisted of:

Component	Weight (lb)
Portland Type I	264
Eniwetok fines	1827
Attapulgite	47
Friction Reducer	2.8
Salt water	810
Total	2950

Laboratory batches of grout showed an unconfined compressive strength of 135 psi after seven days.<sup>12</sup>

An 18 in. thick concrete cap was placed over the hardened grout/waste mixture. The solidification process has been considered successful in containing the radioactive constituents in the contaminated sand and the grout had satisfactory engineering properties.

## CONCLUSIONS

Grout chemistry and grout technology can be useful in the treatment and containment of some types of toxic wastes. Grouts can be applied as barriers to water or waste movement or mixed directly with the waste. Because a wide variety of grouts have been developed and the advanced technology is available for their formulation, mixing and/or injection, they will find increased use where *in-situ* containment of waste is necessary. Examples of successful applications to large scale waste problems are already available. The most obvious potential application involves sites where widespread low-level contamination (mine tailings or contaminated soil) is the major problem.



**Figure 5.**  
Grout pipeline and grout placement system at Cactus Crater, Runit Island, Eniwetok Atoll.

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# CRITERIA FOR COMMERCIAL DISPOSAL OF HAZARDOUS WASTE

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## INTRODUCTION

Specific techniques and needs of off-site hazardous waste treatment firms are not well known. Even for chemists with some background in waste water chemistry, the day to day goals, specifications, and problems associated with the operation of a commercial treatment plant, are often foreign.

The burden of managing a generator's hazardous wastes usually falls on the engineering department of that generator. Therefore, an engineer's knowledge of what commercial firms look for in their daily operations is critical for cost effective collection and segregation of wastes.

Many times a simple policy instituted at the point of generation could mean the difference between getting paid \$15.00-\$30.00 for a drum of waste or having to pay nearly \$100.00 per drum in disposal charges. This often happens when a company is generating flammable organic wastes (e.g., xylene, toluene, various thinners) and chlorinated solvents (e.g., 1,1,1-trichloroethane, TCE, other degreasing solvents). If these wastes are mixed in the same drum when collected, the disposal option is usually limited to high temperature destructive incineration. The cost for this technique in drummed quantities is in the \$100.00 per drum range.

If on the other hand these wastes were kept separate, that is if the chlorinated materials were collected in different drums from the flammables, the disposal costs would be dramatically different. Unmixed chlorinated solvents with a high enough recoverable yield are often purchased from generators by reclaimers. Flammable solvents with a low halogen content can be used for their thermal value and usually incur a low disposal charge.

This same kind of information on how an outside TSDF (treatment, storage and disposal facility) operates is also essential for a consulting engineer who finds himself facing a mountain of thousands of drums, two 500,000 gal lagoons, and one million gal of tankage on an abandoned site. If a consulting engineer were trying to prepare a meaningful bid package in the above situation, but did not know what criteria would be needed by the TSDFs, chances are the figures quoted in the TSDF's proposal would be inflated to cover those gaps in the information or to satisfy unnecessary requirements.

Some of the most common techniques used by TSDFs operating in the eastern U.S. today include: 1) chemical secure landfill, 2) deep well injection, 3) encapsulation, 4) incineration, 5) recovery, and 6) chemical treatment. Immediately following each type of TSDF disposal process description will be a summary of some of the most critical criteria used by that TSDF to evaluate waste streams. These criteria will be the basis for the TSDF's decision on acceptance or rejection of a stream and decisions on pricing. Much of this information is applicable to both current generators of wastes and also abandoned site cleanup categorizations.

In the last section of this paper, the author will offer suggestions for better bid package preparation.

## TECHNIQUES AND CRITERIA OF TSDF OPERATIONS

### 1. Chemical Secure Landfill

Some landfills constructed in New York State have generally had to truck in and compact the clay needed to achieve permeability ratings of  $<1 \times 10^{-7}$  cm/sec. A 10 ft bottom layer of clay is com-

pacted first. Then a 30 mil hypalon membrane is placed over the bottom layer. Next 2 ft of compacted clay covers the membrane. Drums of waste are placed vertically on this surface which is sloped to various leachate collection points. Bulk dump trailer loads are also accepted. Stand pipes are placed at the collection points to eventually pump leachate to the surface. Vent pipes are also installed to permit gases to escape. Clay walls are arranged within the landfill to form cells and subcells to prevent co-mingling of incompatible wastes. The drums are covered daily and eventually the landfill takes a domed shape. It is covered again with layers of clay, polyethylene, sand, more polyethylene, clay and seeded cover.

Monitoring wells are also installed. A grid system is used as the landfill is being filled to record the locations of each drum.

The secure landfill in Alabama is designed to meet similar requirements. However, the natural clay deposits at that site facilitate construction. In many areas the first aquifer lies beneath 700 ft of clay. The walls of the landfill are cut vertically into the clay. The drums are laid on their sides and covered with clay and absorbent material. Bulk sludges as well as liquids are accepted. Leachate collection and subcell segregation are similar to New York landfills.

Some of the criteria to keep in mind that secure landfills use are:

- NY—No free liquid by state regulations.
- NY— $<5\%$  (approximately 1 in) free air space in drums.
- NY, AL—No reactives. At this writing this rule is in a state of flux for both locations. Currently NY permits  $<1\%$  CN and Alabama permits  $<5\%$  CN.
- NY—Bulk sludges must be solid enough for a man to walk on in order to be acceptable. If drums, material must not flow if the drum is tipped over.
- AL—Liquids are accepted in bulk, however, they are actually mixed with absorbent material and landfilled as solids.
- NY—No water solubles are acceptable, e.g. nitrates.
- NY—PCB solids only. The amount of PCB residue must be expressed in Kilograms and the amount of filler material also expressed in Kilograms must be provided.
- AL—PCB liquids  $<500$  ppm accepted. This will also be landfilled after being solidified.
- NY—Flash point of solids must be  $<80\%$ .
- AL—Flammable solids are acceptable if the drums are banded together and then banded to pallets.
- NY—An EP Toxicity test on the leachate is usually required before a solid is approved for acceptance.

### 2. Deep Well Injection

Wastes are injected under pressure to depths of 2,800 ft into porous rock (usually sandstone). The porous rock rests on impermeable granite layers. Before injection, the wastes are blended into acidic lagoons and then filtered.

Criteria for deep well injection are:

- Wastes must meet a relatively tight suspended and settleable solids specification to prevent clogging of the sandstone layer.
- Streams usually preferred are inorganic with low organic contamination. The receiving lagoons are acidic so as to minimize precipitation of solids, therefore precluding wastes which would generate toxic fumes, layer, or cause odor problems upon acidification (e.g. sulfides, mercaptans, etc.).



### 3. Encapsulation

This technique employs a cement-like matrix to encapsulate the wastes into a non-leaching solids. Some companies are able to use the solids as fill or building materials. Stabilization works best on materials like pickle liquors and other inorganic waste streams. Most often small organic contamination adversely affects the solid's solubility.

### 4. High Temperature Incineration

This method thermally degrades wastes which are of greater than average toxicity, usually very stable, and not readily treated using less expensive technology. Most incinerators blend wastes with supplemental fuel and inject them into the burn area. Temperatures of approximately 2,000 °F and dwell times over 2 sec provide enough energy to break the aromatic ring compounds and split halogens from carbon. There is usually a chamber to further burn the waste gases before cooling and passing through a caustic scrubber, then up the stack. The criteria for incineration are:

- The solids must be able to pass through the nozzle readily. Each incinerator has its own specification, however, they usually can accommodate solids which can pass through a 60 to 80 mesh screen.
- The thermal value has a considerable effect on the disposal price. Obviously an aqueous stream which has to be slowly injected, using up a great deal of supplemental fuel, will be more expensive to dispose of.
- The amount of halogens and alkali metals in the waste stream also has a significant bearing on the price since these contaminants deplete the caustic scrubber solution and attack the refractory linings of the equipment.

•The ash content or ash on ignition also is a factor which incinerators have to consider. The ash disposal cost to the incinerator and is passed along to the generator, usually as an incremental cost per gallon of waste.

•Some cement companies and more recently steel companies are paying for organic wastes with good thermal value. They have strict specifications for halogen, metals, and sulfur content, however. Generally a waste is a candidate for this method if the halogen content is <2%. The metals and sulfur must not jeopardize the burners air emission permits, or cause undue damage to the refractory lining here also. The thermal value should exceed 15,000 Btu/lb.

### 5. Recovery

Although the amount of reclamation in the U.S. is increasing the country has a long way to go to approach European successes. Various US regional industrial waste exchanges are having increasingly good results. Checking these should become a standard part of procurement procedures.

The most common area of reclamation is chlorinated solvent recovery. Many companies have stills which can reclaim 1,1,1-trichloroethane, trichloroethylene, methylene chloride, and perchloroethylene. Some reclaimers have refrigerated columns and can reclaim Freons as well. Other larger reclaimers have fractional distillation columns and work on a larger bulk scale.

The single most important criterion for recovery of these solvents is that the different species must be kept separate when collecting the wastes. Most of these solvents form azeotropes when mixed. This means that they do not boil off at their respective boiling points when being distilled. Instead they both come over at a new boiling point. This makes its resale virtually impossible. Instead of a valuable waste product, the generator now has an expensive liability.

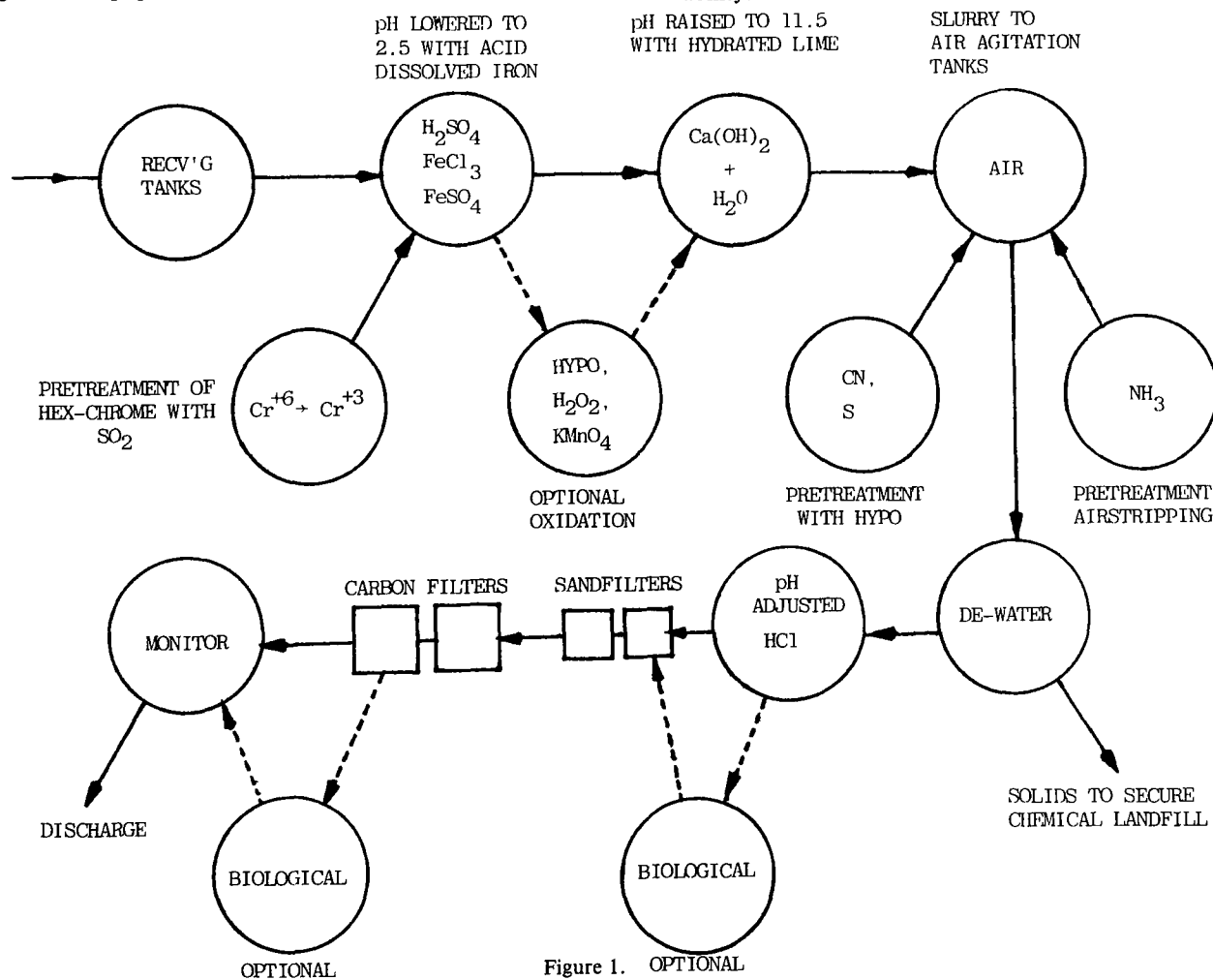


Figure 1. OPTIONAL  
Chemical treatment flow chart

The same holds true for metals. Some reclamation of metals (e.g. Cr, Cu) is economically feasible today if they are kept separate, and not in a mixed metal hydroxide sludge.

## 6. Chemical Treatment

This technology (Fig. 1) usually employs ferro-lime treatment of aqueous streams with small to relatively large concentrations of organics and metals. First, iron is added to the waste. Normally ferric chloride is used, but many times spent pickle liquors are employed as a substitute. Also ferrous sulfate crystals can be dissolved and used. The addition of an acidic iron solution serves: to adjust the pH (usually to approximately 2), as a filter aid later on in the system; and as a reducing agent. Next the pH is adjusted back up to 11-12 with NaOH or lime. NaOH has the advantage of not generating much sludge; however, it tends to produce more soluble salts. Lime does improve the filterability of the sludge but generates more of it. This treatment step forms insoluble metal hydroxides which start to precipitate. At several points in this initial pH adjustment sequence, or after filtration, oxidizing agents such as chlorine, hypochlorite, or hydrogen peroxide may be introduced to attack the organic constituents of the stream.

The heavy metal hydroxide slurry is now ready to be dewatered. Methods employed include centrifugation, rotary vacuum filtration, and plate and frame filtration. The latter seems to be the most forgiving in terms of ability to filter a less homogeneous feed. The filter cake, approaching 50% solids by weight, is laden with heavy metals and a considerable amount of organics which the iron seems to attract. This cake is disposed of in chemical secure landfills.

After another pH adjustment downward to neutral, the supernatant is now ready for secondary treatment. Most companies use carbon adsorption to further remove organics. Some companies utilize biological treatment before or after this step. The aim with activated carbon, whether it be powdered or granular, is to remove organic materials, long-chained aliphatics and ring compounds. These chemicals are generally the more toxic organics and include halogenated compounds, pesticides, herbicides, and other potential carcinogenic or bio-accumulative compounds.

The final effluent is discharged into a waterway or to a municipal wastewater treatment plant which in turn holds the permit to discharge into a waterway.

Other waste streams cannot be directly introduced into this ferro-lime system. Wastes like cyanides for example must first be pretreated using alkaline chlorination before the reaction products are put back into the main waste feed. Sulfides also are first broken down in this fashion. Ammonia containing streams must first be air stripped. Hexavalent chromes must be reduced to trivalent.

Some of the criteria used by chemical treatment plants in evaluating wastes are:

- For both drummed wastes or in bulk there should be a description of layering, solids, and how the material became a waste. Layering generally refers to different liquid phases, for example 20% top oil layer, 10% middle emulsified oil layer, and 70% bottom aqueous layer. The term solids to a TSDF does not just mean hard, dry material. It includes that of course, but also is taken to mean sludges, and non-pumpable viscous material like some resins.

Many times an item can only be identified by a trade name or its manufacturer will not divulge its proprietary composition. This is why it is often very helpful for a TSDF to know how that item was used. What was the process that changed the commodity into a waste and what contaminants could have been picked up in that process? An experienced staff at the TSDF has probably seen 90% of the total variety of waste streams generated within a 400 mile radius. The waste generation information will often help the TSDF's laboratory to determine a starting point. For example, an aluminum anodizing operation usually signals the presence of hexavalent chrome. Any strong caustic stream is always suspected of containing cyanides. If a person tells the

TSDF that the waste came from a cadmium plating bath, the suspicion is nearly always confirmed. If, however, the caustic stream was called aluminum De-Smut, it would be highly unlikely to contain cyanide.

- Is the waste aqueous or organic? If it is aqueous, is it acidic or alkaline/neutral? If acidic, TSDFs need to know the type of acid. Sulfuric acid is generally handled easily. Corrosion problems occur at medium concentrations, however. Hydrochloric acid is also relatively simple to treat, however, corrosion problems are significantly greater. Nitrating acids have the potential for releasing NO<sub>x</sub> fumes and cannot be handled by many TSDFs. Hydrofluoric acid is difficult to handle because its corrosivity is similar to HCl with respect to stainless steel, but it also attacks the glass fibers in many fiberglass liners or reinforced tanks. Therefore the TSDF must be extremely careful to greatly dilute these acids before treatment. The following components are also important information for a TSDF when evaluating acids: pH, free and total acidity, hexavalent chrome concentration, total organic carbon (TOC), chemical oxygen demand (COD), metal concentration, and phenol concentration.

If the waste is alkaline or neutral, evaluations will be based on: pH, free and total alkalinity, TOC/COD, amount of solids, and the presence and concentrations of ammonia, cyanide, metals, sulfides, and phenols.

The above factors are critical in both the acidic and alkaline/neutral categories because the TSDF will be doing treatability studies to answer questions such as:

- What is the initial organic concentration?
- How much acid is required to lower the pH?
- Are there any fumes liberated upon acidification?
- What metals are present?
- How much alkaline solution is required to raise the pH?
- What kind of temperature rise is associated with the acid and lime steps?
- Are the reactions controllable?
- How well does the metal hydroxide slurry filter?
- What is the solids concentration?
- How well are the organics removed after ferro-lime treatment?
- How much carbon is consumed per gallon of waste?
- What is the final organic concentration after carbon treatment?
- How much further oxidation is required with hypochlorite, chlorine, peroxides, permanganates?
- Will the waste require, and is it amenable to, biological degradation?
- How much hypochlorite and caustic will be needed to completely destroy any cyanides?

If the waste is organic, it is usually broken down into flammable or halogenated categories.

- Flammable organic criteria are: what types of compounds, thermal value per pound or gallon, halogen content, alkali metals concentration, metals such as lead and chrome which would cause air emission concern, water content, both free and entrained, specific gravity, suspended and settleable solids, size of solids and presence and concentration of PCBs.

- Chlorinated organics criteria are: specific gravity, % recoverable yield, species, whether two or more species mixed, oil content, flammables present, PCB concentration, (see Fig. 2).

## SUGGESTIONS ON IMPROVING ABANDONED SITE BID PACKAGE PREPARATION

Now that the basics for treating wastes by the most common types of TSDFs have been outlined, some direction can be given to the approach taken when preparing abandoned site categorizations and requests for proposals (RFP).

Drums or Bulk Layering, Solids, How Generated			
Aqueous		Organic	
Acidic	Alkaline/Neutral	Flammable	Halogenated
Type	pH	Type	Specific Gravity
pH	Free & Total Alkalinity	BTU Value	% Recoverable Yield
Free & Total	TOC/COD	% Halogens	Species Type
Hex Chrome	Solids	Alkali Metals	Species Mixed
TOC/COD	Ammonia	Lead, Chrome	Oil Content
Metals	Cyanide	Sulfur, Water	Flammables
Phenol	Metals	Specific Gravity	PCBs
	Sulfides	Suspended Solids	
	Phenols	Settleable Solids	
		Particle Size	
		PCBs	

Figure 2.

Criteria for evaluating common waste streams

This is an appeal for practicality. The overall concern at abandoned sites should certainly be safety. However, due to the emotional impact of the term hazardous waste in the post-Love Canal era, governmental agencies at all levels have required increasing levels of overkill. Overkill when it comes to site characterizations by engineering firms, which becomes magnified in the directions those firms give to TSDFs in the RFP. Consequently an RFP may become so specific, down to the last detail of how a site should be cleaned up, that the RFP effectively precludes techniques that might be just as safe and many times more practical and cost saving.

It is not the purpose of this discussion to change the direction of government procedures. Instead, this discussion is directed at the consulting engineers who categorize and prepare RFPs for abandoned sites, and corporations' normal waste disposal needs. You may be constrained to fulfill the same governmental requirements as in the past, probably more in the future. But, if you try to incorporate the following suggestions in your work, the net result will be reduced cleanup time and lower overall cost to everyone. Hopefully this will have the added benefit of stretching superfund dollars, enabling more sites to be cleaned up sooner.

First of all, much of the chemical analyses provided is extensive, elegant, and unnecessary. A complete metals scan does not contribute to the information needed by a TSDF. Most of these metals will be removed during treatment anyway. Likewise a complete priority pollutant scan for every so many drums is very expensive and also superfluous. Assuming the TSDF is using proper oxidizing agents and carbon adsorption, the organics in question will be reduced so that the TSDF's discharge is acceptable. If the disposal method is high temperature incineration, the toxic organics will also be degraded properly. Moreover most laboratories can only perform 10 scans at a time, with a 4 to 6 week lag in providing results.

Physical information is often overlooked. It is important to note the presence of layers in tanks or drums and estimate the amount of layered material within each vessel. For example, information like the following is virtually worthless: out of 8,000 drums, 3,000 were found to contain a top organic layer or a composite sample of these drums showed metals and priority pollutant concentrations as follows; etc.

Much more valuable information would look like this: out of 8,000 drums, 3,000 contained a top organic layer which averaged 20% of the drum volume. Of these, 2,100 appeared to be a medium viscosity petroleum hydrocarbon with a flash point of  $>200^{\circ}\text{F}$ . Of these 2,100 drums, 75 were found to contain organo-chlorine levels of  $>2\%$  but  $<10\%$  and 530 had  $>10\%$  chlorine with the balance below 2%. The 900 remaining layered drums showed a flash point of  $<100^{\circ}\text{F}$  and had an odor of xylene. Chlorine levels were all below 2%. In all 3,000 organic-layered drums PCBs were found to be less than 50 ppm using 10 drum composites, etc.

Likewise physical information should be provided about the solids content of the drums. The condition of the containers and the need for overpacks is important. How many drums are open top (lid and ring) and how many are bung type is useful. If the

material is in tanks, are there solids and layering in them? An estimate of how much solids and their pumpability is needed. What kind and sizes of fittings or access openings are available to a tanker is good information. A real bonus would be the availability of samples for bulk materials or even drum composites so that TSDF's could perform their own treatability studies. If the site needs considerable excavation work, a two stage bid should be prepared. The first, to contract experts in this phase with adequate supervision for safety considerations. Then the wastes would be more closely examined and a more meaningful RFP could be engineered for the second cleanup phase.

Some practical financial considerations should also be considered. A lump sum bid requirement for the entire cleanup or even on individual phases is the least cost saving way of all. With so many unknowns at an abandoned site, a TSDF which is forced to respond with one price for the job will most certainly build in enough cushion to guarantee a profit. It will probably be somewhere in the area of the most pessimistic costing for all of the wastes thought to exist at the site. If the agency overseeing the administration of the contract insists on this type of lump sum response, a means of adjustment should be provided in case of extenuating circumstances. For example, some RFPs provide that if an error of  $\pm 10\%$  in the estimated volume of any given line item results in  $>\pm 5\%$  total bid cost variation, then adjustments will be made. These can be in the favor of either the agency or the contractor.

The best type of proposal as far as both fairness and cost effectiveness is concerned would be a combination of a unit price and a cost-plus. The cost-plus aspect of the job would have to be strictly supervised to be sure. However, this would give the agency via the consulting engineering overseer even better control of the costs and disposal methods to be employed. Flexible bid options are also a good idea. A contractor should be able to quote as directed, but also include a second price if he could do the work a different way. For example, he might say, "our price is x, but since we will be using high temperature incineration for item y, our price will be z due to the elimination of 5 priority pollutant composite scans."

Certain calculated risks have to be considered when dealing with the practical aspects of bid requirements. For example, if after categorizing the wastes on site it can be safely assumed that radioactives and explosives are not present, requirements that radiation-bomb proof buildings be constructed for these materials' storage are unnecessary. A phrase in the RFP that could save considerable time and expense would ask that these be built if these types of items were discovered.

Likewise, on most abandoned sites much of the ground is permeated with a number of different wastes. It seems most unnecessary to require that extensive decontaminated areas, docks for quality control, washing areas for trucks, etc., be constructed only to have them all excavated and landfilled upon site cleanup completion.

Smaller items but ones that are often overlooked are: much more time should be provided for the TSDF to quote; technical contacts and phone numbers need to be provided; workers who are required to wear the complete self-contained breathing apparatus and moon suits in the summer might last 15 minutes at a time. If they were able to carry air packs or other emergency escape devices with self-contained devices in stationed areas, efficiency would be greatly improved without sacrificing safety; keep in mind the costs of various laboratory analyses. Sometimes requiring a drum by drum PCB analysis or small 5 drum composite sample analyses of a large number of drums will result in the laboratory and regular disposal cost far exceeding the cost of treating the drums as if they all contained PCBs.

Again, by being aware of the treatment methods available today and following some practical suggestions on approaching the problems associated with hazardous waste evaluation, engineers can significantly reduce costs to the taxpayer and industry alike. This will contribute to a cleaner environment by directly reducing the costs of cleanup of the hundreds of sites targeted around the country. It will stretch federal and state superfunds further to do more.

# ABOVE GROUND STORAGE OF HAZARDOUS WASTE

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## INTRODUCTION

A long-term monitorable and retrievable storage facility for hazardous wastes was investigated as an alternative to the land disposal of hazardous wastes in Minnesota. The proposed conceptual design and subsequent analysis was conducted for the Minnesota Waste Management Board as part of Minnesota's Comprehensive Hazardous Waste Management Plan.

During the statewide meetings regarding the management of Minnesota's hazardous waste, public sentiment was strongly in support of above-ground storage as an alternative to a hazardous waste land disposal facility. Prompted by public interest and a lack of definitive information on this concept, an in-depth analysis of the technical, economic, and institutional feasibility of above-ground storage was undertaken.

Monitorable and retrievable storage describes a secure system for the long-term management of hazardous wastes in anticipation of the development of new economical recycling, treatment or destruction technologies. Wastes stored above-ground remain visible where a leak can be detected and contained before release to the environment occurs. An above-ground storage facility has applicability to wastes generated in the state as well as those recovered from uncontrolled hazardous waste sites in the upper midwest. Wastes accepted by such a facility would likely be those which:

- There does not currently exist practicable alternatives to land-fillings
- Are considered too toxic, persistent, and leachable for land disposal
- In the case of wastes removed from an uncontrolled site, are stored while the responsible parties are identified and litigated

The study identified the types and quantities of Minnesota's wastes which cannot be reasonably recycled, treated, or destroyed and analyzed the regulatory requirements, design and operating parameters, environmental aspects, costs, and economic feasibility of above-ground storage.

## WASTE INVENTORY

The quantity of Minnesota's hazardous waste available for long-term storage was estimated by completing the following tasks:

- Identifying the types and quantities of hazardous waste generated each year
- Specifying the likely management technologies for each waste stream category
- Determining those waste streams for which the only management technology is secure landfilling
- Identifying those treatment technologies which produce a hazardous residual

The waste categories and quantities are presented in Table 1, and are based on management plans reported by waste generators to the Minnesota Pollution Control Agency and the Metropolitan Counties through December, 1981. As indicated in the table, approximately 52,000 tons/yr (TPY) of hazardous wastes were reported to be generated in Minnesota at the time this study was undertaken. Subsequent plan data received by the regulatory agencies and estimates made by the Waste Management Board since the study's completion indicate that the actual waste generation amount is higher. The relative mix of waste types did not change significantly, however.

Waste streams were then assigned probable management technologies such as oil and solvent recovery, incineration, neutralization, precipitation, and biological treatment processes that exist within the State. Technologies that generated a hazardous residual (e.g., sludge, ash, etc.), which would normally be landfilled, were also identified. Estimates of waste and residual quantities (and their physical characteristics) for each selected management technology were prepared. Wastes which could neither be treated nor destroyed would require a secure landfill, and consequently became candidates for above-ground storage.

An annual amount of 6650 tons, or approximately 13% of Minnesota's hazardous waste stream, are available for above-ground storage. This total quantity represents 4450 TPY which cannot be practically treated plus 2200 TPY of residual sludges generated by various waste treatment technologies. Nearly 90% (5900 TPY) of the wastes available for long-term storage are sludges/solids that require containerization. The remaining 10% of the wastes are liquids that would be stored in above-ground tanks.

**Table 1.**  
**Summary of Minnesota's Reported Hazardous Wastes<sup>(1)</sup>**

Waste Category	Waste Quantity (tons/yr)
1. Solvents	6,884
2. Halogenated Hydrocarbons	1,550
3. Cyanides	163
4. Oils	
a. Petroleum oil	15,795
b. Organic, synthetic, and other mixed unknown	2,214
5. Other Organic Wastes	
a. Paints/inks	1,258
b. Organophosphates	20
c. Mixed, unknown pesticides	21
d. Phenol	51
e. Polymeric	590
f. Polynuclear aromatics	196
g. Other, mixed, and unknown, general	878
h. Photochemicals	4,249
6. Acids	4,168
7. Alkalis	7,536
8. Metals and Toxic Non-Metals	4,368
9. Reactives	
a. Oxidants	1,488
b. Ammonium salts	145
c. Other and mixed, unknown	339
<b>TOTAL</b>	<b>51,913</b>

## REGULATORY BACKGROUND

Federal and State hazardous waste regulations, as well as appropriate fire and building code requirements, were reviewed and applied to the proposed facility design. In addition to requirements assuring container and tank integrity, waste compatibility, and monitoring procedures, proposed State hazardous wastes regulations<sup>2</sup> require secondary containment more stringent than existing Federal rules.<sup>3</sup> Container and tank storage areas holding free liquids must be designed and operated with the following major provisions:

- An impervious base that contains all leaks, spills, and accumulated precipitation
- A drainage system to remove standing liquids, unless the containers or tanks are protected from contact with accumulated liquids
- A containment system which is able to contain 10% of the volume of the containers or tanks (or volume of largest container/tank, whichever is greater).

Fire protection standards regarding the construction and operation of liquid storage facilities were evaluated from the National Fire Protection Association Code.<sup>4</sup> The code specified minimum distances between adjacent tanks, elements of the containment dikes, and fire control system requirements that were useful in developing the facility design.

Building code standards<sup>5</sup> for the proposed container storage buildings specified additional fire protection measures. Using Type I fire resistive construction, the allowable floor area for buildings\* one story in height containing various classes of flammable and hazardous materials is 15,000 sq ft. Buildings of this type include steel, iron, concrete or masonry structural elements that provide four hours of fire protection to exterior bearing and non-bearing walls, and three hours to interior bearing walls and structural frame. Container buildings were conceptually designed in accordance with these and other applicable requirements, such as setback, access, aisle spacing, and air exchange provisions.

\*Each portion of a building separated by one or more area separation walls may be considered a separate building provided the area separation walls meet building code requirements. Area separation walls shall be not less than four-hour fire-resistive construction in Type 1.

## CONCEPTUAL DESIGN AND ENGINEERING

Based on the quantities of waste allocated to above-ground storage, the facility was designed to store 22,000 drums in a container building and 185,000 gal in bulk-liquid tanks each year. By

assuming an operating life of ten years, the facility would require an area of 60 acres. The important design assumptions are described below, and are presented to characterize the conceptual development and engineering of the proposed facility. The significant tank design specifications are summarized in Table 2. In addition, two conceptual drawings were prepared to depict a possible site layout (Fig. 1) and the container building components (Fig. 2).

### Facility Design Assumptions

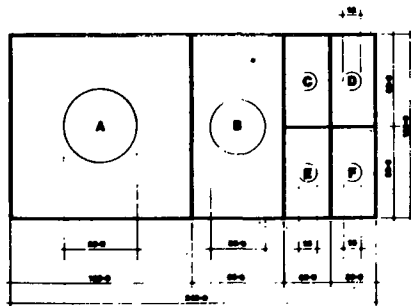
- A buffer zone of 200 ft will be allowed between the property fence line and all structures.
- The site headquarters building will contain the administrative offices, laboratory facilities, lunch room, supply storage, lockers and showers, process control and monitoring room, and equipment maintenance garage.

**Table 2.**  
**Tank Specifications (Five-Year Storage Capacity)**

Waste Types	Tank Type	Contr'n Material	Vol. (gal)	Diam. (ft)	Height (ft)
Paints/Inks	Cone Roof (w/internal floating roof)	Steel	588,000	50	50
Organo-phosphates & Pesticides	Cone Roof	Steel	19,830	15	15
Other Mixed Organics	Cone Roof (w/internal floating roof)	304 Stainless Steel	256,000	35	36
Reactives	Cone Roof	Glass Lined Steel	12,909	13	13
Reactives		316 S.S.	19,830	15	15
Reactives		Fiber Reinforced Plastic	28,500	12	38

**TANK LEGEND**

A PAINTS AND INKS  
B OTHER MIXED ORGANICS  
C ORGANO-PHOSPHATES AND PESTICIDES  
D OTHER REACTIVES  
E OTHER REACTIVES  
F OTHER REACTIVES



5 YEAR TANK STORAGE PLAN  
7' x 100'



5 YEAR TANK STORAGE ELEVATION  
7' x 100'

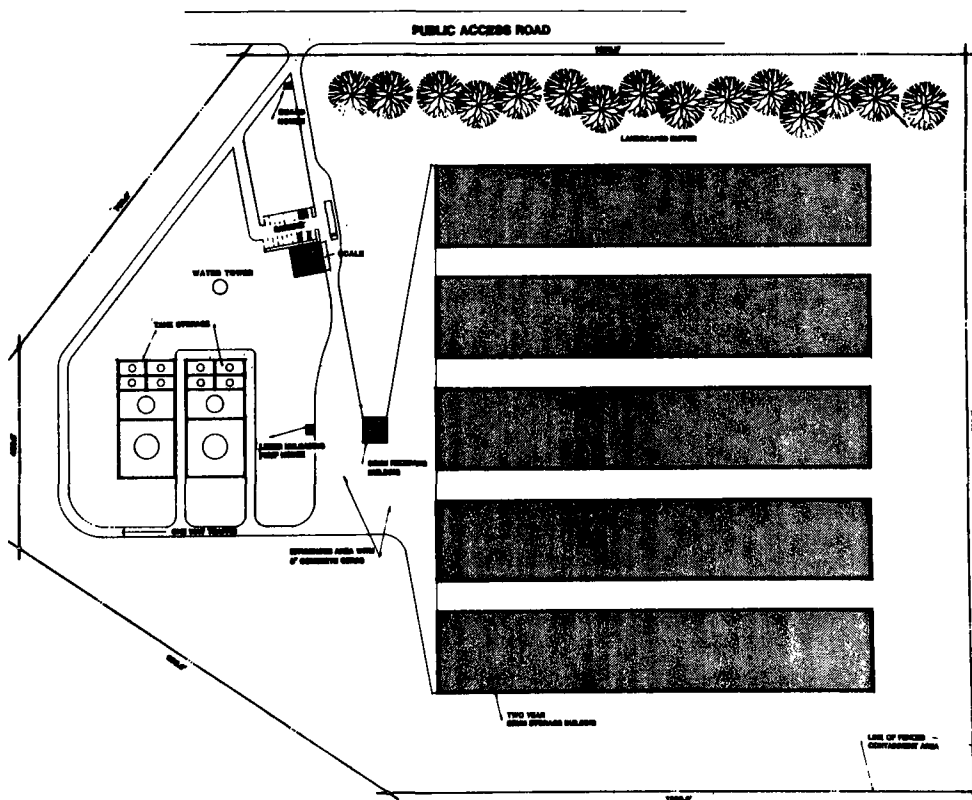


Figure 1.  
Above-Ground Storage Facility Site Plan

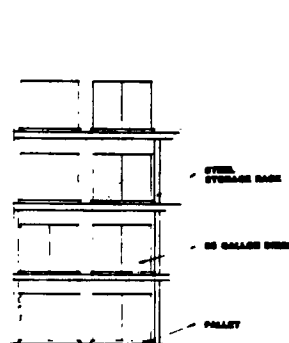
TEN YEAR SITE PLAN

- A packaged wastewater treatment system will be installed. Dilute, decontamination wastewaters from spills on roads, receiving areas, or in buildings will be conveyed via the sewer system to the wastewater treatment system.
- A waste supply, storage, and distribution system will be provided, and a sewer system will be constructed. Provision will be made to limit contaminated water or waste liquids entering the sewer system.
- A fire detection system, consisting of fire, sprinkler, and stand-pipe alarms, control panels, and remote annunciators will be installed and monitored in the control room.
- A fire pump, hydrants, hoses, and other miscellaneous fire equipment such as nozzles, couplings, and portable extinguishers for all lift trucks and maintenance vehicles will be provided.
- Groundwater monitoring wells will be installed on a basis of one well per 20 acres of area, with a minimum number of 4 wells.
- All roads will be asphalt paved and curbed with 6 in. concrete to contain any spills or leaks.
- A microcomputer, printer, and storage discs will be purchased for inventory control. Functions to be provided include: waste

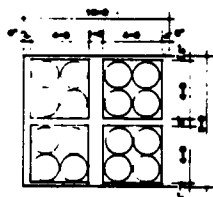
identification, location, quantity, type, generator, storage date, and special considerations or handling procedures.

#### Container Storage Design Assumptions

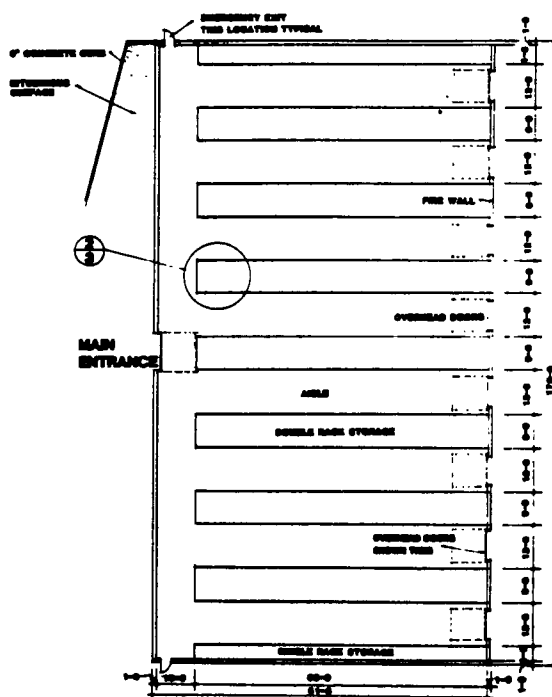
- Container storage buildings will be constructed as two units over a two year period, each unit has a capacity for one year of drums.
- Each completed container building will have a capacity for two years of drum generation (approximately 44,000 drums).
- Storage buildings will be further divided into a ten week operating bay due to limitation of allowable floor space of 15,000 sq ft.
- Drums will be placed on steel storage racks, four high, with the maximum number of drums in a double row section to be 64.
- The container building will be constructed with fire resistive, preformed insulated concrete panels and steel roof joists.
- Each building will contain an automatic sprinkler system and heating and ventilation components.
- Each ten week operating area will be separated by a fire wall and automatic overhead fire doors on each aisle.
- Monitoring instrumentation to detect harmful ambient air levels of a variety of organic constituents will be installed.



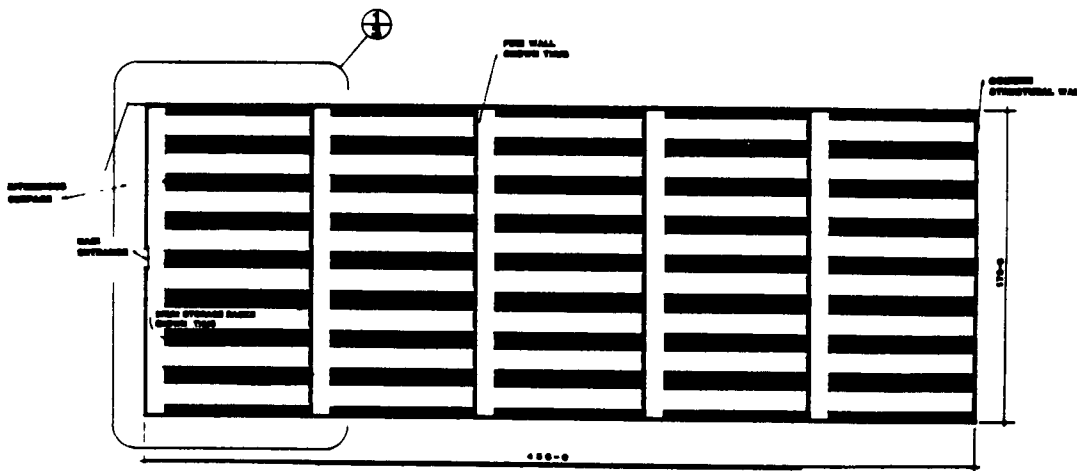
DRUM STORAGE ELEVATION  
1/4" = 1'-0"



DRUM STORAGE PLAN  
1/4" = 1'-0"



TEN WEEK STORAGE PLAN  
1/4" = 1'-0"



ONE YEAR STORAGE PLAN  
1/8" = 1'-0"

Figure 2.  
Container Storage Plan

- Each building will contain floor drains and sumps to collect and store temporarily any liquid spills that cannot be immediately contained and removed with absorbent materials and redrummed.
- A central drum receiving building will be constructed near the container storage buildings. This building, which will have an available floor space for five days of inventory, will serve as the truck receiving, record-keeping, testing, and pick-up area for drums entering the storage buildings.
- The redrumming area will be a separate, well ventilated portion of the building, complete with spill containment diking, drains, monitoring instrumentation, and an automatic fire suppression system.
- The drum receiving area will also contain a redrumming area and equipment used to recontainerize leaking containers in overpack drums.

#### Tank Storage Design Assumptions

- Each individual tank will be sized to a capacity approximately equal to five years generation of a specific waste type.
- The materials specified in the construction of each tank were selected based on their compatibility with the individual waste types.
- All tanks will be insulated and vented to condensers that recycle the condensate to the tank.
- All tanks will include continuous level monitoring instrumentation.
- A concrete dike will be constructed around each tank to contain the contents of the full tank, plus an allowable freeboard of at least four inches, and to keep individual waste streams from coming in contact with each other in the event of a tank failure.
- The dike network and tank foundations will be constructed with concrete and sealed to form an impervious barrier to waste spills.
- Service roads will be constructed between the diked tank area to provide easy access for fire control, tank maintenance, and spill/precipitation removal.

The design of this facility was based on the assumption that the State's waste stream would remain relatively constant and few, if any, stored wastes would be removed for processing during the operating life of the facility. These assumptions were made in order to determine the maximum amount of storage space needed for the State. If, during the lifetime of the facility, some wastes are removed for processing or disposal, the resulting storage space would be available for incoming waste. Coupled with a projected decrease in the amount of incoming waste due to the advent of new treatment technologies, the design capacity of the facility could be reduced. Predictions of future treatment capabilities and their affects on Minnesota's waste stream are, of course, difficult to make. Any potential reduction in the design capacity, however, would likely be offset by the acceptance of materials from uncontrolled hazardous waste sites.

#### OPERATIONS

From an operating standpoint, the most important consideration is the condition in which the drummed wastes are received. The condition of the container will determine the associated risks and costs of the material during its storage. To help assure container integrity, while minimizing repacking costs, containers will be inspected in the receiving area for proper labeling, content and condition. Containers failing the facility standards during the initial check-in will be denied long-term storage and returned to the generator.

In addition, a program will be instituted to monitor all container failures or related problems necessitating drum repacking. Data collected in this program will be periodically analyzed to determine the probable reasons for failure. Facility receiving requirements, handling procedures, and inspection schedules will be modified based on program results in an effort to reduce the number of container failures. With a concerted effort to reduce the likelihood of container deterioration and failure, drum repacking rates would be minimized. Other important operating conditions and assumptions, as well as some resulting cost components, are presented

below:

- Container repacking requirements were based on an assumed replacement rate of 1% of the accumulated inventory each year (excluding repacks).
- Damaged or leaking containers will be repacked in 80 gal overpack drums, absorbent added, and the drum returned to a container building.
- Costs for repacking include contracted labor, overpack drum, absorbent and miscellaneous items (protective clothing, spill containment materials, decontamination chemicals, etc.). Total repacking costs were estimated at \$150/drum.
- Utilities and fuel cost estimates were based on natural gas requirements for heating all buildings, electricity for building ventilation, tank heating, pumps, office, lift-trucks, and lights, and fuel requirements for maintenance vehicles and standby electric generator.
- Laboratory analysis of incoming wastes will consist only of such basic analysis as pH, ignitability, corrosivity, etc. More detailed analyses, when required, will be conducted under a contract established with a private analytical laboratory.
- Sufficient water storage and supply will be maintained for sprinkler and fire hydrant demands for a duration of two hours.
- Disposal costs of the inventory at facility closure were estimated by allocating an average cost of \$200/ton for transportation and disposal of the waste at a secure landfill in Illinois.

#### ENVIRONMENTAL ASPECTS

The proposed above-ground storage facility would significantly reduce the environmental impact of a land disposal facility by providing monitorable and retrievable storage of hazardous wastes within controlled environmental conditions. Wastes in the proposed storage facility can be inspected easily and problems repaired quickly before they develop into significant environmental hazards.

The sources of potential environmental impact from the above-ground facility are container failures, spills during materials transfer, fires or explosions, and volatile emissions. Specific designs and operating procedures were developed to mitigate or minimize these potential hazards. Leaks or spills resulting from container or tank failures, for instance, will be contained in either the storage buildings (each with concrete walls, floors, and floor drains) or in the tank basin which contains an impermeable base and diking. Both the container building and tank basin are constructed to contain the material until it can be removed.

Spills incurred during materials transfer, either in the drum receiving building where repacking is conducted, or in the liquid unloading structure, will be contained and removed. The drum repacking area will be constructed with spill containment walls and drains. The liquid unloading structure will contain an underground holding tank for emergency by-pass, an impermeable foundation, curbing, and emergency pumping capabilities. All site roads will be paved and curbed for spill containment.

The provisions to prevent and control the spread of fires at the site are extensive. Briefly, all container buildings will be sprinkled and possess fire partitions. The drum receiving building and liquid unloading structure will also be sprinkled. A site fire detection and control system will be present. In addition, potentially reactive materials will be segregated within facility buildings and tank areas.

Emissions of organic vapors will be present from the tanks and container buildings. These emissions, however, will be minimized through the use of insulation of the tanks and buildings to control temperature fluctuations, the use of internal floating roofs and condensers on specific tanks, and the placement of ambient air monitors in the buildings and other site locations to monitor emission rates.

Other measures taken to assure the environmental integrity of the site and safety of the public include:

- Placement of groundwater monitoring wells
- Security fencing and personnel to prevent unauthorized entrance
- Monitoring instrumentation, communication, and process control located in central control room



- Auxiliary power supply
- Rigorous facility standards, inspection schedules and personnel training
- On-site wastewater storage and treatment
- Drum repacking capabilities to mitigate or prevent leaks
- On-site laboratory analyses
- Drum failure analyses and preventative program

### COSTS AND ECONOMIC FEASIBILITY

Facility investment costs were prepared and are summarized in Table 3. These costs would be incurred in the development of the site prior to actual facility operation. Significant component costs in this development stage are the bulk-liquid tanks (5-year storage

**Table 3.**  
**Initial Facility Investment Costs**

Component	Investment Cost	
1. Land	\$300,000	
2. Fencing & gates	78,000	
3. Security station	1,500	
4. Facility hdqtrs.	180,000	
5. Parking area	18,000	
6. Scale	41,000	
7. Signs	500	
8. Drum receiving bldg	80,000	
9. Communication system	20,000	
10. Bldg fire detection	9,000	
11. Water distribution system	220,000	
12. Auxiliary power supply	40,000	
13. Groundwater monitoring wells	8,000	
14. Inventory control computer	14,000	
15. Wastewater treatment system	66,000	
16. Office equip/furn	16,000	
17. Laboratory equip	25,000	
18. Site clearing	73,000	
19. Site vegetation	23,000	
20. Outdoor lights	24,000	
21. Gas distribution	21,000	
22. Visual screening	4,000	
23. Site roads, curbing & paving	243,000	
24. Tank truck unload	11,000	
25. Tank basin & dike construction	95,000	
26. Tank Costs—5 yr storage capacity		
•Paints & inks		443,000
•Organophosphates & pesticides		130,000
•Other mixed organics		707,000
•Reactives		146,000
•Reactives		44,000
•Reactives		48,000
•VOC removal		72,000
•Delivery pumps		67,000
•Emergency pump		15,000
•Retrievable pump		24,000
Tank Subtotal (includes fees)		\$1,696,000
27. Facility vehicles		
•Lift trucks		90,000
•Maintenance trucks		25,000
28. Air monitoring instrumentation		32,000
29. Container storage bldg (2 yrs)		4,536,000
30. Rack storage constr		440,000
31. Subtotal (1)		\$6,734,000
32. Engineering/contractor's fee (15%)		\$1,010,100
33. Subtotal (2)		\$7,744,100
34. Contingency (15%)		1,161,000
35. Subtotal (3)		\$8,905,700
36. Tank Subtotal (fees included)		1,696,000
37. Total		\$10,602,000

capacity) and the construction of a container storage building (2-year storage capacity). Investment costs would also be incurred during the life of the facility. On a yearly basis, with the exception of the first and last operating years, the facility will require the construction of an additional container building unit, storage racks, and air monitoring instruments. After five years, costs will also be incurred for new lift trucks, maintenance vehicles, tank basin, and bulk-liquid storage tanks. All facility cost estimates are in second quarter 1982 dollars.

Annual facility operating and maintenance costs were estimated and appear in Table 4. These costs assumed that the facility would be owned and operated by the state. Other ownership options were considered in the study, but are not included here. A state owned and operated facility would be exempted from property taxes, and would assume all site liabilities during operating and post-closure periods.

An annual revenue requirement of \$7.2 million was determined for the state owned and operated facility. No return on investment was assumed, and a 9% capital recovery rate was applied. Costs for final disposal of the inventory were also included. The price for hazardous waste storage at the facility (under state ownership and operation) was nearly \$1100/ton. Other ownership options that include private investors and operators increase the price to approximately \$1300/ton.

### CONCLUSIONS

In summary, the above-ground storage facility would present hazards similar to those from manufacturing operations where hazardous materials are handled. Within the facility, workers would bear some risk of exposure to hazardous wastes. The risk to the environment and to persons outside the facility from an accident, although real, would be small since the facility would contain safeguards against foreseeable accidents, and operating procedures would be designed to minimize the impact from any accidents. There are no technological barriers to storing hazardous wastes in any form. It was possible to conceptualize a facility meeting all current hazardous waste regulations and building codes which would serve the intended purpose.

The high storage costs were due to significant capital investment (mainly buildings) necessary for the storage facility. Changing design or operating assumptions to account for removal of wastes during the operating life of facility, variations in ultimate processing cost (or credit), or increasing the proportion of wastes stored in bulk did not lower the cost of storage to a level comparable to other waste management methods.

**Table 4.**  
**Annual Operating and Maintenance Costs**

Year	Investment	Drum Repacking	Total Labor	Utilities & Fuel	Lab Sup & Contr	Wastewtr Trtmt	Off Oper Supplies	Maint Supplies	Total Ann O&M
1982:0	\$10,602,000								
1983:1	---	\$ 33,000	\$522,000	\$139,000	\$25,000	\$15,000	\$5,000	\$106,000	\$ 845,000
1984:2	3,298,000	66,000	522,000	198,000	25,000	15,000	5,000	139,000	970,000
1985:3	3,298,000	98,000	522,000	258,000	25,000	15,000	5,000	172,000	1,095,000
1986:4	3,298,000	130,000	522,000	317,000	25,000	15,000	5,000	205,000	1,219,000
1987:5	5,166,000	162,000	522,000	382,000	25,000	15,000	5,000	257,000	1,368,000
1988:6	3,298,000	193,000	522,000	442,000	25,000	15,000	5,000	290,000	1,492,000
1989:7	3,298,000	224,000	522,000	501,000	25,000	15,000	5,000	323,000	1,615,000
1990:8	3,298,000	255,000	522,000	561,000	25,000	15,000	5,000	356,000	1,739,000
1991:9	3,298,000	285,000	522,000	620,000	25,000	15,000	5,000	389,000	1,861,000
1992:10	---	316,000	522,000	620,000	25,000	15,000	5,000	389,000	1,892,000
Total:	\$38,854,000								\$14,096,000

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# UNCONTROLLED HAZARDOUS WASTE SITE CONTROL TECHNOLOGY EVALUATION PROGRAM

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## INTRODUCTION

In anticipation of the passage of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund),<sup>1</sup> the Office of Research and Development, of the USEPA began a program in 1980 to support the Agency's activities concerned with uncontrolled hazardous waste sites. In the area of environmental engineering and technology, the Agency looked to the ongoing and established program in the Solid and Hazardous Waste Research Division of the Municipal Environmental Research Laboratory. This Division had a base of expertise that could quickly relate to the uncontrolled hazardous waste problem.

The Oil and Hazardous Materials Spills Branch (OHMSB), located at Edison, New Jersey, had been actively pursuing research on the identification, containment, control, removal, and ultimate disposal of hazardous spills since 1971. These activities could be directly related to the removal aspects of Superfund. The Disposal Branch, located in Cincinnati, Ohio, has been actively pursuing research in the area of waste disposal control to the land since 1965. These activities could be directly related to the remedial action aspects of Superfund.

Since CERCLA only provided for a five year program for the uncontrolled hazardous waste site problem, time was not available to establish a fundamental research and development program. The approach taken by the Agency for the Office of Research and Development was one of technical support to the Office of Emergency and Remedial Response. Technologies that had been developed under the Clean Water and Solid Waste programs were adapted to the uncontrolled hazardous waste site situations. In addition, construction techniques, e.g., slurry trench cutoff walls, injection grouting, and chemical stabilization, that had been used for other purposes, were evaluated to determine their applications to uncontrolled sites. Also there were very limited data available on the cost and effectiveness of various remedial techniques. The task of collecting and analyzing the available data was initiated.

Once CERCLA became law, the Office of Research and Development developed, in consort with the Office of Emergency and Remedial Response, a five year support strategy which is updated each year. The strategy outlined a program with peak funding in the early years to meet the immediate needs of the program; the latter years concentrates on technical assistance.

The environmental engineering and control technology research program divides activities along the lines of CERCLA, i.e., removal and remedial actions. In the following sections, details of each program are presented.

## REMOVAL TECHNOLOGY PROGRAM

### Approach

The overall goal of the Oil & Hazardous Materials Spills Branch is to provide scientific and engineering expertise in the area of removal (emergency response) activities. Specifically, the OHMSB

evaluates and demonstrates new or improved equipment, devices, systems, and data analysis techniques for the prevention, identification, containment, control, removal and ultimate disposal of hazardous substances released to the environment. This includes the cleanup and recovery of hazardous substances from accidental releases as well as from uncontrolled hazardous waste sites, and is consistent with the definition of "removal" in Section 101 of the Superfund legislation. Additionally, the OHMSB demonstrates the equipment and systems to actively encourage the commercial use of cost-effective, advanced technologies during cleanup operations. Once an item is completed and has undergone various field testing, the plans, specifications, and other information are made available publicly for the purpose of encouraging commercialization of the new technology. Numerous systems, including a mobile water treatment unit and a mobile laboratory, have been completed and are now available commercially.<sup>2</sup>

The OHMSB also provides input into regulation development, enforcement, and technical support needs of the USEPA's Program Offices and the ten Regional Offices. Regulation development is being assisted through technical background investigation, such as updating the list of Superfund designated hazardous substances and attendant "reportable quantities." Regulation support is also provided by evaluating new cleanup techniques that will be incorporated in the regulations by reference. In this area, the OHMSB provides user manuals for emergency response, including sampling and analysis, monitoring techniques, technology evaluation, and guidance for on-scene response personnel. In addition to specific projects addressing decontamination of personnel and equipment, and specialized protective clothing for personnel, all projects in this program area place special emphasis on personnel health and safety.

### Major Outputs to Date

#### Mobile Incineration System

The OHMSB recently completed construction of a mobile incineration system<sup>3</sup> designed for field use to destroy hazardous organic substances collected from cleanup operations at spills and at uncontrolled hazardous waste sites. The system is designed to the USEPA's PCB destruction specifications (under the Toxic Substances Control Act) to provide start-of-the-art thermal detoxification of long-lived, refractory organic compounds. Hazardous substances that could be incinerated include compounds containing chlorine and phosphorus (i.e., PCB's, kepone, dioxins, and organophosphate pesticides) which may be present in sludges or in soils. In order to systematically evaluate and demonstrate the equipment, a trial burn is currently underway.

#### Ultrasonic Submerged Pollutant Detector

Using existing ultrasonic reflectometry technology, a detector—a sophisticated "fish-finder" for locating insoluble hazardous sinkers (chemicals that sink instead of float or are soluble) at the bottom of waterbodies—has been developed. The detector measures

variations in acoustic return echoes, and can be used to uniquely identify the acoustic "signature" of a sunken pollutant. During its development, the device was used to profile a spill of approximately 350,000 gal of toxic ethylene dichloride into Lake Ferguson near Greenville, Mississippi.<sup>4</sup> The device performed exceptionally well and located pools of pollutant ranging in depth from less than ½ in. to 20 in.

#### Hazardous Material Spill Case History Computer System

A computerized data base system,<sup>5</sup> which provides a centralized information bank of past hazardous substances incident response experiences has been developed and is currently being evaluated. This system will serve to aid on-scene personnel in deciding what treatment or technique to use, what degree of cleanup to employ, and what priorities to initiate for cleanup in relation to environmental fate and effects.

The system is based upon a standardized after-action data report form which is to be filled out by On-Scene Coordinators, their advisors, or a trained interviewer at the conclusion of a hazardous material incident. The report is in a format and arranged in such a way that the experiences can be subsequently retrieved for use by others who may be facing the same or similar situations. The computerized data base is continually updated with after-action report forms.

#### Field Test Kit for Measuring Redox Potentials of Waste Chemicals

A field test kit, for measuring oxidation-reduction (redox) potentials of organic and aqueous waste chemicals, has been developed and evaluated. Using the test kit, measurements can be made of the redox potential by using a portable, battery-operated instrument containing electrode probes and electrolyte solutions. The entire procedure for obtaining redox measurements requires only a few minutes and can be performed by inexperienced operators. The redox kit was developed as a screening procedure for segregating drums at uncontrolled hazardous waste sites to preclude the danger of an explosion due to a reaction between oxidizing and reducing agents. Field evaluations of the redox kit were successfully performed during Jan. and Nov. 1981.

#### Major Future Outputs

##### Mobile Soils Washer

A mobile treatment system has been designed for on-site extraction of a broad range of hazardous materials from excavated soils.<sup>6</sup> The system is expected to be an economical alternative to the current approach of excavation, hauling off-site to a landfill, and replacing the excavated soil. The system can be used to extract contaminants from soils—"artificially leaching" the soil using water—and enabling operators to leave the treated soil on-site. The extracted hazardous materials are separated from the washing fluid using physical/chemical treatment procedures. The cleaned washing fluid is recirculated, and the separated and concentrated hazardous materials are disposed of by appropriate means. The system is currently undergoing shakedown tests and is expected to be available for field demonstration during FY-83.

##### Mobile Carbon Regenerator

Water contaminated with hazardous substances has been successfully cleaned using water decontamination equipment such as the USEPA's mobile physical/chemical treatment system.<sup>7</sup> This system, which utilizes granular activated carbon to concentrate dilute dissolved organic contaminants, can be made more cost-effective with on-site regeneration of the spent carbon as opposed to transporting the carbon for off-site regeneration or placing it in a secure landfill.

In order to provide a safe and effective method for handling contaminated carbon, the OHMSB has developed a mobile unit for detoxifying/regenerating the carbon at the cleanup site.<sup>8</sup> The system has recently undergone initial shakedown and preliminary testing, and is expected to be ready for field demonstration and evaluation during FY-83.

#### Mobile *In-Situ* Containment/Treatment System

The OHMSB has developed an innovative, mobile system for treating contaminated soils in place at reduced costs, in terms of dollars per pound of contaminant removed.<sup>9</sup> The technique employs flushing with additives and detoxification by chemical reaction. *In-situ* containment is accomplished by the mobile unit through direct injection of grouting material into the soil around the contaminated area in order to isolate the released chemicals.

The chemicals are then treated in place by water flushing with additives, or by other methods such as oxidation/reduction, neutralization, or precipitation. The collected chemically contaminated wash solution can be processed through a mobile water treatment unit where contaminants are removed. The mobile *in-situ* containment/treatment system is currently undergoing shakedown tests and will be available for field evaluation during mid FY-83.

#### Manuals

The OHMSB is currently preparing documents for release to the user community during FY-83/84. Each of these user-oriented field manuals is being prepared in close cooperation and coordination with representatives of private organizations who would potentially use the manuals. These manuals are the following:

- *Environmental Emergency Control Handbook for First Responders* which will cover specific environmental-related practices to assist first-on-scene personnel, such as firefighters, in their decision-making process during the first critical minutes of a hazardous substance spill or release incident, where fire is not involved.
- *Manual on Physical and Chemical Countermeasures* which will provide general recommendations for using physical and chemical countermeasures to mitigate frequently occurring hazardous substance releases in subsurface soils and in large, relatively quiescent waterbodies such as lakes, ponds, canals, and slowly moving rivers. These recommendations will take the form of a matrix of countermeasures versus release types and will be applicable to the cleanup of spills as well as uncontrolled hazardous waste sites.
- *Spill Prevention Manual*, which will provide a matrix for various classes and groups of chemicals and spill-prevention techniques for these chemicals. This matrix will be developed primarily through communication with trade associations (such as the Chemical Manufacturers Association and others) and organizations engaged in producing, storing, and transferring hazardous substances. The manual will also be developed into a training course/workshop.

#### REMEDIAL TECHNOLOGY PROGRAM

##### Approach

The overall goal of the Disposal Branch is to assess and validate new or improved remedial action technologies or schemes to minimize pollutant release from uncontrolled hazardous waste disposal sites. More specifically, the remedial activity includes site survey and assessment studies, bench and pilot studies, field verification studies, cost-effectiveness and model studies. These studies are being performed to validate control technologies as they relate to surface water control, groundwater control, plume management, chemical immobilization, and excavation and reburial. The activities are consistent with the definition of remedial action in Section 101 of Superfund (CERCLA).

The Disposal Branch has pursued activities for new landfill design in the research areas of pollutant identification, pollutant generation, pollutant transport, pollutant control, and economics. These activities have direct relationships to the remedial action schemes for uncontrolled landfill sites. These research areas include bench, pilot, and field studies accompanied by the predictive modeling work. This research activity has produced eight technical resource documents<sup>10-17</sup> which reflect best engineering judgment for the design of waste disposal facilities as relate to landfills, land treatment, and surface impoundments.

The Disposal Branch also assists the Office of Emergency and Remedial Response and several of the Regional Offices in the areas of regulation development, technical and enforcement support, and assistance in the development of the National Contingency Plan.<sup>18</sup> This support typically includes the development of technical documents describing the design and construction of a variety of remedial action schemes which could be utilized as control measures at uncontrolled landfill sites.

### Major Outputs to Date

#### Handbook—Remedial Action at Waste Disposal Sites

The Disposal Branch, in consort with the Office of Emergency and Remedial Response, recently published the subject technology transfer document.<sup>19</sup> With this information the reader can then develop a preliminary remedial action plan and cost estimate. The objectives of the Handbook are twofold: (1) to provide the reader with a generalized understanding of the pollutant pathways involved in waste disposal sites, the remedial actions as they apply to each pathway, and the process of selecting the appropriate remedial actions; and (2) to provide detailed information on specific remedial actions including applications, state-of-the-art, design, construction, and/or operating considerations, advantages, disadvantages and costs.

#### Remedial Actions at Hazardous Waste Sites: Survey and Case Studies

A survey<sup>20</sup> of 169 waste disposal sites was performed to identify what type of remedial action was implemented. Technologies employed at these sites included: (1) containment, (2) removal of wastes for incineration or secure burial, (3) institution of surface water controls, and (4) institution of groundwater controls. A major deficiency of this study was that only 9 of the 169 sites were able to be investigated in detail. The other 160 sites were given only a cursory survey investigation. Remedial measures usually consisted of containment of contaminants or waste removal. The survey determined that a lack of sufficient funds and/or selection of improper technologies was responsible for remedial actions having been applied effectively at only a few of the uncontrolled waste disposal sites. This survey is currently being updated.

#### Guidance Manual for Minimizing Pollution from Waste Disposal Sites

The purpose of this manual<sup>21</sup> is to provide guidance in the selection of available engineering technology to reduce or eliminate leachate generation at hazardous waste disposal sites. The manual emphasizes remedial measures for use during or after closure of the sites. Some of the measures are passive, that is, they require little or no maintenance once emplaced. Others are active and require a continuing input of manpower or electricity.

#### Block Displacement Technique of Waste Isolation

A field demonstration of a technique to construct a clay isolation barrier around hazardous waste sites was recently completed. The block displacement technique is accomplished through a phase sequence of drilling, fracturing, and bentonite slurry injection around the bottom and sides of a waste disposal site with the resultant upheaval of the waste site to form a block, isolated by an impermeable bentonite barrier. USEPA was unable to demonstrate the full isolation at the study site, especially in the vertical plane, because of certain site specific anomalies such as the presence of tree roots below the local groundwater level and the presence of a variable iron-cemented strata immediately overlying the horizontal plane of bentonite injection across the bottom. However, there was evidence that the bentonite slurry did penetrate the horizontal fracturing plane.

#### Guidance Manual for Slurry Trench Design and Installation

A Guidance Manual for slurry trench cut-off wall design, construction, and performance evaluation is near completion. It provides recommendations on a variety of scientific and technical

parameters relevant to using this approach to isolate hazardous chemicals in near-surface groundwater regimes. The accomplishment of this effort required extensive information gathering and integration of technical data gathered from a diverse array of experience and authorities.

Conclusive recommendations reported within the Guidance Manual were determined by investigating areas of influence. These areas included historical perspective, present methodology, chemical compatibility tests, shortcomings of common backfill materials, positive recommendations for resistant backfill materials, detailed site soil and geologic characteristics which impact cut-off wall success, vegetation, checklists of design construction, performance factors, and documenting the quality and performance of completed construction.

### Major Future Outputs

#### Physical and Hydrogeologic Models for Hazardous Waste Sites

Remedial action alternatives for uncontrolled hazardous waste sites must be described in terms of attenuation of mitigation of existing or eminent public health/environmental problems, capital costs, O&M costs, design life, and risk of failure. This task will develop two complimentary levels of modeling.

Level 1 will be a relatively detailed modeling level for specific site engineering, and will consider detailed site factors, contaminant migration, detailed models of technologies, interrelationship among technologies, costs, design lives, and risk of failure. Level 2 will be simplified desktop procedures for use primarily by state and federal personnel for problem assessment, preliminary screening of the cost and effectiveness of remedial actions, and rapid review of remedial action plans. Level 2 will be based on sensitivity and factor analysis of key site and technology characteristics using the detailed Level 1 models. Both levels will describe the effectiveness of remedial actions considering site factors and characterization of the control technologies.

#### Cost Analysis of the Effects of Human Safety and Degree of Hazard as They Affect Remedial Actions at Uncontrolled Hazardous Waste Sites

This study will seek to determine the factors which contribute to the increased costs and ascertain the magnitude of additional costs associated with various components of remedial action unit operations. Primary source for data will be the private contractors and project officials having knowledge of the specific elements of project costs, and the manner in which these vary as a result of proximity to hazardous waste materials. Estimates of the additional costs incurred will be indicated in terms of percentages of ordinary or unusual costs, and in absolute terms where appropriate. The information produced will be valuable to program offices and others in evaluating costs of remedial actions.

#### Update of Survey Information on Completed and Ongoing Remedial Action Efforts

Since the time the study "Remedial Actions at Hazardous Waste Sites: Survey and Case Studies"<sup>20</sup> was made more recent information on remedial actions has become available. There is an obvious need to bring together and analyze the current up-to-date information, including effectiveness and cost. This information will serve as a foundation for future decision making with regard to presently uninitiated remedial action efforts.

#### Reliability of Available Technologies When Considered with Cost-Effectiveness

This study has been initiated to develop procedures for conducting the cost-effectiveness analysis at uncontrolled hazardous waste sites. Various remedial action options are available for any uncontrolled hazardous waste site. In broad categorical areas they are: alternative measures, active measures, and passive measures.

The "alternative measures" category is meant to include such actions as moving the affected population away from the site or providing alternative water supplies. The "active measures" would

include treatment scenarios applied directly to the site such as excavation and reburial in a secure site, waste stabilization, neutralization, treatment and/or elimination of problem. "Passive measures" would include entombment or isolation techniques using slurry walls, grout curtains, capping, bottom sealing, etc.

#### Collection of Data on Compatibility of Grouts with Hazardous Wastes

Available data from the literature and industrial sources will be collected on the compatibility of various types of suspension and chemical grouts with various classes of hazardous wastes and leachates. In addition, information will be collected on the procedures available to test the durability of grouts in the presence of hazardous wastes and leachates.

#### *In Situ* Treatment Techniques Applicable to Large Quantities of Hazardous Waste Contaminated Soils

The project addresses detoxification of large quantities of hazardous waste contaminated soils located at Superfund or other uncontrolled hazardous waste sites. *In situ* chemical and/or biological treatment methods presently available will be identified and evaluated. The feasibility and effectiveness of these methods will be assessed based on waste, soil type, site conditions and economic considerations. The output, a technical handbook, will include pertinent information concerning soil sorption and chemical and soil interaction influences on waste degradation. The remedial action identified as the most promising of the evaluated methods may be applied in a follow-up study (Phase II) on a full scale basis at a Superfund site.

#### Field Evaluation of Drum Encapsulation Techniques

A process for encapsulating drums containing hazardous waste is being demonstrated. Efforts will include evaluating the overpack/cover weld, resistance to physical stress (drop test, puncture resistance, etc.), and equipment performance. Mobility of the process and equipment is important and evaluations will develop criteria for mounting the hardware on a flat bed tractor/trailer vehicle.

#### Development of Methods and Pilot Test for *In Situ* Hazardous Waste Stabilization by Injection Grouting

This project will provide pilot scale tests to predict applicability to specific sites with specific waste compounds and expand the state-of-the-art to hazardous waste *in situ* stabilization. The pressure injection of grout to a variety of waste types will be investigated to develop a matrix of grout types to waste types with appropriate grout pressures and tube spacings included.

#### Manuals

The Disposal Branch is currently preparing documents for release to the user community during FY-83 and FY-84. Each of these user-oriented field manuals is being prepared in close cooperation with representatives of private organizations, and State and Federal agencies who would potentially use them. These manuals include the following:

- *User Guide for Evaluating Remedial Action Technologies*: The objective of this task is to produce a Remedial Action Technical Resource Document describing how the technologies and methods for evaluating proposed RCRA new hazardous waste disposal sites can be applied to site-specific remedial response activities for uncontrolled hazardous waste sites. The Remedial Action Document will be based on the state-of-the-art technical and cost information in eight TRDs<sup>10-17</sup> for design and evaluation of new hazardous waste disposal sites under RCRA. That information will be reviewed for relevance to remedial response at uncontrolled hazardous waste disposal sites, and will be edited and refocused to address the needs of personnel involved in response and remedial action planning under CERCLA.

- *Guidance Manual for Fixation/Solidification of Wastes in Surface Impoundments*: This project will define the limits of applic-

ability of fixation/solidification techniques to remedial actions at uncontrolled sites when considered in perspective with alternative or competing options. Information will be drawn from available fixation/solidification technology. The major problem with using these techniques at uncontrolled hazardous waste sites is that the composition of the waste is often unknown.

- *Guidance Manual for Cover Design and Installation*: A specification manual for the selection, design, and installation of covers or surface caps for uncontrolled hazardous waste sites is being prepared. Much of the information developed from two existing EPA reports<sup>10,22</sup> will be incorporated into this manual that will be specific to the problems of uncontrolled sites.

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# APPLICATIONS OF SOLUBLE SILICATES AND DERIVATIVE MATERIALS IN THE MANAGEMENT OF HAZARDOUS WASTES

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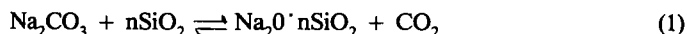
## INTRODUCTION

Soluble silicates are currently being used in chemical based methods of waste disposal, but the authors feel they could be utilized much more. This report is a review by the authors of the literature pertaining to waste treatment for disposal, with emphasis on solidification of liquids and sludges. The chemical methods currently used, using both silicate-based, and those that use silicates indirectly, are described. Some theoretical papers with implications for this use are reviewed, and possible new ways of using silicates are described:

- Solidifying solvents for transportation
- Grouting landfills to reduce permeability and divert or block sub-surface flows
- Modifications of other processes to improve leaching and physical properties

## SOLUBLE SILICATES

The soluble silicates useful for waste management are a class of materials made by reacting  $\text{Na}_2\text{CO}_3$  and quartz sand,  $\text{SiO}_2$ , in oil- or gas-fired open hearth regenerative furnaces.<sup>1</sup> This reaction;



where the "ratio", (n) varies between  $\sim 1.6$  and  $3.9$ , produces a water soluble glass. Sodium silicates are usually sold in a liquid form. The ratio is an important factor in determining both the chemistry and applications of these materials. The more alkaline (lower values of n) silicates are used in the manufacture of detergent and cleaners, whereas the higher ratio products are usually used to produce the various silicate derivatives, e.g., silica sols and gels, precipitated silicas and synthetic clays, zeolites and miscellaneous crystalline and amorphous products. These two broad category uses account for roughly 75% of the volume consumed. Other large applications include coatings, binders, adhesives, soil grouts and cements.

### The Properties of Sodium Silicates

The properties of interest in waste treatment are:

- Alkalinity
- Gel forming capability
- Reactivity with multivalent cations
- Environmental acceptability

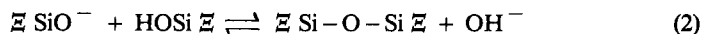
#### Alkalinity

Sodium silicates are the salts of a weak acid and strong base, thus their aqueous solutions are very alkaline. The pH values of concentrated solutions with values of n between 1.0 and 3.9 vary from  $\sim 13.8$  to 10.7. The neutralization capacity can be calculated from the level of  $\text{Na}_2\text{O}$  which is normally part of the product specification.

#### Gel Forming Capabilities

The silica in solutions of soluble silicates is present as a complex distribution of polymeric silicate anions. These anions are thought to

be in a metastable equilibrium state which is very slowly over time tending to produce more polymerized species. This condensation reaction may be written as shown:

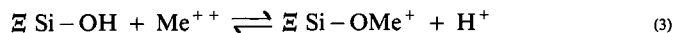


The condensation of silicate anions is enhanced by the addition of mineral acid and/or acidic salts (relative to silicate anions). When the soluble silica concentration is sufficiently high ( $>1\%$ ) silica polymer "sol" crosslinking occurs and a gel network is formed.<sup>2,3</sup> The rate of gel formation is maximal near neutrality and increased silica concentrations generally increase the rate of gelation and gel strength.

Other matrix components may have a significant effect on mechanical strength. These gelatin properties account for their usefulness in soil stabilization and for diversion or blocking of subterranean fluid flows.

### Reaction with Multivalent Ions

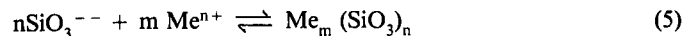
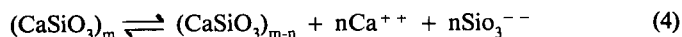
The reaction of soluble silicates with metal ions under ambient conditions are generally thought to lead to mixtures of silica gel and hydroxylated metal ion gels. Specific interactions with the silica are expected to be primarily due to cation exchange, i.e.,



In more dilute solutions, the activities of several metal ions in the presence of higher ratio soluble silicates were suppressed to a great degree than expected based on solution pH value alone.<sup>4</sup> This may be attributed to a stronger affinity of the metal ion for the surface of the more condensed silicate species.

In more practical studies Connors<sup>5,6</sup> and Gowman<sup>7</sup> have shown that the metal ion leaching from solidification methods employing soluble silicates is significantly reduced compared to hydroxide precipitation.

Ponomareva *et al.*<sup>8</sup> suggest that the removal of cations from solution by calcium silicate slags proceeds by the dissolution of the calcium silicate, which provides silicate ions, followed by the precipitation of heavy metal silicates:



However, the dissolution of the slag is fairly slow and limits the rate of removal of the cations. The authors have shown that the introduction of silicate ions into the system as sodium silicate results in much faster reaction with the heavy metals, and decreases the amount of slag needed.

The use of  $\text{Ca}(\text{OH})_2$  and other alkalis (including sodium silicate) for the removal of heavy metal cations, in the absence of slag, results in the formation of fine precipitates with poor settling characteristics and dewatering properties. However, the continued use of slag and sodium silicates gives a sludge with good dewatering properties, because the slag serves as a support for the epitaxial deposition of precipitates.



### Environmental Acceptability

Since silicates are made from sand and alkali, they are universally judged to be ecologically acceptable. Recently the Task Force on ecological effects of non-phosphate detergent builders<sup>9</sup> concluded that sodium silicate is neither toxic nor otherwise harmful to the fresh water environment. Evidence was presented as part of this report that the presence of silicates in waste water being treated led to an increased collection of metal ions in the waste sludge. High pH values were identified as a possible problem; however, silicates used in waste treatment would presumably be neutralized and harmless to the environment.

In summary, it appears that the chemical properties of these ecologically safe soluble silicates make them interesting raw materials for the modification for matrix leachability characteristics through reduction in matrix permeability, diversion of fluid flows and enhanced metal ion affinity.

### GENERAL CHEMICAL METHODS OF WASTE TREATMENT

The term solidification implies methods that fix or encapsulate wastes in solid matrix end products. Fixation processes bind the wastes by chemical or physical means, using solidification agents. Encapsulation methods physically surround the wastes with the agent. These methods have been used in the U.S. for radioactive wastes, but until the RCRA and other environmental protection acts were passed, most non-radioactive wastes have been disposed

of by the less acceptable methods such as lagooning, sewerage, landfilling in an unfixed state, bleeding into stream, etc. Under pressure from the recent environmental protection laws, many more wastes are being solidified.

Pojasek<sup>10,11</sup> discusses methods for converting hazardous wastes to non-hazardous substances. He describes five basic technologies, one of which can be adapted to handle any specific waste:

- Silicate and cement based
- Lime-based
- Thermoplastic-based
- Organic polymer-based
- Encapsulation techniques

Table 1, taken from Pojasek's work,<sup>10</sup> gives the advantages and disadvantages of these solidification processes. The cement- and lime-based methods are suitable for toxic inorganics and stack gas scrubber sludges, but are generally not suitable for toxic anions and organics. The other three methods are suitable for toxic inorganics, but are not suitable for strong oxidizers and organics.

Maugh<sup>12</sup> has also reviewed the hazardous waste problem, and discusses various general methods of coping with it. He emphasizes that the non-nuclear is much greater than the nuclear waste problem. As of 1979, about 5,000 tonnes of nuclear wastes had been accumulated since the beginning of the nuclear era; this is four orders of magnitude smaller than the volume of non-nuclear toxic waste generated in one year.

Table 1.  
Technical Comparison of Solidification Processes

Process	Advantages	Disadvantages
Cement-based	<ol style="list-style-type: none"> <li>1. Additives are available at a reasonable price.</li> <li>2. Cement mixing and handling techniques are well developed.</li> <li>3. Processing equipment is readily available.</li> <li>4. Processing is reasonably tolerant of chemical variations in sludges.</li> <li>5. The strength and permeability of the end-product can be varied by controlling the amount of cement added.</li> </ol>	<ol style="list-style-type: none"> <li>1. Low-strength cement-waste mixtures are often vulnerable to acidic leaching solutions. Extreme conditions can result in decomposition of the fixed material and accelerated leaching of the contaminants.</li> <li>2. Pretreatment, more-expensive cement types, or costly additives may be necessary for stabilization of wastes containing impurities that affect the setting and curing of cement.</li> <li>3. Cement and other additives add considerably to weight and bulk of waste.</li> </ol>
Lime-based	<ol style="list-style-type: none"> <li>1. The additives are generally very inexpensive and widely available.</li> <li>2. Equipment required for processing is simple to operate and widely available.</li> <li>3. Chemistry of pozzolanic reactions is well known.</li> </ol>	<ol style="list-style-type: none"> <li>1. Lime and other additives add to weight and bulk of waste.</li> <li>2. Stabilized sludges are vulnerable to acidic solutions and to curing and setting problems associated with inorganic contaminants in the waste.</li> </ol>
Thermoplastic	<ol style="list-style-type: none"> <li>1. Contaminant migration rates are generally lower than for most other techniques.</li> <li>2. End-product is fairly resistant to most aqueous solutions.</li> <li>3. Thermoplastic materials adhere well to incorporated materials.</li> </ol>	<ol style="list-style-type: none"> <li>1. Expensive equipment and skilled labor are generally required.</li> <li>2. Sludges containing contaminants that volatilize at low temperatures must be processed carefully.</li> <li>3. Thermoplastic materials are flammable.</li> <li>4. Wet sludges must be dried before they can be mixed with the thermoplastic material.</li> </ol>
Organic polymer	<ol style="list-style-type: none"> <li>1. Only small quantities of additives are usually required to cause the mixture to set.</li> <li>2. Techniques can be applied to either wet or dry sludges.</li> <li>3. End-product has a low density as compared to other fixation techniques.</li> </ol>	<ol style="list-style-type: none"> <li>1. Contaminants are trapped in only a loose resin-matrix end-product.</li> <li>2. Catalysts used in the urea-formaldehyde process are strongly acidic. Most metals are extremely soluble at low pH and can escape in water not trapped in the mass during the polymerization process.</li> <li>3. Some organic polymers are biodegradable.</li> <li>4. End-product is generally placed in a container before disposal.</li> </ol>
Encapsulation	<ol style="list-style-type: none"> <li>1. Very soluble contaminants are totally isolated from the environment.</li> <li>2. Usually no secondary container is required, because the coating materials are strong and chemically inert.</li> </ol>	<ol style="list-style-type: none"> <li>1. Materials used are often expensive.</li> <li>2. Techniques generally require specialized equipment and heat treatment to form the jackets.</li> <li>3. The sludge has to be dried before the process can be applied.</li> <li>4. Certain jacket materials are flammable.</li> </ol>



The approaches which Maugh suggests, in order of decreasing preference, are these: eliminating the production of wastes, recycling to recover values, chemical or biological degradation, incineration, deep well injection, and finally solidification and land filling. While not a preferred technique, an increasing amount of toxic waste is being solidified, and at least 41 different companies have developed proprietary processes for this step.<sup>13</sup> Maugh divides these into cement-based, pozzolanic or lime-based, thermoplastic, and organic binders. Advantages and disadvantages for the various techniques, as outlined by Maugh, agree with Table 1.

## SOLUBLE SILICATE BASED SOLIDIFICATION METHODS

### Methods Using Soluble Silicates Directly

**Chemfix:** The earliest patents for a silicate-based solidification system are those issued to Conners, of Chemfix, Inc., at that time a Pittsburgh, PA Company.<sup>14,15</sup> The patents describe the use of an alkaline metal silicate and a setting agent containing polyvalent metal ions (particularly those which provide free calcium ions) to solidify waste sludges. They claim that wastes consolidated with soluble silicate and cement give leachates with low heavy metals concentrations. In fact, when leachates from raw, unconsolidated wastes, containing relatively high toxic metals levels were percolated through beds of waste treated by the Chemfix method, the metal concentrations in the original leachate are greatly reduced. Reductions from 85 to 100% are found. The same is true for cyanide, ammonia and nitrates, and chemical oxygen demand. The treated waste is therefore recommended as a liner for landfills, and as a cover for layers of unconsolidated waste.

The Chemfix process got considerable publicity in the 1970s.<sup>16-24</sup> In addition Conners prepared a number of papers, information packages, and data sheets describing the process and giving both laboratory and field test results.<sup>6,7,25-28</sup>

Leaching tests were reported with  $H_2SO_4$  and HCl solutions at pH values of 1.0 without significant solubility of the metals. (Concentrations of Cr, Cu, Fe, Mn, Ni, and Zn remained below 0.1 mg/l.) It is said that for many Chemfix sludges which contain high levels of toxic heavy metals, the leachates easily meet USPHS drinking water standards.

The Chemfix process increases the volume of the waste by 5-10%. Treated wastes can be used for landfill and can support vegetation.

A recent British Patent Application<sup>29</sup> describes a trailer-mounted apparatus for mixing a setting agent and silicate with waste sludges for solidification. An example cites 500 kg Portland cement and 0.225 m<sup>3</sup> of sodium silicate for 5.5 m<sup>3</sup> of waste sludge. This appears to be very similar to the Chemfix method.

**Hittman Nuclear:** This company is engaged in the fixation and transporting of low level nuclear wastes. The Hittman method<sup>30</sup> is to convert the waste slurries to a rock-like mass, using Portland cement as the main solidifying agent. A certain amount of anhydrous sodium metasilicate is added to the slurry to give a harder product and a quicker set time.

Elaborate conveying and feeding equipment is used to mix the slurried wastes, cement and silicate in the proper proportions. The treated wastes are dropped into disposable containers, sealed and transported to secure landfills. The Hittman organization is planning to market their method and services in the non-nuclear hazardous waste field.

This approach differs in two ways from the Chemfix method:

- Cement is the main ingredient. rather than the setting agent for the silicate
- A solid anhydrous metasilicate is used instead of a high ratio liquid

**Hayes Method:** This patent<sup>31</sup> specifically addresses the fixation of cesium. Limited success is obtained using clays, shales or the Chemfix approach. Hayes claims that the use of sodium silicate, a silicate hardening agent and finely divided shale results in decreased mobility of the cesium. In this process the function of the shale is to

ion-exchange with the radioactive cesium. When silicate is present in the solidifying mass, leaching of the cesium is decreased by a factor of 10.

### Methods Using Soluble Silicates Indirectly

**Soliroc Process:** This process<sup>32</sup> is based on the premise that heavy metal hydroxides, precipitated in the pH range of 9-11, will dissolve significantly when exposed to leachates at low pH values. The inventors claim further that other silicate-based methods simply encapsulate the wastes; if the solidified waste products are crushed, as in hauling, dumping or compacting, the resulting higher surface areas would allow significantly increased leaching of the wastes.

In this approach, the heavy metals are dissolved in acid, and are reacted at low pH with a "siliceous reagent". The mixture is then adjusted to a higher pH value causing the silicates to polymerize and gel. Lime and a setting agent such as cement are used for final solidification.

The siliceous reagent (also called low molecular weight or low polymerization silicic acid) is prepared by adding alkali or alkaline earth silicates or aluminum silicate to an excess of mineral acid. Residues or waste streams are suggested for both the silica source and the acid starting materials. For instance, siliceous wastes such as blast furnace slag or flue dusts are suggested for the silica source, and waste plating solutions as the acid source.

The dissolved heavy metal ions react with the low molecular weight silicic acids, and as the pH is raised to about 7 with an alkaline material, the liquid starts to gel. Final setting is accomplished by the addition of more lime and cement. Hardening takes about three days.

Low leachability and high mechanical strength are claimed, but no information on these are given in the patent. Rousseaux and Craig<sup>33</sup> have evaluated the process. A blend of four wastes was solidified by this process. The source of the silica was not specified. Results for five runs, made under different conditions, are summarized below:

Metal	Conc's in Waste (mg/l)	Leachate Conc'n for five runs (mg/l)
Cd	2890	0.01 - 5.6
Cr	10390	0.01 - 0.5
Cu	7100	0.05 - 0.64
Ni	2640	0.01 - 1.30
Pb	1710	0.008 - 0.017
Zn	7650	0.41 - 34.8

Compressive strengths ranged from 8 to 156 psi.

Ontario Liquid Waste Disposal, Ltd.: A patent describes the following process<sup>34</sup>:

- Reacting the liquid waste with an acid ferrous solution at a pH range 2-5
- Neutralizing the reaction mix with an alkali (NaOH or lime) to raise the pH to the range 9-12, which yields an inert precipitate
- Adding a silicic compound to form large complex silicate molecules
- Adding an alkaline earth material to raise the pH to the range 12-13

The silicic compounds for the third step can be sodium silicate, but also cement, fly ash, general ash, siliceous slag, clay, silt, sand, and siliceous stone or soil. The alkaline earth compounds for the final step include lime, MgO, BaO, Ca(OH)<sub>2</sub>, and cement. Hardening takes place over several days.

The compressive strengths and leaching properties of samples cited in this patent were as good as the Soliroc samples. This treatment suppressed the offensive odors of putrified wastes.

The Research-Cottrell approach<sup>35</sup> is to blend fly ash with the sludge which has been dewatered to about 69-70% solids. The proportion of fly ash must be greater than 80% of the total to achieve a dry, transportable product. This process is most suitable for low

sulfur coal containing 2% S or less. For high sulfur coals, they recommend the addition of an extra reactant, such as lime, Portland cement, sodium silicate or other proprietary substances.

The Stablex Corp. patent<sup>36</sup> describes a process of treating hazardous wastes with an aluminum silicate or aluminosilicate, and with Portland cement, to form a slurry which will set into a rock-like crystal matrix having low permeability and high ultimate strength. The aluminosilicate is generally fly ash. The use of alkali metasilicate to shorten set time is mentioned in the patent in one example and in one claim. The process appears to be sorption of the toxic wastes by the aluminosilicate, followed by the immobilization of the loaded fly ash in a cement matrix.

The process has been used since 1974 in England, and has also been used in Japan.<sup>37</sup> Waste treatment units are currently being built in the U.S.<sup>38</sup> Stablex claims that a wide range of wastes, comprising about 70% of existing hazardous and toxic wastes, can be handled.

### GENERAL ASPECTS OF SILICATE AS A MODIFIER

Heacock and Riches<sup>39</sup> compare three processes for the solidification of radioactive wastes. These are Portland cement, sodium silicate-modified Portland cement, and urea-formaldehyde. Unfortunately the details of the processes are not given in the paper, and neither the ratio nor the concentration of the silicate is specified. In a table of ten solidification properties for the three processes, the silicate-modified cement method equaled or exceeded the competing processes in each case; in five comparisons, physical properties, shipping efficiency, residual water, and tolerance for chemical composition of basic wastes and regenerant wastes, it was listed as "best". (Shipping efficiency is related to the volume expansion caused by the solidification step.)

In annual operating cost comparisons, the silicate-modified cement method showed a definite advantage: costs for the silicate-cement approach were only 70-80% of those for the other two methods. These results combined with the work of Ponomavera suggested that soluble silicates could be beneficial additives to other cement based processes, e.g., the Stabatrol Corp., Terra-Tite<sup>4</sup> method and the Pec-Engineering, Petrifix<sup>4</sup> method.

### A SUMMARY OF RECENT LABORATORY STUDIES

A preliminary investigation of individual hazardous wastes was conducted in PQ Corporation laboratories to determine the effectiveness of sodium silicates in treating materials with a wide range of physical and chemical properties. Wastes selected are listed in Table 2; each was chosen because it represented a different disposal problem. A variety of silicate based treatment processes were employed to solidify, fix or encapsulate these materials and the resulting waste/sludge mixtures were evaluated using standard analytical procedures. The following is a brief summary of the work done.

Sodium silicate consolidation and fixation of waste fly ash was evaluated using two different types of ash (type A&B). While the ashes chosen displayed comparable physical properties, the ashes were quite different chemically (Table 2). Two silicate based techniques were used with equal success in treating these materials, and a lime-based solidification method was used as the standard treatment. These techniques are outlined in Table 3 and the results for physical strength and leachability are outlined in Tables 4 and 5. Fly ashes consolidated using these silicate based methods displayed better strengths and water resistance and reduced leaching characteristics than the lime-based standard.

The benefits of treating municipal and plating wastes with sodium silicates were assessed for two sludges containing a mixture of organics and toxic heavy metals (analysis in Table 6).

These materials were consolidated using both a gel solidification and a silicate-cement process (Table 7). Leachability of the materials was evaluated using the EP batch leaching test and results compared to those for the untreated wastes are shown in Table 8. Both silicate based treatments resulted in a solid material able to meet the EPA limits for heavy metal leaching. It has been proposed

**Table 2.**  
**Wastes Selected for Sodium Silicate Treatments**

Waste	Criteria for Hazardous Status	Disposal Problems
Fly Ash A	Corrosivity (low pH) Respiratory irritant (particle size)	Material must be neutralized and consolidated for landfilling
Fly Ash B	EP toxicity (heavy metals) Respiratory irritant (particle size)	Toxic metals must be fixed for safe landfilling Material must be consolidated for landfilling
Plating Sludge	EP toxicity (heavy metals)	Toxic metals must be fixed for safe landfilling Solidification of sludge to improve landfilling
Municipal Sludge	EP toxicity (heavy metals and organics)	Toxic metals must be fixed for safe landfilling Solidification of sludge to improve landfilling
Refinery Waste	Corrosivity (low pH)	Waste must be neutralized for landfilling Solidification to improve landfilling and contain organic material
Liquid Organic Solvents	Ignitability (low flash pt)	Flammability must be reduced for landfilling Liquid material must be solidified for transport and landfilling

**Table 3.**  
**Fly Ash Solidification Techniques**

#### Direct Solidification

Fly ash is wetted out with diluted sodium silicate solution. Dilution factor and amount of solution added to ash were calculated to deliver 4% SiO<sub>2</sub> based on weight of material. Material may be air set or oven set at 75 °C.

#### Gelled Solidification

Fly ash is slurried in 14% sodium silicate solution (4% SiO<sub>2</sub> based on weight of ash) and then gelled with 12% H<sub>2</sub>SO<sub>4</sub>.

#### Lime Treatment (Standard)

Fly ash slurried in H<sub>2</sub>O. 10% lime added based on weight of ash. Material is air set.

**Table 4.**  
**Compression Results for Consolidated Fly Ashes**

Fly Ash	Fresh* (1 Hr)	Oven Dried* (75 °C)	Water Soaked* (4 Hrs)
A	64.3	128.4	75.5
B	58.4	134.4	87.0

\*Results reported in LBS/IN<sup>2</sup>

that this reduction in heavy metal leaching is due to the formation of less soluble metal silicates and an improved containment matrix, both directly related to the addition of sodium silicate.

Compatibility and effectiveness of silicate based treatment processes with wastes containing high levels of organic and petroleum by-products were determined during our investigation of refinery sludge. The waste was composed of waste-produced from an acid-oil treatment process that had become saturated with water. This sludge had a low pH value, low heavy metal concentrations and high sulfur content. Treatment was directed at achieving a solid material with a minimum compressive strength of 1 ton/ft<sup>2</sup> to allow proper landfilling. The waste could be solidified by a number of

**Table 5.**  
**Leaching Results for Fly Ashes A and B**

All Concentrations in mg/l.

RESULTS FROM EP LEACHING TEST

FLY ASH A

HEAVY METAL	FRESH	GELLED	% CHANGE	FRESH	LIME	% CHANGE
Co	0.31	0.08	- 74	0.41	0.13	- 68
Cd	0.86	0.19	- 78	0.73	0.27	- 63
Zn	36.0	11.0	- 69	15.0	7.0	- 53
Sn	0.57	0.48	- 23	0.77	0.83	+ 8
Cu	2.0	0.13	- 94	1.8	0.48	- 73
Ni	1.6	0.28	- 83	2.2	0.84	- 62
Cr	0.14	0.09	- 36	0.39	0.08	- 79
Pb	3.2	1.2	-167	0.51	0.44	- 14

FLY ASH B

HEAVY METAL	FRESH	GELLED	% CHANGE	FRESH	LIME	% CHANGE
Co	0.12	0.07	- 46.8	0.12	0.12	0.0
Cd	64.0	24.0	- 62.5	64.0	26.0	- 59.3
Zn	8600	4200	- 51.2	8600	4100	- 52.3
Sn	0.94	0.77	- 18.1	0.96	1.1	+ 14.8
Cu	37.0	14.0	- 62.2	37.0	20.0	- 45.9
Ni	0.4	0.23	- 42.5	0.4	0.28	- 30.0
Cr	0.13	0.06	- 53.8	0.13	0.26	+100
Pb	170	74	- 56.5	170	350	+106

**Table 6.**  
**Analysis for Mixed Municipal and Plating Waste**

	Mixed Municipal	Plating
% Solids	28.1	38.2
pH	9.1	9.5
COD	217,000	N/A
Arsenic	23	N/A
Cadmium	0.9	3.2
Copper	8.9	10.4
Chromium	353	56.0
Lead	823	1048.0
Mercury	0.06	N/A
Nickel	564	23.4
Selenium	0.07	20.1
Silver	0.1	20.1

**Organics in Sludge**

Acetone	56.9	N/A
Chloroform	5.5	N/A

All metal concentrations reported in mg/l.

**Table 7.**  
**Treatment Formulations for Mixed Municipal and Plating Wastes**

**Gelled Solidification**

14 pphw N<sup>+</sup> sodium silicate added to waste. Material gelled with 1.5-2.0 pphw H<sub>2</sub>SO<sub>4</sub>.

**Cement/Silicate Solidification**

14 pphw N<sup>+</sup> sodium silicate and 10 pphw Portland cement Type I added to waste; set time—1 week.

pphw—parts per hundred parts of waste

sodium silicate-cement-fly ash combinations, with strengths exceeding the required 1 ton/ft<sup>2</sup> value. Costs for several of these treatments were lower than the cement-lime-clay standard treatment.

The final phase of these initial investigations concentrated on solidifying a variety of organic solvents (Table 9) with a gelling process to reduce ignitability and flash point and produce a material that would be safe and easy to transport. Three distinct techniques utilizing sodium silicates were developed (Table 10).

The physical properties and characteristics of solvents solidified by silicate gellation are compared to standard absorbent treatment and reported in Table 11. All solvents investigated were successfully

**Table 8.**  
**Heavy Metal Leaching Results for**  
**Mixed Municipal and Plating Wastes**

\*All concentrations in mg/l.

PLATING WASTE

HEAVY METAL	FRESH WASTE	GELLED WASTE	% CHANGE	HEAVY METAL	CEMENT FIXED WASTE	GELLED WASTE	% CHANGE
Co	1.1	0.15	-86	Co	0.47	0.15	- 68
Cd	0.33	0.05	-76	Cd	0.12	0.05	- 58
Zn	20.0	6.2	-69	Zn	4.1	6.2	+ 51
Sn	4.0	1.8	-55	Sn	4.0	1.8	- 55
Cu	2.6	0.14	-95	Cu	0.48	0.14	- 71
Ni	44.0	1.4	-97	Ni	1.9	1.4	- 26
Cr	2.5	0.42	-83	Cr	1.4	0.42	- 70
V	0.32	0.47	+47	V	1.5	0.47	- 69
Pb	8.6	2.7	-69	Pb	12	2.7	- 78

MIXED MUNICIPAL WASTE

HEAVY METAL	FRESH WASTE	GELLED WASTE	% CHANGE	HEAVY METAL	CEMENT FIXED WASTE	GELLED WASTE	% CHANGE
Co	0.19	0.04	-79	Co	0.09	0.04	- 44.4
Cd	0.20	0.06	-70	Cd	0.10	0.06	- 60.0
Zn	30.0	8.3	-72	Zn	22.0	8.3	- 37.7
Sn	0.78	0.27	-65	Sn	0.13	0.17	+130.0
Ni	4.7	1.7	-64	Ni	2.2	1.7	- 77.3
Cr	0.13	0.15	+15	Cr	0.19	0.15	- 78.9
V	0.07	0.04	-42	V	0.04	0.04	0.0
Pb	4.5	2.5	-44	Pb	3.2	2.5	- 15.5

**Table 9.**  
**Solvent/Solvent and Solvent/Silicate Compatibility**

<b>Water</b> $\xi = 78.5$	M						
	C						
	G						
<b>Glycerol</b> $\xi = 42.5$	M	M					
	C	C					
	G	G					
<b>Ethylene Glycol</b> $\xi = 37.7$	M	M	M				
	C	C	C				
	G	G	G				
<b>Methanol</b> $\xi = 32.6$	M	M	M	M			
	I	I	I	I			
	P	P	P	P			
<b>Acetone</b> $\xi = 20.7$	M	M	M	M	M		
	I	I	I	I	I		
	P	P	P	P	P		
<b>Pet. Ether</b> $\xi = 10.0$	N	N	N	M	M	M	
	I	I	I	I	I	I	
	S	S	S	P	P	S	
<b>Toluene</b> $\xi = 2.4$	N	N	N	M	M	M	M
	I	I	I	I	I	I	I
	S	S	S	P	P	S	S

M—Solvents Mix  
N—Solvents Don't Mix  
C—Solvent Compatible with Silicate  
I—Solvent Incompatible with Silicate  
G—Gel Formation  
P—Precipitation  
S—Phase Separation

**Table 10.**  
**Approaches to Solvent Gelling**

**Direct Gelling**

For solvents compatible with water and silicates. Solvents characterized by high dielectric constants and miscible with water. Gel forms directly in solvent by condensation of silica to form gel network.  
Examples: Water, Ethylene Glycol, Formamide

**Indirect Gelling**

For solvents compatible with water but not with silicate solutions. Solvents miscible with water and have medium range dielectric constants. Silica in solution must be protected from dehydration by solvent. Acidify silicate solution and initiate gelling before adding to solvent.  
Examples: Acetone, Alcohols

**Encapsulation**

For solvents incompatible with water and silicate solutions. Not miscible with water and low dielectric constant. Solvent must be encapsulated in a gelling silicate through mechanical procedures.  
Examples: Toluene, Benzene, Pet. Ether

**Table 11.**  
**Comparison of Solvent Solidification Using**  
**Shale Absorbent and Silica Gel**

	Gel	Absorbent
Amount solidification material added (based on weight of solvent).	30%	110%
Volume increase	20%	40%
Ignitability	Would not ignite or support combustion.	Material ignited and burned until solvent exhausted.

solidified and contained using one or more of these techniques and in each case the ignitability and the ability to support combustion was reduced.

In summary, these results show that silicate addition reduces leaching characteristics of heavy metals from wastes vs untreated wastes and the standard treatment used. Further benefits observed were the improved mechanical properties of the cement based method used. Containment properties of gelled silicates extend to certain solvents in addition to inorganic wastes.

#### FUTURE WORK

The results discussed in the previous section show that silicates can be used to solidify a variety of materials, and that silicate-bonded wastes appear to have advantages in fixing heavy metal ions, or in suppressing the leachability of those ions. In addition, a wide range of organic solvents can be solidified by silicate based methods and solidified organics have much lower flammability characteristics than the liquid form.

The key objective of future work will be to optimize the use of silicates in three areas; permeability, leachability and mechanical strength.

- Permeability of silicate-bonded wastes and silicate grouts vs. wastes bonded by other methods
- Resistance to leaching of silicate-bonded heavy metals vs hydroxides, over a range of pH values
- Mechanical strengths of silicate-based consolidated wastes

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# DEVELOPMENT AND DEMONSTRATION OF SYSTEMS TO RETROFIT EXISTING LIQUID SURFACE IMPOUNDMENT FACILITIES WITH SYNTHETIC MEMBRANE

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## INTRODUCTION

Surface impoundment facilities such as pits, ponds, and lagoons are used extensively throughout the United States to store, treat and dispose of hazardous wastes. These impoundments usually are designed to contain fluids, utilizing native materials or liners and in the past, many were constructed with little concern for preventing seepage from the facility. In fact, many such facilities were designed to seep water into the ground as a means of disposal. Unfortunately, many of these facilities are presently causing groundwater contamination problems.

With the establishment of regulations passed under authority of the Resource Conservation and Recovery Act (RCRA) legislation, retrofitting in-service disposal and treatment impounds may be required to prevent continued seepage. Retrofitting with impermeable liners may accomplish this objective. Liners may also be required to protect against wind and water erosion, another objective of RCRA regulation requirements.

Retrofitting an in-service impoundment with a flexible membrane liner generally implies the emplacement of liner material on the bottom and sides of a facility to mitigate leakage without removing any *in situ* fluid (hazardous material) in the impoundment. Such action may be desirable as a temporary measure, while a new impoundment is constructed, or as a permanent step to upgrade an untrustworthy facility. As RCRA regulations are implemented and groundwater studies confirm contamination from seeping impoundments, information about retrofitting techniques will be needed to assist owners and operators in upgrading existing facilities.

The main purpose of a membrane liner system in a fluid impoundment is to prevent loss of liquid to the groundwater, but a liner can also prevent bank erosion due to wave and wind action. Flexible liner membranes are manufactured using a variety of polymeric materials such as polyethylene and polyvinyl chloride. During construction of new impoundments, the liner materials are installed over compacted subgrade. Sheets of membrane liners are placed over the subgrade and connected together using a variety of seaming methods. The most common methods are heat sealing and solvent bonding. The sheet is attached at the top of the perimeter using an anchoring system, usually an earthen anchor trench. The finished liner serves as a relatively impermeable continuous barrier covering the earthen impoundment.

The implementation and enforcement of RCRA regulations concerning hazardous waste impoundment will create a need for owners/operators to cease the contamination of groundwater due to seepage. In many cases, it may be desirable or even necessary, to make design modifications while the facility is in service, while in others it may be necessary to temporarily reduce seepage while a facility is closed or a new one is constructed. Retrofitting of membrane liner systems offers a potential way for owners of such hazardous waste fluid impoundments to reduce or stop seepage.

Unfortunately, retrofitting existing impoundments has not been routinely performed. Many questions need to be answered before

this approach to sealing an existing impoundment can be implemented. Information concerning the size of facilities which can be retrofitted, equipment needed, the most efficient retrofitting system, labor requirements and costs needs to be developed.

In this paper, the authors report on an ongoing project that Southwest Research Institute is conducting for the USEPA, for the development and demonstration of systems to retrofit existing liquid surface impoundment facilities with synthetic membrane liners.

## PROJECT OBJECTIVES

The primary objective of this project is to determine the feasibility of retrofitting an existing surface impoundment with an effective membrane liner system without taking the facility out of service. Anticipated project results are the following:

- Identification of one or more technically feasible retrofit liner installation techniques
- Demonstration of the feasibility of each system on a pilot scale
- Preparation of a full scale demonstration plan if the systems prove feasible at pilot scale

The results of the project will determine the feasibility of retrofitting existing surface impoundments with a membrane liner system. Conceptual approaches to retrofitting different types of impoundments will be developed and evaluated. The most promising approaches will be attempted at a pilot scale to verify or deny their feasibility. From these activities, the important procedural and physical parameters to consider when retrofitting will be established. Limitations of each approach will be defined, e.g., which approach is best suited for a particular impoundment geometry. A plan will be developed for full scale implementation of those retrofitting systems shown to be feasible at pilot scale. Potential sites will be identified where the retrofit approaches could be implemented.

The most significant benefit which could be expected as a result of successful completion of this project will be the development of a promising technique(s) which could be used to halt the release of hazardous fluids into the environment. Preventing or stopping the contamination of surface and/or groundwater may be important to protect drinking water supplies. If a surface impoundment containing hazardous wastes is found to be seeping contaminated fluids, retrofitting the facility with an effective membrane liner system should provide mitigation. This project should provide information needed about retrofitting in order to ascertain the feasibility of full scale utilization.

## WORK ACCOMPLISHED

### Load Analyses

A theoretical stress/strain analysis has been performed for the various retrofit membrane materials. Mechanical properties and coefficient-of-friction and failure data for different types of liner

material were obtained and used during the analyses. A load analysis program has been written to calculate the stresses on liner materials resulting from installation using the pull-thru concept for retrofitting. The program is set up to run on a HP9325A desktop computer. Required input data are:

- Length of the first sheet to be pulled into the pond
- The footage of liner covering the end slopes of the pond
- The footage of liner covering the side slopes of the pond
- Coefficients of friction values for soil and water
- The tensile strength of the liner material at elongation
- The thickness and density of the liner
- The length and width of the pond

This program will calculate these stresses for any impoundment geometry and liner material. Calculations for four generic liner materials and three different sizes of impoundments are shown in Table 1. The pond geometry varies as does the size of the panels to be seamed together as the material is pulled into the water.

These calculations provide a very gross estimate of the forces to be expected. Critical factors yet to be answered are: (1) can the maximum force required to pull the liner be distributed evenly along the edge of the liner; (2) what are the coefficient of friction values for each material and how can they be reduced; and (3) what effect will weighting the draw bar to keep the liner on the bottom have on the stress distribution to the liner? The values shown in Table 1 are likely more accurate for the pull-over retrofit concept than the pull-through concept. Note that the calculated tensile values for all cases do not exceed the tensile at elongation values of the various materials.

#### Considerations in Retrofitting Liners

A study has been made of considerations in retrofitting liners. Two general approaches to retrofitting ponds have been analyzed. These are pulling the liner along the contour of the pond and pull-

ing the liner on top of the fluid, with subsequent sinking of the liner to conform to the contour. Each approach has positive and negative features.

#### Pull-Through Concept

##### Assembly

The liner will be assembled by one of three methods:

- All of the membrane panels are laid out, seamed and then fan folded.
- The panels are laid out, seamed and then fan folded.
- The panels are laid out and seamed one at a time.

##### Pulling

The leading edge of the assembled panel will be wrapped around a heavy catenary cable or chain or clamped between sections of heavy steel plates to distribute the pulling load along the edge of the panel. A battery of cable pullers or winches would be mounted at the opposite end of the impoundment to pull the panel into and across the basin.

#### Bottom Contour and Side Slope Following

While new impoundments with membrane liners generally have smooth flat bottoms to facilitate proper placement of the liner, existing unlined impoundments will most likely not have smooth flat bottoms or straight side slopes since that would not have been a design requirement at the time they were built. Thus, even with the use of rollers at the bottom of the side slopes and in the corners, it will be difficult to prevent bridging by the liner as it is pulled across depressions in the bottom or irregularities along the sides.

Large pockets of liquid will then be trapped beneath the liners. The implications of this entrapped liquid are discussed in a later section. However, a drag caused by the digging in of the leading edge of the liner, or by the buildup of mud or sludge balls along

Table 1.  
Calculated Tensile and Pulling Forces for Four Liner Materials\*

Liner Type	Thickness (in)	Pond Size (ac)	Geometry (ft)	Panel Size (ft)	Liner Density (gm/cm <sup>3</sup> )	Liner Tensile (psi)	Slide Slope (ft)	Liner Weight (lbs)	Max Tensile (psi)	Max Force (lbs)
CSPE	.036	1	200 x 200	200	1.3	1500	20	9752	102	8776
CSPE	.036	1	100 x 400	200	1.3	1500	20	9752	203	8776
CSPE	.036	5	447 x 447	200	1.3	1500	20	48711	132	25560
CSPE	.036	5	300 x 667	200	1.3	1500	20	48782	153	19816
CSPE	.036	10	1414 x 1414	200	1.3	1500	20	487428	145	88694
CSPE	.036	10	500 x 4000	200	1.3	1500	20	487574	294	63544
HDPE	.080	1	200 x 200	33	.94	2800	20	15699	37	7018
HDPE	.080	1	100 x 400	33	.94	2800	20	15699	76	7262
HDPE	.080	5	447 x 447	33	.94	2800	20	78271	40	17375
HDPE	.080	5	300 x 667	33	.94	2800	20	78384	58	16703
HDPE	.080	10	1414 x 1414	33	.94	2800	20	783216	46	62520
HDPE	.080	10	500 x 4000	33	.94	2800	20	783453	157	75324
PVC	.030	1	200 x 200	200	1.3	2300	20	8126	102	7314
PVC	.030	1	100 x 400	200	1.3	2300	20	8126	155	5578
PVC	.030	5	447 x 447	200	1.3	2300	20	40592	132	21300
PVC	.030	5	300 x 667	200	1.3	2300	20	40652	153	16513
PVC	.030	10	1414 x 1414	200	1.3	2300	20	406189	145	73912
PVC	.030	10	500 x 4000	200	1.3	2300	20	406312	294	52954
CPE-S	.030	1	200 x 200	200	1.2	1433	20	7501	94	6751
CPE-S	.030	1	100 x 400	200	1.2	1433	20	7501	143	5149
CPE-S	.030	5	447 x 447	200	1.2	1433	20	37470	122	19662
CPE-S	.030	5	300 x 667	200	1.2	1433	20	37525	141	15243
CPE-S	.030	10	1414 x 1414	200	1.2	1433	20	374944	134	68226
CPE-S	.030	10	500 x 4000	200	1.2	1433	20	375058	272	48880

\*Coefficient of friction of soil =.90; Water = .01 for all cases.



this edge, can greatly increase the required pulling force or cause the cable or load distributing panel to fail.

Mitigating actions to reduce bridging and entrapment of liquids will be accomplished by the frequent use of rollers to keep the liner on the bottom of depressions or irregularities and by the careful design of the leading edge of the load distributing panel to prevent digging in. A slight rise in the weighted leading edge will cause the liner to dig through the sludge but not into the harder underlying soil. If the impoundment is filled with filamentous sludges (as might be the case for some sewage wastes) it may not be possible to place the liner by dragging because of balling of the sludge.

#### Tearing

Existing impoundments are likely to have protrusions that will cause excessive stress concentrations in the liner and failure by tearing. Irregularities in the bottom, rocks, pipes and other debris, known or more likely unknown and unseen, can cause ripping. Because the ripping is likely to occur beneath the surface of what is perhaps a murky liquid the tear may not be noticed or detectable.

Mitigating actions may be to search the impoundment with a drag wire survey to locate and/or remove the larger protrusions, by reducing friction forces so that the localized tension forces at the protrusion are less, and thus the near buoyant liner might ride over it without tearing, or by using a tougher fiber reinforced liner that is less likely to tear on small protrusions.

### Float and Sink Concept (Pump-Over)

#### Assembly

The liner is assembled using one of the methods described for dragging, however, the end that is pulled across the impoundment is doubled back over a stiff hose, or sections of rods, for a sufficient distance so that when the liner is deployed, the end will fall several feet short of the "shoreline" when fully deployed. Clamps around the liner and hose or rods are then installed to permit pulling the liner without excessive strain.

#### Placement

The liner will be pulled across the impoundment in a fashion similar to the pull-through concept, however, in this method of placement, the leading edge of the liner and the pulling lines will be kept as light as possible so that the liner would remain on or near the surface during the deployment period.

#### Sinking of Liner

The deployed liner will be lightly held in position during the sinking phase. If the liner has a density greater than the liquid it will slowly sink. As it sinks, the liquid underneath the liner would escape and flow over the top at the open water margin between the folded end of the liner and the far shore line.

If the liner is made of buoyant material, e.g., HDPE, ballast such as coarse sand would be used to sink the liner. The ballast would be placed on the liner starting at the initial deployment end. Only a small amount of ballast should be required. Only 2.5lb/100 ft<sup>2</sup> should be required to sink 80 mil HDPE. Similar to the dense liner, the displaced water will move toward the gap at the far end as the liner is slowly covered with ballast. When the liner has completely sunk, the doubled back flap is opened up and pulled toward the far end to close the gap. One end of the gap will be left down until the very end to let any remaining liquid escape. For the pump-over concept, fluid would be pumped onto the liner rather than allowing it to flow over the leading edge.

#### Advantages

Placement of the panel will cause minimal stress to the liner since only the dry land friction should be of any magnitude and, as discussed earlier, this can be mitigated. There should be negligible tearing since the liner is not dragged across potential tearing protrusions. Holing of the liner should be limited to localized punc-

tures by very sharp protrusion. Since the liner sinks under minimum tension, it should settle into most bottom depressions and side irregularities.

#### Sinking and Liquid Recirculation

Even with the provision of a folded back flap at one end to permit the liquid beneath the liner to recirculate to the top, proper sinking of the liner may be difficult to achieve. The liner will probably not sink uniformly by itself but will have to be constrained around the perimeter as it sinks. Otherwise, the liquid underneath may attempt to recirculate to the surface at locations other than planned with the liner settling to the bottom possibly out of position. This could result in excessive folds in the liner or lack of sufficient coverage around the side slopes.

Also, since the tension in the liner during placement will be less than for dragging, extra care will have to be taken to reduce damage or misplacement due to wind or wave action. Pumping of fluid would allow placement of the water at the end of the facility opposite from the leading edge. This may facilitate controlled sinking of the liner.

#### Entrapped Liquids and Sludges

Whether by pulling or sinking, some liquid or sludge will be trapped between the liner and the bottom of the impoundment. The specifics of the type of waste and the underlying soil conditions will determine what actions should be taken to accommodate these entrapments.

#### Non-Gas Generating Entrapments

If the entrapped liquid or the underlying soil does not generate gases, it may be acceptable to leave the liquid and not attempt to remove it. If the underlying soil is permeable enough, and the water table low enough, the entrapped liquid will percolate into the soil. If the underlying soil or entrapped sludge is not permeable, the bubble of liquid will remain. There is then the danger of ripping or perforation of the liner due to the repeated working of the fabric over the bubble under wave induced or other hydraulic motions.

Methods to remove entrapped bubbles of liquid may include the following:

- One Way Valves could be sidely distributed over the liner. In the placement mode, they will assist in the rapid and uniform sinking of the liner and would permit the entrapped liquids to escape. Detrimental aspects of their use will include clogging by the sludge, complexity of installation and susceptibility to damage, and the likelihood of leakage, albeit a small amount, due to grit lodging on the valve faces.
- The impoundment could be lined with an array of drain pipes with the inlets covered with porous sand, gravel and/or a geotechnical filter membrane. Entrapped liquids would then be pumped out. The placement of the array in an existing impoundment may be difficult and complex. There will also be susceptibility to drain blockage by sludge.
- By the use of either ballast or weighted rollers, entrapped liquids could be rolled out. Starting in the middle or deepest point of impoundment, ballast is placed on the liner to establish an outward moving radial front of the displaced entrapped liquid. The entrapped liquid is then allowed to escape to the surface around the perimeter. Rollers operating in a sequence of outward moving radial rolls can similarly work the entrapped liquids toward the edges and then the surface.

#### Gas Generating Entrapments

Many waste liquids, sludges and underlying soils may generate gases. Bubbles of gas under the liner can raise the liner to the surface or at least separate it from the bottom and make it susceptible to wear and failure from hydraulic motions or induced stresses. In some cases, if the waste material and underlying soil are permeable enough, the entrapped gas will escape by itself. However, if the gas cannot escape, then mitigating actions will have to be taken using the methods for removing entrapped liq-

uids or other techniques:

- If clogging of the valves can be prevented and if leakage is acceptable, one way valves can be effective in the removal of entrapped gas. The escaping gas may also unclog the valve.
- Similarly, if clogging can be prevented, drain fields can be used to remove gases.
- Rolling out or ballasting will not be an acceptable method for gas removal unless only a very small quantity of gas is generated for a short period after the retrofit of the liner.
- Non-clogging geotechnical filter membranes that can block sludge or sediment while passing liquids and gases can be installed under the retrofitted liner. They will then conduct the entrapped liquids and gases to the surface or to either one way valves or a drainage field where the gas can escape. Uncertainties with using permeable membranes include the long term blocking of the pores of the material and compression of the pores due to the overlying load of the waste material.

#### Sludge and Contaminated Soil Removal

The float and sink method will trap all, and the dragging method much, of the solids in the sludge under the retrofitted liner. This sludge and any contaminated soil under the impoundment can leach undesirable trapped liquids or generate gas for many years. In some cases, the leachate may be able to be pumped out from peripheral wells. However, if this practice is determined to be unacceptable it may be necessary to completely remove the sludge and contaminated soil.

The size of many impoundments and other constraints will preclude draining the impoundment and temporarily storing the waste material in another impoundment. Thus, the solid material will have to be removed *in situ* and prevented from settling before the retrofitted liner can be placed. Two methods of dredging and liner installation might be used to achieve this objective. Both methods require that the waste material in the impoundment has the property that suspended solids will settle out under gravitational forces so that there is a clear liquid overlying a sludge blanket. Except for some colloidal suspensions, most aqueous wastes have these properties. Oily wastes may have oil or foam on the surface but there is usually a clear liquid underneath.

**Dragging**—As the liner is pulled along the bottom and into position, a dredge will remove the sludge and contaminated soil immediately ahead of the liner. The dredged spoil is initially pumped and discharged at a far corner of the impoundment. There the suspended sediment settles to the bottom and the clear liquid recirculates back into the impoundment. It may be necessary to install a floating silt curtain around the discharge to confine the dredged material until it has settled out. When approximately half the liner is dragged into position, the discharge will be moved so that the spoil is deposited at a far corner of the lined part of the impoundment. Care will have to be taken to widely spread the spoil over the liner since it will still be moving into position and thus, it will be desirable not to create abnormal stresses in the liner by weighting it down with sediment. If there is a very large mass of heavy settled sludge, this method of installation may not be usable.

**Placement**—In this method, part of the impoundment is sectioned off by a floating curtain similar to those used in controlling oil spills. The bottom edge of the curtain is weighted and lies on the bottom of the impoundment as a seal. The sediment from the sections is dredged and deposited far behind the curtain. The clear supernatant is permitted to recirculate over the top of the curtain. After dredging, the liner is placed using the methods discussed earlier. The curtain is then moved to enclose the next adjacent section. After completion of dredging of this section, the liner is placed with an overlap over the previously placed liner. With sufficient overlap, acceptable small leakage rates can be achieved. Similarly to the procedure for the pull-through method of installation, when the impoundment is half lined the spoil discharge point is moved to a remote position over the retrofitted liner. Since in the placement method of installation the liner is not moved over the bottom, the mass of the settled sediment at a particular place is

not as critical using this method. While small road transportable cutter head or dust pan dredges can be used to move the sludge, consideration should be given to pneumatic dredges that have been developed for dredging contaminated sediments. This type of dredge entrains considerably less liquid and the discharged spoil tends to settle out with a considerably smaller surface plume.

**Folds**—The topography of impoundments in which retrofitted liners will be placed will most likely be quite irregular. In installing the liner, it will be very difficult, if not impossible, to prevent folding of the liner. Where the liner is above the liquid, as around the sides of the impoundments, folds can be cut out and the liner patched. However, when folds occur in the liner beneath the surface of the liquid waste, it may not be possible to remove the folds using these methods because (1) the fold may not be detectable if covered by sludge or a murky waste and (2) it may not be possible to patch the liner underwater. If the fold is left unattended, the liquid confined in the fold may drain out by itself or may be withdrawn using the methods for removing liquids and gases discussed earlier. However, the base of the fold may seal the fold thus trapping the liquid in the fold. Similar to the entrapped bubble, the material in the fold will work under various hydraulic actions which may ultimately cause the liner to wear or rip. If the fold material just wears enough so the entrapped liquid can escape, the fold may collapse and two overlapping halves may form a seal. If the fold material tears, the two halves of the fold may move apart and an appreciable leak path may be created. Thus, a liner material that wears and leaks may be preferable to one that does not wear but tears. Folds in the subsurface part of the retrofitted liner may have to be accepted. Perhaps in areas where folds are likely to be encountered, a second layer will be installed to reduce leakage through failed folds.

#### Double Perforated Liner With Permeable Geotechnical Filter Membrane

For the many reasons discussed in this presentation, the probability of having leakage after the installation of a retrofitted liner is quite high. Proper design, selection of materials and placement can result in an installation with greatly reduced leakage but there is still likely to be some. If this less than perfect performance is acceptable then the utilization of two layers of liners that are intentionally perforated may lead to a superior installation system. Aspects of a two liner systems are:

**Installation**—If the perforated liner is installed using the placement method it will sink more rapidly than a non-perforated liner and will require less control around the perimeter. Any residual trapped liquid will be displaced as the liner sinks to the bottom. Liquid trapped in folds will also readily leak out, permitting the fold to collapse. In the installation of buoyant liners, porous ballast such as sand or gravel would not block the perforations. If the second layer of the perforated liner is laid at right angles to the first likelihood of folds lying on top of each other and of being parallel is reduced.

**Perforations**—Perforations in the liner would not be uniformly placed but would be located in a pseudo-random pattern. That is, there might be one hole randomly placed in each square foot. With this random placement there would not be a row of holes in one liner aligning over a row of holes in the other liner.

**Leakage**—If the lower layer is lying firmly on the bottom and the facing surfaces of the two liners are clean, then the double perforations would make an effective one-way valve or hydraulic diode. Either due to negative buoyance or added ballast the two layers will be pressed together blocking any leakage. If there is any trapped liquid or gas at a higher pressure than the overlying liquid, the upper layer will lift, permitting the gas or liquid to escape through the perforations in the upper layer. Once the fluid has escaped, the pressure is reduced and the upper layer will collapse re-sealing the bottom layer. Since, with many randomly placed holes, some holes in one layer will align up with holes in the other layer there will be some leakage. However, the area of the perforations will be a very small part of the total area so leakage would be very

small for a double layer system. A 0.375 in. hole in every square foot of each liner would permit the upward flow of all trapped liquids, yet would have a porosity of less than  $10^{-3}$ . A double layer would then have a porosity of less than  $10^{-6}$ . When combined with existing porosity of the impoundment bottom there should be very little leakage.

**Clogging**—The efficiency of a perforated double layer retrofitter liner system is dependent upon keeping the perforations open and the facing surfaces of the liner clean. Blockage of the perforations will not permit the trapped fluids to escape and grit caught between the two layers might create a leakage path. If a liquid and gas permeable geotechnical filter membrane is installed under the perforated liners, sludge and grit underneath would not move up and block the perforations or contaminate the facing surfaces of the liners. A very effective retrofitted liner system would then be achieved.

**Gas**—Gas trapped beneath the liner system or subsequently generated in the underlying sludge or soil will be able to escape through the filter membrane to a perforation and then to the surface. If there is a heavy or impermeable waste fill in the impoundment, the gas will move laterally until it can escape through an unblocked perforation or until it reaches the surface around the perimeter of the impoundment.

#### Laboratory Scale Studies

A 10 by 20 ft scale model impoundment has been constructed and is being used to make qualitative studies or retrofitting liners. The model was constructed outside on the ground, lined with 10 mil black polyethylene sheeting for water retention and then filled with an inch or so of sand to simulate an unlined impoundment. The sand was also banked up the sides and stabilized with cement.

At the time of writing only one series of experiments has been undertaken: the floating and sinking by pump-over of a buoyant membrane liner. A 4 mil polyethylene liner was pulled over and floated on the impoundment, overlapping both the sides and ends. Water was pumped from one end and released at the opposite end at the same time as sand ballast was being put on the liner to sink it. The following observations were then made:

- The liner would not sink to the bottom even with the ballast and water added. Archimedean buoyance forces and tension in the liner from friction forces around the perimeter kept the liner afloat.
- The liner was moved back several inches from the pumping end of the impoundment and a fold worked back toward the ballasted end. When the fold was adjacent to the ballast the liner would then sink to the bottom.
- With no longitudinal tension the ballasted section of the liner will fold under the remaining buoyant liner. Light tension will keep the size of this fold manageable.
- An advantage of floating and sinking is that the liner is not dragged over the bottom. However, the liner will move a little along the sides of the impoundment as it is sunk. Provision will have to be made to accommodate this movement without over-stressing the liner.

#### Pilot Scale Demonstration

A pilot scale demonstration facility has been designed to test the retrofit system on a larger scale. The facility is presently being constructed at Southwest Research Institute. It will allow field testing of retrofit concepts under controlled conditions and in the absence of hazardous fluids. This is necessary in the early stages of system development to avoid risk of injury to field crews.

#### FUTURE WORK

Following further laboratory scale studies retrofitting concepts will be selected for demonstration in the pilot scale facility. The pilot scale demonstration will be conducted and then evaluated. A retrofit system field test plan for an actual hazardous waste site will then be developed.

#### ACKNOWLEDGEMENT

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# A BLOCK DISPLACEMENT TECHNIQUE TO ISOLATE UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Foster-Miller, Inc. has developed a technique for complete *in situ* isolation of uncontrolled hazardous waste sites. This technique is intended to emplace a seal at low cost around the sides as well as underneath contaminated ground. Under contract to the USEPA, demonstration of the Block Displacement Method (BDM), was conducted over a four month period adjacent to the Whitehouse Oil Pits site in Whitehouse, Florida.

The purpose of the demonstration project was to add this technique to the list of available construction technologies applicable to chemical waste remedial action by:

- Demonstrating the BDM in the geologic conditions of an existing chemical waste site
- Developing BDM specifications for "A User's Guide for Evaluating Remedial Action Technologies"
- Evaluating the applicability of the BDM to existing site geologic/hydrologic conditions
- Establishing BDM implementation procedures for remedial action designers and contractors

## DESCRIPTION OF THE BDM

The BDM is a patented<sup>2</sup> technique for vertically lifting a large mass of earth. The technique produces a fixed underground physical barrier placed around and beneath an earth mass. The barrier is formed by pumping slurry composed of local soil, bentonite and water, into a series of notched injection holes. The resulting barrier completely encapsulates the earth mass or block. A typical BDM barrier is shown in Fig. 1.

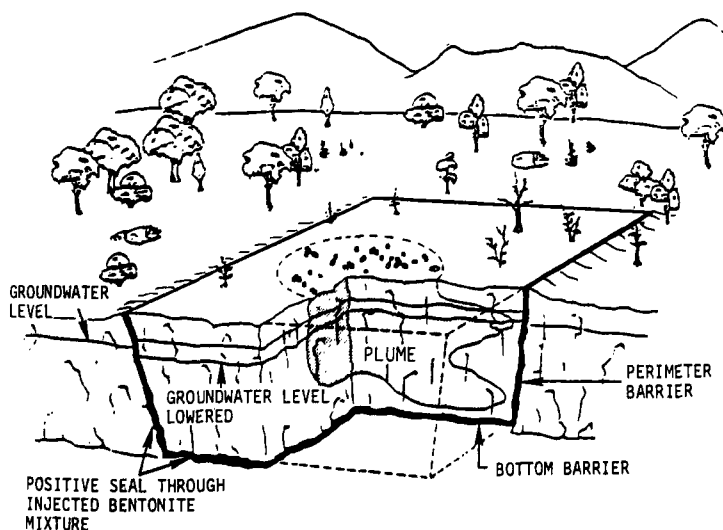


Figure 1.  
BDM Barrier in Place

The BDM is of particular value in strata where unweathered bedrock or other impermeable continuum is not sufficiently near the surface for a perimeter barrier alone to act as an isolator. The barrier material should be compatible with soil, groundwater, and leachate conditions.

A perimeter separation is first constructed and then surcharged to ensure a favorable horizontal stress field in the formation (Fig. 2). Surcharge is additional pressure transmitted to the fluid slurry in the perimeter separation by raising the slurry fluid level above ground level.

Construction of the perimeter separation can proceed using one of several techniques including thin slurry wall, vibrating beam or drill notch and blast techniques. The thin perimeter separation must be constructed on a slight angle,  $\phi$ , off vertical tapering inward toward the block center. Upward displacement,  $d$ , of the block resulting from injection along the bottom barrier will then increase the perimeter separation,  $W_o$ , to the desired barrier thickness,  $w$ , according to:

$$W = d \sin \phi + W_o \quad (1)$$

A bottom barrier is formed when lenticular separations extending from horizontal notches at the base of injection holes coalesce into a larger separation beneath the block. Continued pumping of slurry under low pressure produces a large uplift force against the bottom of the block and results in vertical displacement proportional to the volume of slurry pumped.

Construction of the bottom barrier proceeds in four phases: (1) formation of notches at the base of the injection holes, (2) initial bottom separation at the notched holes, (3) propagation of the

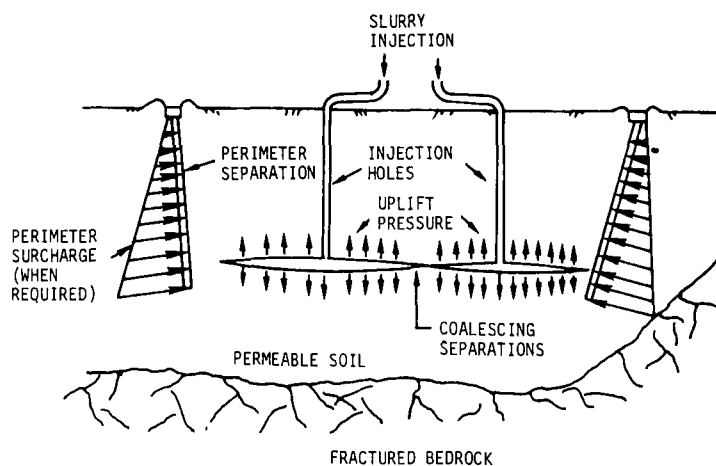


Figure 2.  
Creating Separation to Induce Displacement

local separations at each injection point coalescing into a single larger bottom separation, and (4) generation of a complete bottom barrier by controlled vertical displacement of the earth mass using low pressure slurry injection into the horizontal separation. Each of these phases is carried out through controlled monitoring of the slurry pressure, slurry flow rate, total volume injected, and slurry composition.

The notching operation requires a high pressure rotating jet at the base of the injection hole. The jetting slurry must be composed in a manner which optimizes notch erosion, removes cuttings, and minimizes leak off into the soil. The initiation of bottom separation (3) requires a slurry pressure,  $P_o$ , at the separation defined by:

$$P_o = \rho_r gh + \Delta P \quad (2)$$

where

$\rho_r$  is the average earth mass density

$g$  is the gravitational constant

$\Delta P$  is the pressure in excess of the overburden

$h$  is the depth of the bottom separation

$\Delta P$  increases with the increasing slurry viscosity and decreasing notch radius and in general depends on soil characteristics and the speed of operation. The bottom separation is initiated when slurry pressure exceeds  $P_o$  inducing flow.

Separation coalescence is brought about by adding slurry volume and by gradually increasing the viscosity of the slurry. Slurry pressure required to propagate the horizontal separation will decrease during this phase due to the increased area over which it is acting. Increasing the viscosity of the slurry serves to limit flow in preferential directions.

Vertical displacement utilizes the maximum capacity of the pumping equipment, along with a high solids slurry that will form the final barrier. The pressure required to continuously increase the barrier thickness by lifting the buoyed block eventually decreases. The slurry pressure, in excess of the overburden,  $\Delta P$ , measured at the bottom of the injection hole approaches that required to balance the resistance of the perimeter surcharge ( $q$ ) and to overcome fluid drag in the perimeter ( $\Delta P_2$ ) and in the bottom separation ( $\Delta P_1$ ). The final pressure relationships are:

$$\Delta P = \Delta P_1 + \Delta P_2 + q \quad (3)$$

$$\Delta P_2 + \frac{\Delta P_1}{n} + q = (\rho_r - \rho_m) gh \quad (4)$$

where

$\rho_m$  is the density

$q$  = surcharge on perimeter slurry

$n$  depends on the number of injection holes

(= 3 for a single central hole)

Bottom barrier thickness can vary from a few centimeters to more than a meter. The thickness is increased by further pumping of slurry down injection holes. Selective pumping coupled with a high viscosity slurry design enables relative variation or adjustments on bottom barrier thickness during block displacement.

Continuity of the bottom barrier can be checked by pressure communication between injection holes and by surface level survey during block displacement. Verification of barrier completeness can be attained following construction by long term monitoring of draw down within the isolated block. If deemed necessary, continued pumping can further increase the perimeter thickness locally or in general until satisfactory verification results are attained.

The permeability of the barrier depends on both the filter cake that forms on the separation surfaces and on the permeability of the residual slurry which consolidates with time. As water in the residual slurry leaks off with time, the permeability of the entire barrier approaches that of the filter cake. Permeabilities of  $10^{-8}$  cm/sec are attainable with proper slurry design. The effectiveness of the barrier is based on the permeability of the consolidated slurry material and the thickness of the barrier.

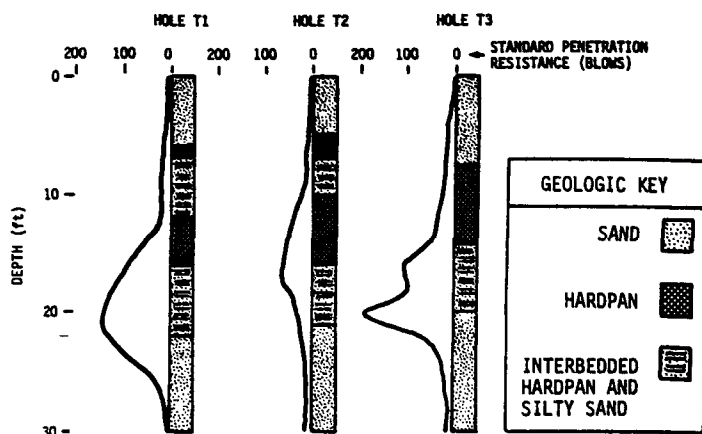


Figure 3.  
BDM Demonstration Geology

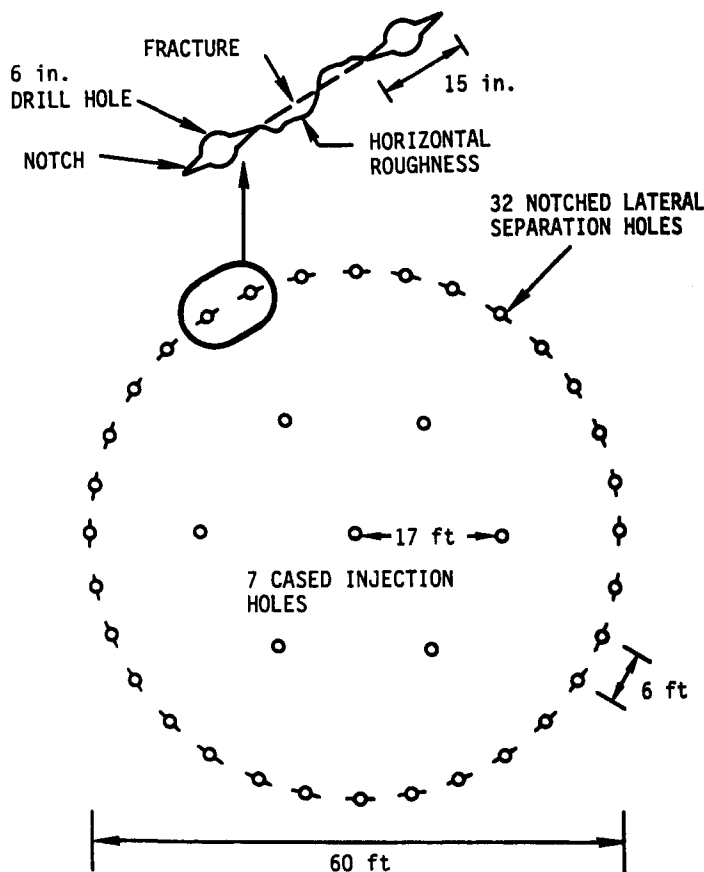


Figure 4.  
BDM Perimeter and Injection Hole Spacing

### Demonstration of BDM

The Whitehouse Oil Pits site in Whitehouse, Florida was selected from a list of 114 top priority superfund sites. It offered favorable winter weather conditions, acceptable geology and easy access to uncontaminated soil adjacent to the contaminated area.

A demonstration site was selected 200 ft from the oil pits boundary on level ground up gradient of groundwater migrating from the oil pits site. Geologic and chemical surveys were conducted to verify that the soil stratum was suitable and that the demonstration would be conducted in uncontaminated ground. Continuous soil sampling and standard penetration tests verified a marginally stratified silty sand (marine sediment) containing a 5 to 10 ft thick hardpan layer from the 10 to 20 ft depth throughout the site (Fig.

3). A circular block 23 ft deep and 60 ft in diameter was to be displaced in excess of 1 ft vertically.

Two types of holes, 32 uncased perimeter holes and 7 cases injection holes were drilled in preparation for the block displacement process. The perimeter separation was to be constructed by line drilling 6 in. diameter perimeter holes with a taper angle,  $\phi$ , of  $14^\circ$ . These holes were to be notched and blasted with line charged explosives to induce fracturing between the holes.

Following trial blasts on three test holes spaced 3 ft and 6 ft apart respectively, a final perimeter pattern of 6 in. diameter holes on 6 ft spacing was drilled (Fig. 4). These holes were each notched from top to bottom with a 15 in. span notching tool (Fig. 5), following tests with three earlier notching tool designs.

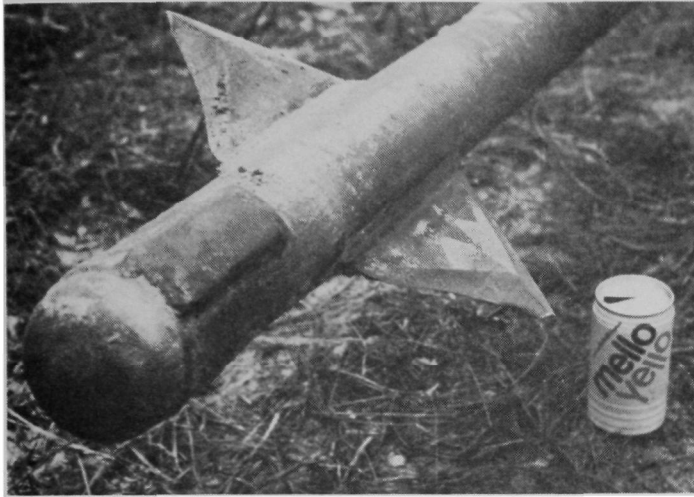


Figure 5.  
Perimeter Notching Tool



Figure 6.  
Bottom Notching Tool

Seven injection holes were drilled and cased with 25 ft long 6 in. diameter PVC tubing which was cemented in place at the base. The casing extended to a depth of 23 ft leaving 2 ft of casing exposed above ground. Horizontal notches approximately 2 ft in diameter were cut on all seven injection holes using a slurry jet notching tool (Fig. 6).

In parallel with bottom notching, an 18 in. diameter, 5 ft high concrete forming tube was placed over each drilled and notched perimeter hole and filled with high density slurry (Fig. 7). Upon culmination of injection hole bottom notching all 32 perimeter holes were line loaded with prima cord explosive (50 grains/ft) and blasted simultaneously. Connecting fractures were observed at the surface between adjacent perimeter holes.

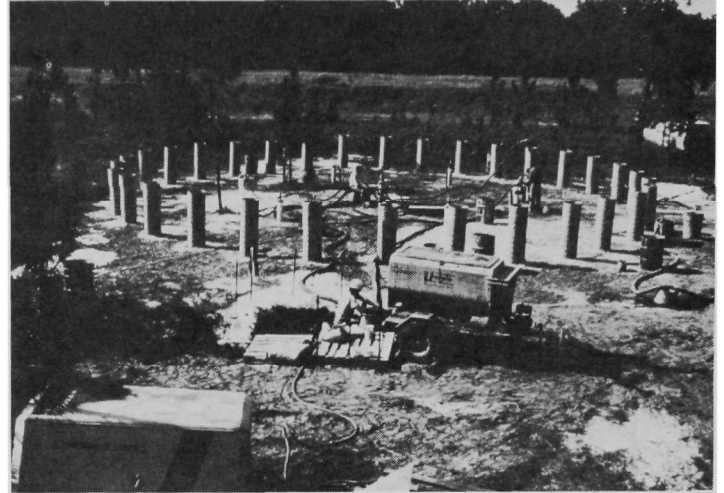


Figure 7.  
BDM Bottom Notching Operation with 32 Perimeter  
Surcharge Tubes in Place



Figure 8.  
Upward Displacement of Block

BDM system analysis indicated horizontal separation should initiate from the bottom notches at an injection hole pressure of approximately 20 psi. Initial attempts at injection required pressures in excess of 40 psi to induce slurry flow indicating that renotching of each injection hole followed by immediate slurry injection was required.

Bottom notched separation propagation was finally realized by increasing notch diameter to approximately 4 ft using a slurry jet in air medium to cut the formation. Each notching operation was followed by immediate slurry injection to propagate a local separation.

Renotching and local propagation was carried out in all six intermediate injection holes. This procedure was then applied to the central injection hole followed by steady state slurry pumping.



Separation coalescence between injection holes was observed after approximately 500 gal of slurry were pumped into the central injection hole. Pressure response was documented at intermediate injection hole well heads followed by observance of slurry flow up the perimeter holes at multiple points around the block. Perimeter flow was characterized by small flows from approximately 10 of the concrete forming tubes. During the course of block displacement several of these tubes were replaced with 10 to 20 ft long plugs to impede excessive flows at the perimeter.

Following separation coalescence, block displacement was observed over most of the block surface. Block displacement then proceeded over a two week period pumping approximately 2 yd<sup>3</sup>/hr alternately pumping to each injection hole. The resulting upward displacement of the block is shown in Fig. 8.

### Demonstration Results

Displacement of the block was monitored by recording the change in elevation of 16 fixed rods (Fig. 9). The numbers in paren-

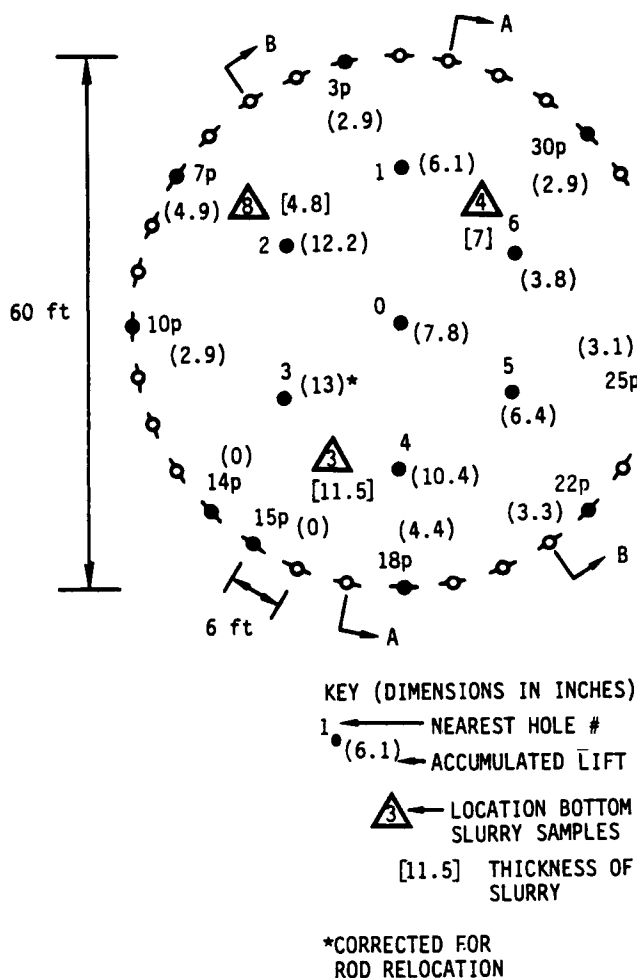


Figure 9.  
Recorded Block Lift and Verified Seal Thickness

theses in the diagram are the total recorded lift in inches at the corresponding positions on the block. Elevations were read through a surveyor's level located 40 ft outside the block perimeter. Additional survey points beyond the block boundary were monitored during a portion of the lift operation to verify that no lift was occurring outside of the perimeter. Survey points 0 through 6 correspond to rods located adjacent to (approximately 3 ft from) injection holes. The remaining 9 survey points 3p through 30p correspond to rods located just inside the perimeter. These survey

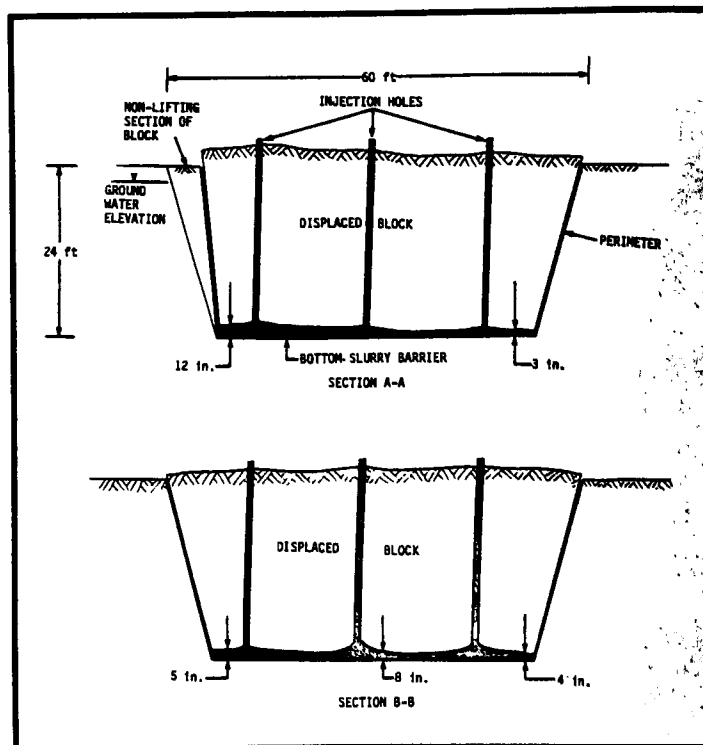


Figure 10.  
Final Block Displacement

point numbers correspond to the closest perimeter drilled hole numbered progressively from 1 to 32 in a counterclockwise direction.

Approximately 10,000 gal of bentonite slurry were injected during the block lift operation. Data from surface topographic surveys combined with accumulated daily lift records was combined to give two profiles of the final block position (Fig. 10). In total the block was displaced upward 12 in. at its highest point and tilted approximately 1° from horizontal. A crescent shaped portion of the block outside of injection hole #3 was sheared free of the lifting block and did not move appreciably. The entire remaining portion of the perimeter lagged behind the inner portion of the block lifting from 3 to 6 in.

The crescent shaped shear zone, tilting of the block and perimeter displacement lag were all attributed to an incomplete fracturing and freeing of the block around the perimeter. Following completion of the block lifting operation, 4 to 6 ft deep trenches were excavated through the perimeter and shear zone to try to determine causes of resistance to perimeter displacement.

Tap roots as large as 12 in. in diameter and typically on 6 ft centers were found extending from approximately 5 ft below surface to the upper boundary of the hardpan layer. Tap roots intersecting the perimeter separation may have acted as dowels to restrict block movement at the perimeter. In addition, perimeter fractures filled with gelled slurry extended down only a few feet before becoming unmapable hairline fractures.

Thin walled tube soil samples were taken 4 weeks after discontinuation of slurry pumping to determine the integrity of the bottom seal. Obtaining undisturbed soil samples of the soft slurry material bounded by hardpan on top and unconsolidated sand beneath was a difficult task. In eight attempts three acceptable samples were obtained at the locations shown in Fig. 9. Sample #8 (Fig. 11), indicated a well defined boundary of separation, between injected clay slurry and the overlapping native sand. Traces of slurry migrated into fractures in the underlying sand.

Final evaluation of data obtained from the field operation will be conducted following additional core sampling and geophysical surveying to assess the complete integrity of the bottom seal.



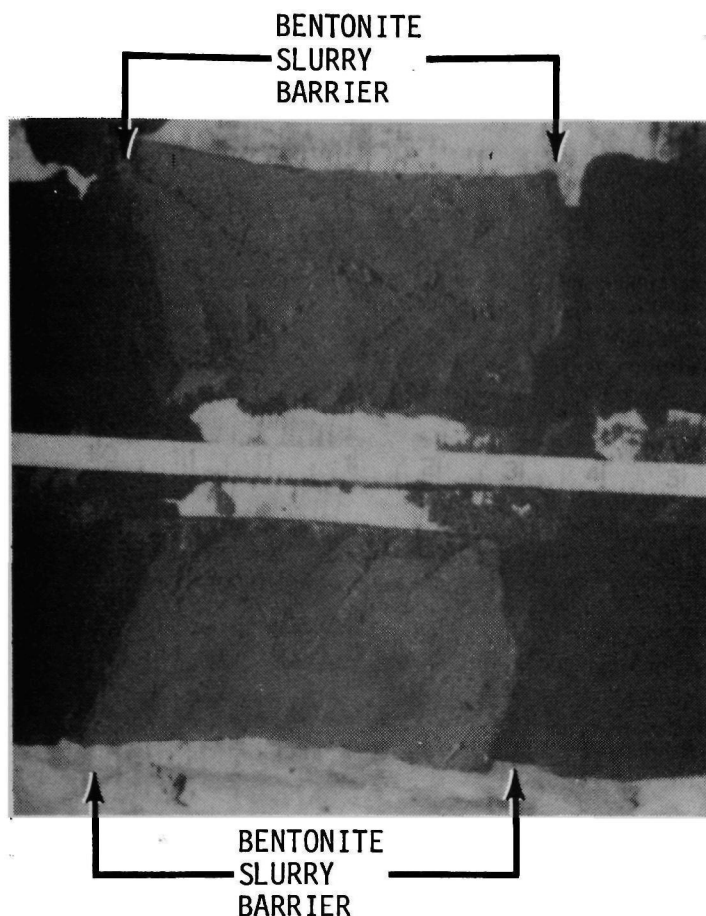


Figure 11.  
Core Sample #8 Showing Slurry Barrier Placed in  
Native Sand at 23 ft Depth

## CONCLUSIONS

Final conclusions and recommendations are pending completion of data evaluation and verification testing still to be conducted.

Preliminary results indicate the following:

- The bottom seal was demonstrated and is apparently continuous under the lifted portion of the block.
- Creating the perimeter separation using the drill, notch, and blast technique was unsuccessful possibly owing to tap roots, insufficient explosive charge size, or excessive local plastic deformation of the soil.
- BDM is a viable method for isolating contaminated ground in unconsolidated stratified soils when used with a proven perimeter barrier construction methodology. Additional information regarding BDM applicability will be contained in the project's final report to be presented to USEPA by the end of 1982.
- Sufficient data were obtained to write specifications for use of BDM for bottom barrier construction. These specifications have been included in the "User's Guidelines for Remedial Action Technologies".<sup>1</sup> The guidelines include slurry designs, general engineering information and suitability of bottom barrier use with applicable complementary perimeter barrier construction.
- BDM implementation procedures should include feasibility analysis, a thorough geologic investigation of the site, and a pilot operation to verify site suitability prior to proceeding with a full scale operation. Details on implementation procedures will be contained in the project final report.<sup>3</sup>

## ACKNOWLEDGMENTS

Acknowledgment is given to Wendy J. Davis-Hoover, the USEPA technical project officer during site selection and preparation, for coordinating program operation with Federal, State and local government agencies.

## REFERENCES

1. "User Guide for Evaluating Remedial Action Technologies", USEPA, To be published.
2. Cleary, J.M., "A Method for Displacing Large Blocks of Earth", U.S. Patent No. 4,230,368, February 1979.
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of the investigation was to determine if the property had been used for the disposal of hazardous waste as alleged by at least two informants.

The investigation was conducted on the surface of the property only; no excavation was done. During the course of the investigation, 38, 55-gal drums were found either protruding from a filled ravine or below the filled area. A composite sample was prepared from the contents of three of the drums. Analysis of that composite sample revealed five chemicals listed in "Missouri's Hazardous Waste Law, Rules and Regulations" as well as seven other organic chemicals not ubiquitous to the environment.

Positive responses from a metal detector were recorded over the entire area of fill. Probing the soil with a metal rod indicated buried metallic objects.

Although it was determined that there were drums of hazardous waste partially buried on the Callahan property, it had not been determined how extensive the hazard was, nor had it been determined to what extent the existing hazardous waste had impacted the groundwater in this area.

### Geology

The geologic setting of the Callahan property is the Caulks Creek Watershed. Drummed wastes were piled in a steep gully in the head waters of Caulks Creek, a tributary of the Missouri River, and were thinly covered with dirt. The soil in the area is a clayey silt (modified loess) overlying the Burlington limestone. The Burlington limestone is heavily fractured, and is used extensively for domestic water supplies in the area. Approximately 30 households in the area draw drinking water in the Caulks Creek Watershed.

### Contamination at the Site

The Callahan site was used for the disposal of containerized liquid and solid wastes. Based on limited analysis prior to the initial removal actions taken by the Missouri Department of Natural Resources, the following contaminants were determined to be leaching into the water of Caulks Creek: nitrobenzene, naphthalene, anthracene, BHC, aldrin, DDE, phenols and various phthalates.

### State Activities on Site

Based on Mr. Callahan's testimony that approximately 80-100 drums of material had been disposed of at the site and preliminary sample analysis data gathered, the Missouri Department of Natural Resources initiated removal actions on Dec. 14, 1981. All removal actions accomplished at the Callahan site were funded under the Comprehensive Environmental Response Compensation and Liability Act, more commonly referred to as the "Superfund."

Mr. Keith Schardien was appointed as the State On-Scene Coordinator (OSC), and Environmental Emergency Services (EES) of Chesterfield, Missouri was chosen as the cleanup contractor to perform the removal operations of the buried drums.

On the site itself, the restricted zones and the hot line or red zone areas were posted utilizing red banner tapes for the hot line area and yellow banner tapes for the restricted access areas. The restricted zone, the periphery of which was marked by the yellow banner, was considered to be a buffer zone surrounding the red or hot zone. In this area personnel were required to be wearing, at a minimum, an ultra twin respirator with combination cartridges, splash or acid suit, rubber safety boots and rubber gloves. The joints of the boots and gloves had to be taped with duct tape in order to prevent contamination by a liquid running into them.

The State of Missouri's scope of work called for a test trench to be dug diagonally across the site from northeast to southwest and another smaller trench at the south face of the fill area where visual evidence on the surface indicated the greatest concentrations of buried drums. As the drums were excavated, the following procedures would be followed to assure that proper custody and documentation would be maintained:

- A control number was assigned to and permanently marked on each drum as it was excavated. Any drum found to be leaking would be placed into an overpack drum.

- The description of each drum type, condition and any visible markings on the drums would be recorded on an individual drum sheet. Photographs would be taken of each drum with visible markings.
- Two full depth representative samples would be obtained by contractor personnel under state supervision of each drum. Full chain-of-custody was to be observed on all field data and sample collection using the bound volume National Enforcement Investigations Center (NEIC) system. All on-site sample collection and analysis would be accomplished under the direction and supervision of a professional chemist.
- On-site analysis would consist of the following checks or tests: (1) radiation checks with a general survey meter and (2) head-space readings at the bung hole of the drum with an organic vapor analyzer.

By Dec. 17, 1981, 187 drums had been excavated from the site and were stored on the surface.

It was obvious that completion of the removal operation would not be possible because funds originally allocated were exhausted by the end of the first week's operation. In addition to the lack of funds several hundred drums were visible in the area excavated. At this point a formal request was made by the State of Missouri to the USEPA for assistance.

Mr. William J. Keffer, Chief of the Region VII USEPA Surveillance and Analysis/Environmental Services Division, was appointed federal On-Scene-Coordinator (OSC) and requested to evaluate the site.

On Dec. 18, 1981, Mr. Keffer and the writer evaluated the site. They were joined by Dr. Joseph P. Lafornera and Mr. Rodney Turpin of the Environmental Response Team (ERT).

On-site inspections (between Dec. 18, 1981 and Dec. 23, 1981) conducted by USEPA, Region VII OSC, TAT, ERT technical staff and state OSC documented the following imminent hazards to public health and the environment:

- Leachate discharges containing several hundred mg/l were entering the Caulks Creek Watershed which enters the Missouri River 2 mi upstream of the St. Louis County, Hazard Bend water intake.
- The fractured Burlington limestone underlying the area is used extensively for domestic water supplies in the area. Approximately 30 households in the area draw drinking water from the groundwater in the Caulks Creek Watershed.
- Volatile organic material were being released to the air at the site. One thousand people live within a one mile radius of the site; the closest residences are within 100 yards and clusters of single family dwellings within 0.25 of the site.
- Drums of toxic organic materials were exposed at the face of the fill and others were stacked on the surface.

Based on this information the OSC recommended to the Region VII Superfund coordinator and Henry D. Van Cleave, Acting Director of the Emergency Response Division, Washington, D.C., that immediate removal funds be authorized with the proposed actions to:

- Continue removal operations with EES
- Provide a guard on-site to prevent casual trespass
- Post the site with warning signs
- Have all on-site media contacts and releases be managed by MDNR—State OSC as part of the community relations package for the remedial actions for all Ellisville sites
- Drain the small farm pond immediately upgradient of the disposal area because it was significantly adding to the leachate and groundwater contamination problems. The pond was to be drained and sealed with Bentonite Slurry.
- Construct surface runoff diversion ditches around the periphery of the disposal area and a small temporary lined containment pond to intercept leachate
- Using a backhoe supported by manual labor, remove and recontainerize when necessary, sample, sort and secure on-site all

drummed material in an aisle arrangement, segregating potentially incompatible materials. On-site sorting to be based on laboratory tests for visual characteristics, flashpoint, photoionizer readings and simple incompatibility testing.

- Two full depth representative sample sets are to be collected by contractor personnel under state supervision using the drum numbering system presently used and maintaining full chain-of-custody. One sample set is to be delivered to USEPA with full documentation of all field tests by a professional chemist.
- Composite soil samples are to be collected at the direction of the OSC and analyzed to determine disposal needs. If disposal of contaminated soil is necessary based on evaluation of contaminants MDNR will arrange for bulk disposal at Bob's Home Service in Wright City, the state's only approved hazardous waste site.
- Drums to be sorted and secured on the Callahan property and placed on a 6 in. gravel pad enclosed by a 6 ft chain link fence pending full identification and arrangement for disposal under the remedial portion of the effort.

## FEDERAL REMOVAL ACTIONS

### Legal

On Dec. 30, 1981, USEPA Region VII received approval for up to \$210,000 to accomplish the immediate removal operations at the Callahan site. Contacts with potentially responsible parties were made by Region VII Office of Regional Counsel (CNSL) and verbal notice of 48 hr given as required. None of the potentially responsible parties responded positively and the landowner, refused to give USEPA clear access to take the necessary removal actions. On Dec. 31, 1981, a search warrant was obtained by the OSC in the US District Court Eastern District of Missouri (81MISC202). All actions on-site during the removal were carried out under the authority of the search warrant.

On Jan. 4, 1982, Mr. Keffer signed the contract with Environmental Emergency Services and discussions were held at this time to include site safety procedures and cleanup priorities.

The owner of the property was also served with the search warrant and the purpose of the on-site cleanup was explained.

## CLEANUP

### Removal Operations

The first week on-site was dedicated almost exclusively to site preparation and the acquisition of the necessary equipment and supplies to carry out the balance of the emergency removal action. A crew of approximately 20 persons was assembled; EES, the cleanup contractor (11 workers), MDNR (2 to 3), EPA (1 to 4), and the Region VII Ecology and Environment, FIT and TAT teams (6 people nearly full time).

### Excavation

Excavation of the buried drums at the site was accomplished utilizing a track mounted hoe. A series of hand signals were worked out by the operator. These hand signals enabled the operator to continue removal of the buried drums from the fill area while not actually being able to see them at times.

By carrying out the excavation portion of the removal operation in this manner the overall efficiency and safety of this phase of operation was greatly enhanced; 1,238 drums were removed from the fill area. The entire excavation was accomplished without any incident, which could have directly affected the health and/or safety of personnel directly associated with this phase of operation.

### Drum Data Collection

The data collection procedure used at the Callahan site is unique and was developed by the on-site team to provide a workable system meeting the following criteria:

- Provide adequate records to support responsible party actions by USEPA legal staff

- Provide a permanent marking/identification system for all drums removed and stored on-site
- Permit transmittal of information from the excavation and sampling areas to the command post by radio because of extreme weather conditions
- Permit on-site containment of spilled and leaking drums in a time frame commensurate with the emergency nature of the removal actions

The system developed for use at the Callahan site is described as follows:

### Data Sheets

To keep track of the drums a single sheet was prepared for each drum containing the following information:

- Person who tagged the drum assigning it a unique and sequential drum number stamped onto a metal tag
- External conditions and markings on each drum
- Photograph number and photographer's name
- Quantity and appearance of drum contents
- Field test results
- Screening category color code assigned to drum based on screening analysis and field tests
- Storage category color code assigned to drum based on screening analysis and field tests

A second set of notes were called the field progress record which was a series of sheets with sequential drum numbers for all drums removed from the site. These sheets contained the following information:

- Drum number
- Date and time samples were collected from the drum
- Summary of all items on drum sheets
- Disposition of the drum—bulk disposal to Bob's Home Service or on-site row storage
- Date drum entered secure storage

Immediately after a drum was removed from the fill area by the backhoe, it was placed on the ground in an adjacent vacant area. The State OSC would then examine the drum carefully, scrubbing it when necessary to uncover markings. After photographing the markings and tagging the drum with its unique and sequentially numbered tag, this information was transmitted by radio to the command post where the information was recorded. The team would proceed to the next drum following the same procedure.

The drum was then transported to the sampling area where a visual description of the waste was recorded along with an HNU organic vapor measurement, radiation and hydrocyanide (HCN) test results. This information was also transmitted by radio to the command post where it was also recorded by specific drum number on the respective drum sheet.

## Sampling, Waste Characterization and Color Code

All of the sample jars were prelabeled in the laboratory before being sent to the site. This minimized the recording responsibility by the sampling and staging crew whose manual dexterity was severely hampered by several layers of rubber gloves. The empty labeled jars were transported from the laboratory to the site and stored in a locked, metal storage shed. To preserve the integrity of the sample jars after they were prelabeled, the cases were sealed with filament tape to be opened only at the drum sampling staging area. When stored on-site, the empty jars were locked in the metal shed.

The cases of sample jars were opened by the sampling crew at the drum sampling area. The sampling crew was responsible for performing the following field tests as the drums were being opened:

- Check for radiation with radiation meter
- Measure the volatiles with an HNU photoionizer unit calibrated to benzene

- Check for hydrocyanic acid (HCN) with a Bendix air monitoring pump
- Give a visual description of the contents and amount of waste in a drum

These results and description were immediately transmitted from the drum sampling crew to the OSC in the command trailer. The OSC then recorded the data on the respective drum data sheet. Three (3) samples (sample A, B, and C) were simultaneously taken of each drum by the drum sampling crew.

After the sample jars were filled, the drum number, time and date were recorded on the sample labels and then the sample jars were sealed. A layer of aluminum foil was placed over the mouth of the sample jar before the lid was screwed on. When the three (3) cases of sample jars (representing 11 drums with a set of blank jars as a control) had been reached, they were transported to the redline and placed in a plastic bag. The sets of samples and the respective drum data sheets were then transported to the field lab, located at EES, via government vehicle.

A Region VII TAT member accepted the drum samples at the laboratory and segregated them according to their A, B, or C designation. Analytical tests were run on the C set. These tests included a water reactivity test, pH determination, oxidizer test, and an open torch flammability test and a Seta flash closed cup test set at 140°F.

After the above tests had been run, the EES chemist prescribed the appropriate compatibility drum color code. (See Table 1—Compatibility Chart and Table 2—Color Code). The drum color code was then relayed to the OSC via telephone or radio. The OSC could then have the individual drum placed in the appropriate compatibility category section. The overpacked drum was then marked with its color code utilizing a grease pencil and placed into its proper secure storage area.

**Table 1.**  
**Compatibility Field Tests**

Test	Category
1. pH*	Caustic (NF) Caustic (F) Acid (NF) Acid (F)
2. Water Reactive	
3. Oxidization/Reduction	Oxidizer (F) Oxidizer (NF)
4. Radioactives	
5. Volatile vapor/gases	
6. Flammability	

\*pH is the level at which the release of cyanide, sulfide and sulfide gases pose a threat.

(F) Flammable

(NF) Non-Flammable

**Table 2.**  
**Waste Group Color Codes and Corresponding Waste Properties**

Color Code	Waste Properties
white	pH >7, non-flammable
red	pH >7, torch test properties
red/orange	pH >7, Seta flash positive
blue	pH <7, non-flammable
yellow	pH <7, torch test positive
yellow/green	pH <7, Seta flash positive
orange	water reactive
green	oxidizer, torch test positive
blue/green	oxidizer, Seta flash positive
blue/white	oxidizer, non-flammable
red/white	radioactive

The procedure utilized for the lab screening analysis was based on the "Compatibility Field Testing Procedures for Unidentified Hazardous Wastes,"<sup>1</sup> developed by Turpin, Lafornera and Allen, Environmental Response Team, USEPA, Edison, NJ.

### Chain-of-Custody

Mr. Michael Clemons was responsible for chain-of-custody of the samples after they reached the screening laboratory. The "B" drum samples were handed to MDNR along with a copy of MDNR's chain-of-custody form for every drum sample, soil sample and blank jar sample. Due to the large quantity of the "A" and "C" drum, soil and blank jar samples, a type-written chain-of-custody form was devised. The samples were aligned in numerical order according to drum number and then placed 11 to a case with a blank jar sample. Each case was then marked in indelible ink:

#### •Callahan

#### •"A" or "C" respectively

#### •The span of drum samples contained with the case, i.e. 13-23

Each case was then sealed with filament tape and an USEPA custody seal placed over the taped joint of each cardboard case. All of the "A" and "C" samples were signed over to William Keffer, OSC of the Callahan site on Feb. 11, 1982.

### Personnel Safety and Decontamination

The guidelines used to determine the appropriate levels of personnel protection are outlined in two manuals developed by E&E for USEPA.

#### •Personnel Protection Manual<sup>2</sup>

#### •Hazardous Waste Site Investigation Training Manual<sup>3</sup>

In addition to these guidelines and with assistance from ERT's safety officer, safety guidelines were developed and furnished to the cleanup contractor and other on-site personnel prior to initiation of the federal removal actions.

These procedures required all personnel inside the posted red zone to be wearing a minimum of a sealed plastic splash suit and an air purifying respirator with combination cartridges for organic vapors and particulates; the masks were changed daily. Neoprene boot and neoprene gloves were also worn with all joints taped. Those personnel in the sample collection area who were routinely leaning over the drums were required to be on supplied air.

All contaminated clothing and used cartridges were placed in the bulk disposal bins and sent to Bob's Home Service for disposal. Monitoring of the site area and personnel was accomplished by daily use of passive carbon vapor monitors supplemented by carbon tubes and Bendix pumps when weather permitted. In addition, HNU photoionizers were used in the sampling and excavation area, as well as at a 20-station network around the site, to determine organic vapor levels.

### Disposal

As a result of the removal activities, 1,238 drums were removed from the fill area. Of the drums removed, 592 were determined to be empty or non-flammable solids with no other hazardous characteristics. The contents of these drums were placed in 15 and 30 yd<sup>3</sup> containers and disposed of at Bob's Home Service. All transportation of drums from the site for disposal was made under Missouri Manifest #02121005001 as Hazardous Waste N.O.S. with the state OSC serving as the generator. This procedure resulted in a very substantial cost saving for the federal action and also minimized the on-site storage space ultimately required.

The remaining 613 drums were all overpacked and were placed in secure row storage according to chemical compatibility category, as determined by the screening test.

### Costs

A summary of the costs incurred during the Federal Removal Actions is given in Table 3.

**Table 3.**  
**Summary of Job Costs**  
**Callahan Site—Ellisville, Missouri**  
**U.S. Environmental Protection Agency**  
**Region VII, Kansas City, Kansas**

Management .....	\$34,824.50
Labor .....	68,123.63
Subsistence & per diem .....	2,576.00
Overpacks .....	52,140.00
Disposal .....	4,105.00
Equipment .....	34,549.68
Analysis (on-site) .....	10,900.90
Analysis (off-site—contract) .....	6,325.00
Safety Equipment & Materials .....	28,119.55
Security Service .....	5,057.67
Fencing .....	4,317.10
Road & Barrel Pad Material .....	4,942.65
Fuel & Lubricants .....	1,289.41
Miscellaneous Expenses .....	1,411.31
<b>Total</b>	<b>\$258,542.92</b>
Cost per drum excavated .....	\$1205.00
Cost per drum removed .....	214.56

### Unusual Working Conditions

A number of unusual working conditions were encountered while conducting the removal operations at the Callahan site. The weather proved to be the main adversary of the site operations. Conditions were indeed variable and ranged from temperatures of  $-50^{\circ}\text{F}$  wind chill, deluge rain storms and blinding snow which accumulated to more than 24 in.

Operations which under normal circumstances are considered to be routine, suddenly became unusually difficult, time consuming and frustrating. When the temperature is below freezing, the field person suddenly is faced with developing new working techniques.

For example, instead of using a glass rod or spoon, chisels and hammers are required to obtain samples of certain materials. The rubber gloves required to maintain adequate personnel protection become stiff, making it extremely difficult to perform even routine tasks such as writing or opening sample bottles or jars. Rubber boots normally issued for hazardous waste site operations are inadequate to protect individual team members from frost bite or extreme discomfort. Special insulated safety boots become a necessity.

Both the MSA 401 self contained breathing apparatus and MSA ultratwin respirators on occasion experience operational difficulties. The low pressure alarms on the regulator units of the MSA 401 must be adequately lubricated to insure that the warning bell goes off at 500 psi. An individual should always be aware of his tank operating pressure when working in extremely cold temperatures.

The hand-keyed microphones used would freeze. Communication was also difficult while wearing either an air-purifying respirator or self-contained breathing apparatus.

Decontamination procedures, normally considered to be quite routine, must be modified. For example, when attempting to rinse an individual and washdown boots and equipment in winter weather conditions, copious amounts of alcohol or methanol must be added to the wash and rinse to prevent freezing. This solution will also freeze posing a slipping hazard for the workers.

### CONCLUSIONS

In retrospect, a great deal was learned about conducting an emergency removal action of this nature under extreme and often harsh weather conditions. These emergency actions were accomplished successfully in a cost effective manner despite the adversity of the weather and operational difficulties encountered. Each difficulty was overcome without serious incident.

### ACKNOWLEDGEMENTS

The author wishes to acknowledge Mr. William Keffer, Chief of the Surveillance Analysis/Environmental Services Division, who acted as the On-Scene Coordinator for the Region VII, USEPA. As such, he was a driving force and inspiration to most of us who spent the duration of the project on-site. Also Environmental Emergency Service personnel, the Missouri Department of Natural Resources personnel, and Ecology & Environment, Inc., all of the author's colleagues who participated on- and off-site. The technical report for the remedial action was prepared by Michael Clemons and William Ritthaler.

### REFERENCES

1. Turpin, R., Lafornera, J.P. and Allen, H., "Compatibility Field Testing Procedure for Unidentified Hazardous Wastes." USEPA, Edison, N.J.
2. USEPA, *Personal Protection and Safety*, Course 165.2, 1980.
3. USEPA, *Hazardous Waste Site Investigation Training*, 1980.

# OPERATING EXPERIENCES IN THE CONTAINMENT AND PURIFICATION OF GROUNDWATER AT THE ROCKY MOUNTAIN ARSENAL

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## INTRODUCTION

The Rocky Mountain Arsenal (RMA) was established by the United States Department of the Army in 1942 on approximately 20,000 acres northeast of Denver. Its mission has been to manufacture chemicals needed by the military branches of the U.S. Government. In more recent years the facilities have been used to destroy and detoxify obsolete chemical weapons and contaminated hardware as well.

Since 1946, some of the facilities have been leased to a private contractor who has manufactured various types of insecticides and herbicides for commercial agricultural applications. In 1974, a por-

tion of the RMA site was taken over by Stapleton Airport (Fig. 1) and additional land acquisition by the airport is expected in the near future. As a result of these manufacturing and demilitarization activities both soil and water have become contaminated with chemicals which are both inorganic and organic in nature. Many of the materials that were processed were either toxic and/or suspected carcinogens.

In 1974, it was discovered that several of the chemicals were being transported off site by ground and surface waters. To address this and other potential problems, a Program of Installation Restoration was established at RMA.

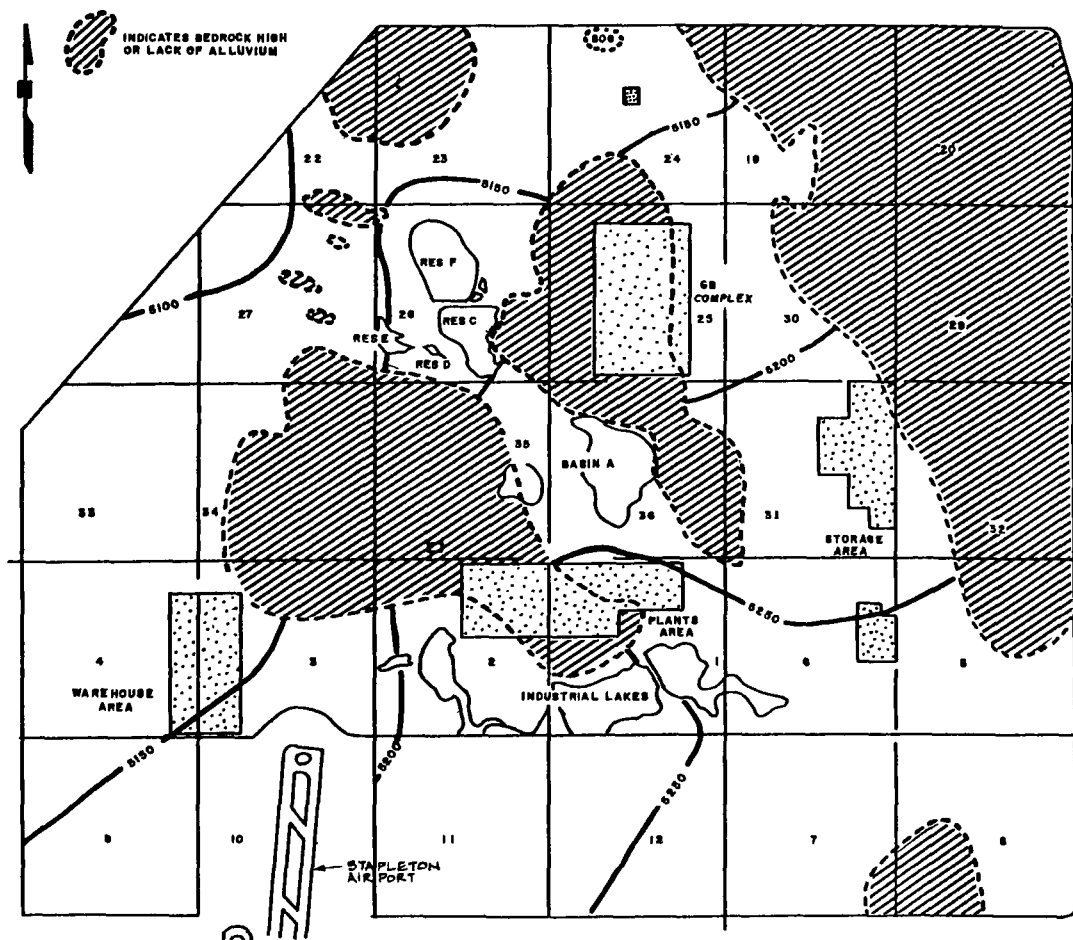


Figure 1.  
Groundwater Contours and Bedrock Highs



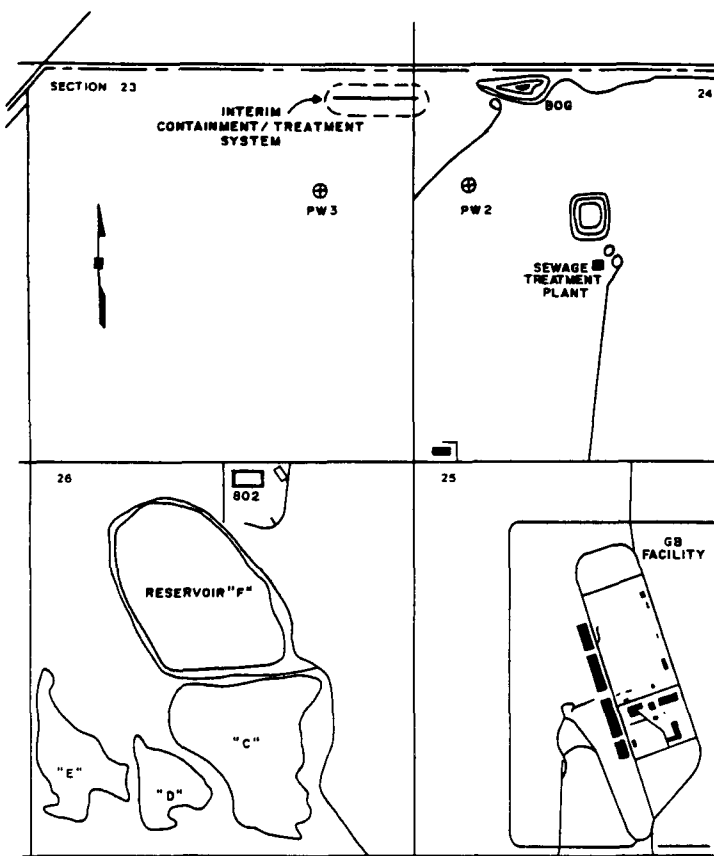


Figure 2.  
North Boundary Plan View

## CONTAMINATION CONTROL ACTIVITIES

Since 1974, extensive hydrogeologic and decontamination studies have been conducted under the direction of RMA, Waterways Experimental Station (WES) of the Corps of Engineers and the Mobility Equipment Research and Development Command (MERADCOM). These studies (Fig. 1) have identified specific areas which are sources of contamination and have defined the pattern of flow of groundwater at the RMA site.

### RMA North Boundary Interim Facility

The initial contamination control project at RMA was initiated at the North Boundary. Several organic contaminants were detected in the bog water (Table 1). An extensive program was initiated to examine this water as well as nearby water from Wells PW2 and PW3 (Fig. 2).

Table 1.  
RMA North Boundary  
Groundwater Contaminants (Wells PW2 and PW3)

Compound	Concentration ( $\mu\text{g/l}$ )	
	PW2	PW3
Aldrin	<2.0	< 2.0
Dieldrin	4.5	< 2.0
Dichloropentadiene	1000	82
Diisomethyl phosphonate	530	2800
Endrin	8.6	< 2.0
Dibromochloropropane	7.6	<1.0
p Chlorophenylmethyl sulfide	68.3	<10.0
sulfoxide	53.3	<10.0
sulfone	40.5	<10.0

Although many purification techniques were evaluated, adsorption on activated carbon was the most cost effective. Dynamic flow granular activated carbon column testing indicated that diisomethyl phosphonate (DIMP) was the first of the contaminants to appear in the effluent of the adsorption test columns. Based upon these laboratory results, several dewatering and reinjection wells were installed in the area shown in Fig. 2 and a full scale interim granular carbon system was constructed in July 1978.

Calgon Adsorption Service equipment was used for the interim purification facilities; it consisted of two multi-media filters followed by a fixed granular carbon adsorber. This system operated from July 1978 to June 1981 using a maximum effluent DIMP concentration of 500  $\mu\text{g/l}$  as the principal operating parameter for carbon performance and periodic replacement. The system design features and salient performance data for the period of July 1978 through June 1981 are shown in Table 2.

Table 2.  
RMA North Boundary  
Interim Granular Carbon Treatment  
(1/7/78 through 6/30/81)

Adsorption Mode	Single stage fixed bed
Carbon Bed Volume $\text{ft}^3$	666
Flow Rate (gpm)	70-100
Contact Time (minutes)	50-300
Type of Carbon	Calgon Service Carbon
DIMP Concentration	
Influent	1200 $\mu\text{g/l}$ average
Effluent	non-detectable
Carbon Use Rate	
Projected	0.33 lbs per 1000 gallons
Actual	1.00 lb per 1000 gallons

The successful three year operating period demonstrated that the granular carbon adsorption process would reliably remove those organic contaminants found in RMA North Boundary groundwater. The system operated virtually unattended except for periodic monitoring, backwashing and carbon replacement procedures.

The carbon exhaustion rate for the demonstration period was one pound of carbon per 1000 gal of water treated. This compares with a projected exhaustion rate of 0.33 lb C/1000 gal based upon the pilot studies previously discussed. Part of this difference may be attributable to air pockets in the granular carbon beds which formed when water drained from the adsorbers during periodic shut-downs. The installation of an anti-siphon valve corrected this early problem.

Based upon these encouraging results, a permanent boundary water containment and purification system was designed and installed.

### RMA North Boundary Expanded Permanent Facility

The permanent facility for groundwater containment at the North Boundary included a 6800 ft long clay slurry wall which was installed 200 ft inside the RMA perimeter. Dewatering and reinjection wells along the clay barrier remove water for treatment at a central facility and deliver the purified water back to the ground flow.

The dewatering system is divided into three separate water collections systems which have waters of varying organic composition. It was anticipated that three adsorption process trains would provide added treatment flexibility than that afforded by treating a mixed influent (Fig. 3).

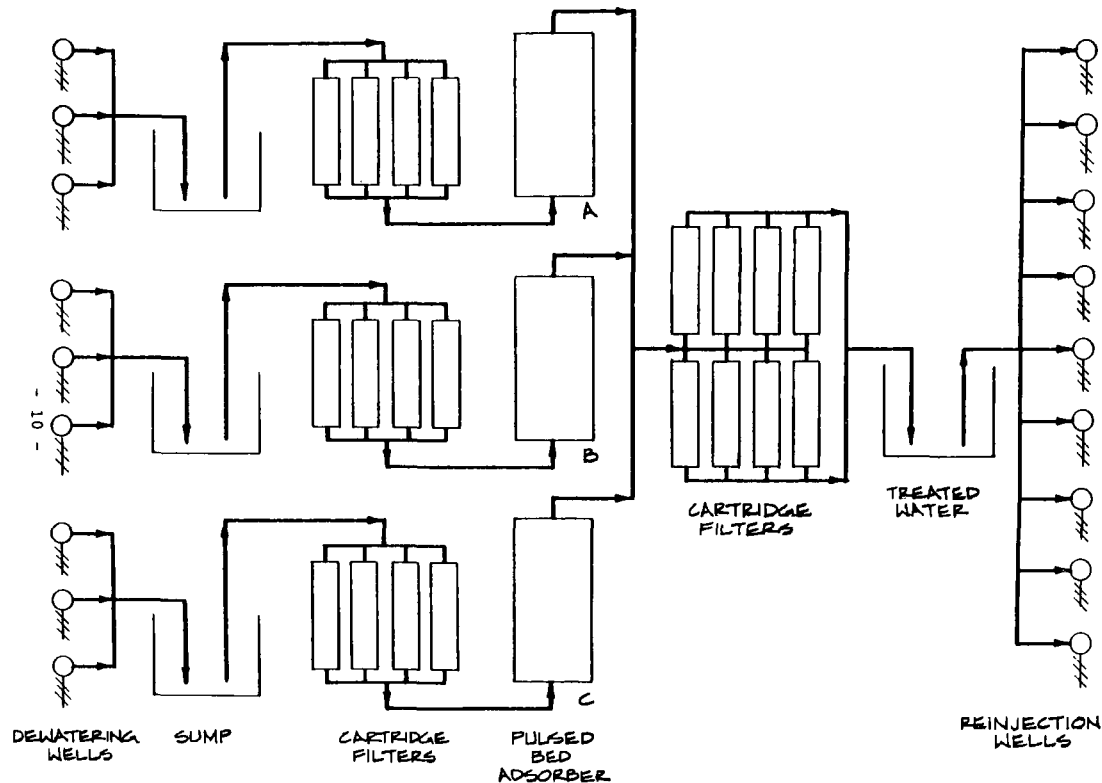


Figure 3.  
RMA North Boundary  
Permanent Granular Carbon Facility

Economic analysis of capital costs associated with on-site reactivation of granular carbon compared with projected carbon usage rates indicated that on-site carbon reactivation was not justified at that time. The granular carbon replacement cost was nevertheless projected to be the principal operating cost. In order to optimize carbon utilization, various countercurrent adsorption systems were evaluated. Commercially proven countercurrent adsorption systems are either two stage downflow fixed beds in series or upflow pulsed beds.

A pulsed bed adsorption system supplied by Westvaco was selected for the permanent RMA North Boundary treatment facility. The system is comprised of three adsorbers in parallel, cartridge filters ahead of and following the adsorbers, storage vessels for both fresh and exhausted carbon and two pressure transfer vessels to move carbon between the equipment in a measured slurry volume. A process diagram for the permanent adsorption system is shown in Fig. 3 while the design features are given in Table 3.

Table 3.  
RMA North Boundary  
Permanent Granular Carbon Treatment

Adsorption Mode	Three pulsed beds operating in parallel			
Carbon Bed Volume (each vessel)	1000 ft <sup>3</sup>			
Volume of Carbon Pulse	70 ft <sup>3</sup>			
Type of Carbon	WV-G 12 x 40			
Design Flow Rate (gpm)	Average 250/Maximum 350			
Contact Time (min.)	Average 84/Minimum 30			

Influent Organic Contaminants	Process Stream A	Process Stream B	Process Stream C	Effluent Objectives
DIMP* $\mu\text{g/l}$	700-1200	100-500	10-100	500
DCPD** $\mu\text{g/l}$	10-2000	500-2400	24	24
DBCP*** $\mu\text{g/l}$	1-5	1-5	1-5	0.2
*Diisomethylphosphonate		**Dicyclopentadiene		***Dibromochloropropane

# COST EFFECTIVE MANAGEMENT OF AN ABANDONED HAZARDOUS WASTE SITE BY A STAGED CLEANUP APPROACH

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## SITE DESCRIPTION

The Bridgeport Rental and Oil Services (BROS) site is a former oil processing and reclamation facility in southern New Jersey (Fig. 1). The site has an overall area of approximately 26 acres, contains an 11.5 acre unlined lagoon and over 88 tanks and storage vessels, and is bounded on three sides by two fresh water ponds, a peach orchard and marshland (Cedar Swamp). A small creek (Timber Creek) running through the swamp passes in the near vicinity of the lagoon and eventually discharges to the Delaware River about 3 miles from the site.

The lagoon has an average depth of 10 to 15 ft but depths as great as 60 ft in places have been reported. A thick layer of heavy oil floats on the surface. Large quantities of construction debris, trash, and several large tank trucks are partially submerged in the lagoon and are all coated with oil. Large numbers of floating drums are also present.

The storage vessels on site range in capacity from a few thousand gallons to tanks with volumes of over 300,000 gal. The volume of material in each tank is not consistent. Initial site surveys have shown the majority of the tanks are either empty or contain only small quantities of bottom sludges. Two of the seven major tanks (i.e., greater than 300,000 gal) contain large quantities of liquid material.

The site poses a threat to both surface and groundwater in the area. Private drinking wells in the area have been contaminated with varying amounts of volatile organic compounds. Previous breaching of the dike surrounding the lagoon has led to discharge of material to Timber Creek and the deforestation of 8-10 acres of land adjacent to the lagoon. There is visual evidence of seepage of oily materials into the surrounding fresh water ponds.

## HISTORY

Since 1969, there have been no known discharges from the lagoon but the general condition of the site has deteriorated. The level of the lagoon has continued to rise far above the surrounding groundwater table, suggesting the bottom sludges may have sealed off, to a limited extent, the lagoon from the groundwater.

From 1975 to 1980, various remedial efforts, such as skimming and pumping of the oil, booming, etc. were proposed or attempted but the size of the lagoon, the large amounts of floating debris, and the viscosity of the oil prevented their successful application.

Due to high lagoon levels, a new dike was constructed in 1981 using funds from Section 311 (K) of the Clean Water Act. The dike was designed to contain the lagoon liquid for 4 to 5 years.

In Sept. 1981, Camp Dresser & McKee (CDM), as USEPA's Zone II contractor, was directed to begin a comprehensive site study leading to the definition of the most cost-effective means for remedial site cleanup. The study was to consist of a review and compilation of existing information, sampling of tanks and lagoon, and the carrying out of a hydrogeological investigation. However, site conditions in the spring of 1982 dictated that a more direct approach to the problem be undertaken.

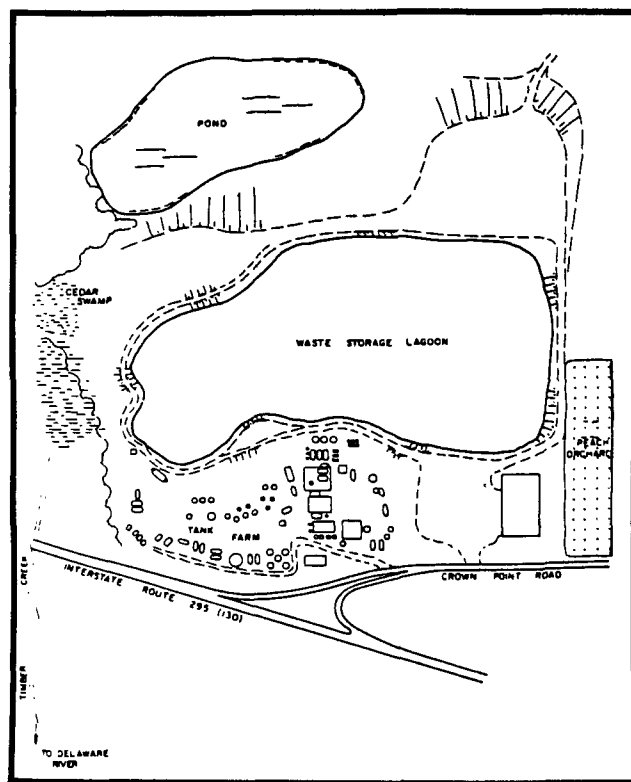


Figure 1.  
Schematic of Site

## JUSTIFICATION FOR A STAGED CLEAN-UP APPROACH

By June 1982, the lagoon surface had risen to approximately 8 in. below the top of the dike, the combined result of higher than average rainfalls and unforeseen limitations in subsurface percolation and evaporation. An emergency action was initiated, and USEPA's mobile activated carbon unit was employed to lower lagoon levels. Operations were terminated in late July when approximately 2 ft of liquid, approximately 5 million gal, had been removed.

Also in June, CDM was directed to develop feasible treatment methods for surficial site clean-up, that is, lowering the level of the lagoon by 10 ft and emptying the large capacity storage tanks. (Lowering to levels below this depth was dismissed without further study due to the possibilities of bottom deposit fracturing and subsequent increases in the rate of groundwater contamination.) This work was to be accomplished in two phases. Technically and economically feasible methods of waste treatment or removal were

to be specified. Following this, technical specifications were to be prepared for incorporation into U.S. Army Corps of Engineers standard specifications for preparation of bid documents.

The objectives of this task were threefold:

- Immediate environmental hazards which would occur as a result of lagoon overtopping or storage tank rupture would be alleviated.
- Operating problems, regulatory requirements and treatment system reliability relative to final site remediation would be identified.
- Lowering of the lagoon levels would expose a large amount of the currently submerged area, thus, allowing the investigation of the lagoon bottom characteristics needed to define final site remediation options.

For cost effectiveness, the surficial clean-up system was to be designed, to the greatest extent possible, to be equally applicable to the long-term site solution.

## SITE SAMPLING AND WASTE CHARACTERIZATION

The first step of CDM's surficial site cleanup study was to obtain representative samples of the lagoon aqueous phase, tanks, and floating oil. A private contractor was called in to perform these services. The work was carried out in three phases. First, the structural integrity of each major storage tank was assessed to evaluate the potential for rupture and also to identify what tanks could be used for either off-site waste transportation staging areas or as components of an on-site treatment system. Secondly, storage tank profiles were prepared detailing the volume, depth and chemical characteristics of each phase, or in the case of empty tanks, contaminants remaining as determined from wipe-testing. Thirdly, a substantial lagoon profiling was undertaken. Samples of surface oil, aqueous materials two feet below the oil surface, and aqueous materials at mid-depth in the lagoon were obtained during four traverses of the lagoon. The samples from each depth were composited for each traverse and submitted to chemical analysis for priority pollutants. Lagoon depth readings were taken at each sampling point to confirm previous data.

Significant operational problems were encountered during lagoon sampling. Fatigue was a major problem, due to the combined effects of high temperature and the protective clothing and respirators worn by all personnel. Also, the large amount of floating debris and oil viscosity greatly decreased the rate at which the floating sampling station could be pulled across the lagoon. The end result was that only three limited traverses could be made in the allotted one-week sample effort. A fourth "traverse" was accomplished by suspending sampling personnel over the lagoon surface (approximately 40 ft from shore) by means of a "cherry-picker". A diagram of the sampling points is given in Fig. 2.

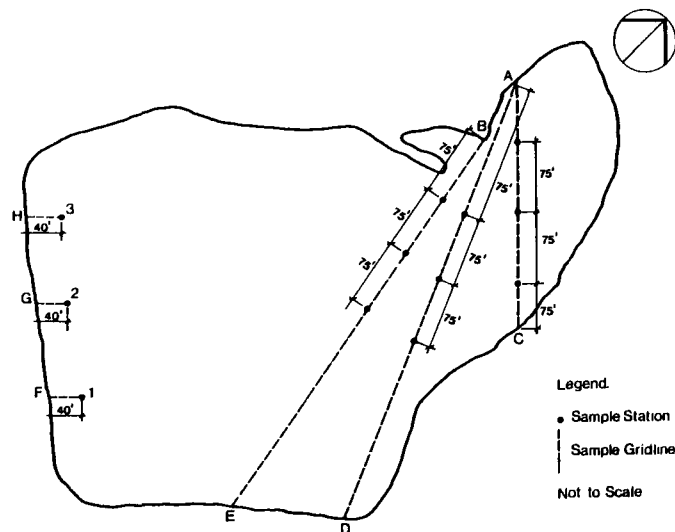


Figure 2.  
Sampling Grid

## Chemical Characterization of Tank Contents and Lagoon Oil

Five of the major storage tanks were essentially empty. Analysis of wipe test samples on the empty tanks showed a large number of generally uncharacterized hydrocarbons, various benzene, and phenolic species, and a number of polyaromatic hydrocarbons, such as phenanthrene and naphthalene. The concentration of these materials was generally less than 200 mg per wipe. Relatively high concentrations (1-15 µg per wipe) of phthalate species including bis (2-ethyl hexyl) phthalate, di-n-butyl phthalate and di-n-octyl phthalate, were found in all tanks.

Three tanks contained significant quantities of liquid or sludge. A composite sample of each phase (i.e. sludge, water and oil) was taken for analysis. A general summary of the amounts of chlorinated hydrocarbons identified during this testing, along with those from the sludge samples in the "empty" tanks, is given in Table 1. Also included in this table are the results from a composited sample of floating lagoon oil.

The greatest threat posed by the site resides in the lagoon surface oil with its very high concentration of solvents and PCBs. The need for preventing the escape of this material into the environment (by preventing overtopping of the lagoon) is readily apparent especially when one realizes that approximately 5 million gal of this material float on the lagoon.

## Characterization of Aqueous Lagoon Contents

In general, the aqueous phase of the BROS lagoon can be characterized as a lightly yellow colored liquid containing a moderate amount of suspended solids. Samples of the wastewater were noted for their strong, "motor-oil" like odor. Although there was no visual evidence of a substantial degree of emulsified oil, some samples were observed to contain a small number of oil droplets and generally uncharacterized settleable materials.

The aqueous waste has a TOC ranging from 180 to 220 mg/l and a COD of 720 mg/l. The 5-day BOD is quite low in relation to these other parameters, amounting to only about 90 mg/l. Total suspended solids were approximately 60 mg/l. The oil and grease content of the waste amounted to approximately 80 mg/l.

Based on the above analysis, in combination with treatability studies conducted in CDM's laboratory, the waste can be said to be composed of 33% readily volatile species and 33% large molecular weight oily type materials. The remaining third of the measured organic matter was generally uncharacterized, containing a wide diversity of organic species.

Only dilute concentrations of the metal species, well below established discharge limits, were found in the waste. Only two metals appear to be of potential concern in meeting discharge criteria, namely lead and zinc, and these exist at concentrations between 0.5 and 5 mg/l.

Organic chemical characterization was provided in four general categories, acid compounds, base/neutral compounds, volatiles and tentatively identified compounds. Significant interferences occurred in the analysis of acidic and base neutral compounds. (The data developed showed remarkable similarity to the type of data expected from the analysis of undiluted crude oil.) The end result of these interferences was that low concentrations of acid or base neutral compounds and pesticides were not determinable to a high level of reliability. Within this context, any species indicated as not detected had to be viewed as being present at a concentration of 50 µg/l or less (in contrast to some tank samples, PCBs were not found in this water). The value for species which were definitely found to be present could, however, be considered to have greater validity. Significant interferences were not encountered in the analysis of the volatile species, and thus the data would be considered as highly reliable.

With the exception of diverse phenolic species, there appeared to be no substantial concentrations of acidic priority pollutant compounds definitely present in the waste. The number of base neutral compounds was also quite limited, being effectively limited to naphthalene. Both of these species were present in quantities significantly less than 1 mg/l.

**Table 1.**  
**General Physical and Chemical Characterization of Tank Contents**

\*ND means not detected

Tank No.	On-Site Designation	Estimated Capacity (gal)	Estimated Sampled Phase	Depth (Vol) of Sampled Phase	Status	Chlorinated Hydrocarbons Solvents	(µg/ml) PCB
1	C-2	280,000	Sludge	(400 gal)	Unsuitable for storage	ND*	ND
2	C-3	300,000	Aqueous	(6400 gal)	Corrosion evident, unsuitable for storage	ND	ND
3	RP-6	300,000	Sludge	(1400 gal)	Unsuitable for storage	18	420
4	RP-7	300,000	Sludge	2 in	Possibly usable for storage; floor must be tested; surrounding dike inadequate	140	260
5	RP-11	300,000		2 in	Unsuitable for storage	7	330
6	C-6	520,000	Oil, Aqueous Sludge	310,00 gal 90,000 gal 13,000 gal	Appears struct. sound; most stable of all tanks	490 52 530	960 130 980
7	T-13	2,000	Oil	(850)	Too small for use as storage vessel	27	1540
8	CC-6	760,000	Aqueous Sludge	(500)	Questionable integrity in places	ND	ND
			Aqueous	640,000		ND	ND
Lagoon Oil						49	1230

Relatively high concentrations of a variety of volatile priority pollutants were measured. Of particular concern were benzene, trans 1-2 dichloroethene, methylene chloride and toluene, all of which had average concentration at or near 1 mg/l. These concentrations also illustrate the hazard which will be associated with treatment of this wastewater, and the care which will be necessary in controlling volatile emissions if required.

Information on the non-priority pollutants identified in the waste is given in a listing of tentatively identified, compounds in a combined waste sample presented in Table 2. A number of large molecular species were shown to be present at or near the 100 µg/l level. Of particular significance in this listing, however, are the large measured concentrations of additional volatile species. Very high levels of acetone (39 mg/l), methyl ethyl ketone (9.6 mg/l) and methyl isobutyl ketone (4.3 mg/l) were observed.

## POTENTIAL TREATMENT OPTIONS

### Tank Contents

Due to unforeseen delays in obtaining the chemical analysis of the storage tank contents and wipe test samples, a detailed review of feasible waste treatment disposal options for these materials could not be prepared in time for manuscript submittal. Brief review of the data indicates, however, the aqueous materials could be treated in the proposed on-site treatment plant.

The high concentrations (greater than 500 mg/l) of various solvents and polychlorinated biphenyls (PCBs) in the organic phases mandate that these materials be shipped to an approved hazardous waste incinerator. Note that in all cases except one, the organic materials in the tanks comprise a relatively small volume, thus shipping costs can be limited.

### Lagoon Water

Determination of the lagoon water treatment system required three decisions: (1) how far to lower the elevation of the liquid level, (2) how and where to treat the water, and (3) how to manage any residues from on-site treatment.

A 10 ft reduction in elevation means removing 67% more water than a 5 ft reduction; it would achieve a new lagoon area approximately half of that achieved by a 5 ft reduction. In combination with cleanup of stranded materials on the newly exposed lagoon

**Table 2.**  
**Tentatively Identified Compounds in Composited Sample of BROS Lagoon Wastewater**

Compound Name	Fraction	Est. Concentration (ug/l)
2-ethyl-1-hexanol	Acid-Base Neutral	100
Heptanoic Acid	Acid-Base Neutral	100
2-ethyl-hexanoic acid	Acid-Base Neutral	110
Octanoic acid	Acid-Base Neutral	100
Decanoic acid	Acid-Base Neutral	110
6-methyl-tridecane	Acid-Base Neutral	100
Heneicosane	Acid-Base Neutral	150
3,5,2,4 trimethyl tetracotane	Acid-Base Neutral	130
Hepta decane	Acid-Base Neutral	500
7-hexaleicosane	Acid-Base Neutral	130
Acetone	Volatile	39,060
Methyl-ethyl ketone	Volatile	9,600
Methyl-isobutyl ketone	Volatile	4,300
Xylenes	Volatile	960

### Options Related to Lagoon Surface Elevations

Past soundings of the lagoon's depth at various locations were used to estimate the physical effects of lowering the lagoon by various amounts, as follows:

Reduction Lagoon Surface Elevation (ft)	New Lagoon Surface Area (ft <sup>2</sup> )	Volume Removed* (gal)
0	500,000	0
5	320,000	15 x 10 <sup>6</sup>
10	165,000	25 x 10 <sup>6</sup>

\*Neglecting rainfall during the removal period.

bottom and re-diking this smaller lagoon will collect less total precipitation than a larger lagoon. In addition, a 10 ft decrease in surface level would eliminate the hydrostatic driving force for fluids to move from the lagoon into the groundwater. Therefore, a drop of the lagoon elevation by 10 ft to an approximate elevation of 3 ft above sea level was recommended.

Flow rates required to achieve this elevation drop over various time periods were computed. Rainfall, based on the mean annual precipitation and conservatively assuming no evaporation, is included:

Time to Lower Lagoon by 10 ft. (months)	Pumping Rate (gpm)*
2	316
4	200
12	74

For concluding surficial cleanup in an expeditious manner, CDM recommended a flow rate of 200 gal/min. An interim treatment system to handle this flow could be used on an intermittent basis in the future to maintain the lagoon at an appropriate level. Operation for six to ten weeks per year would achieve this goal.

### Lagoon Water Treatment and Disposal

A wide variety of cleanup options were reviewed for their applicability to the BROS site. It is not possible to discuss here each reviewed treatment process. A summary of CDM's review is given in Table 3. However, since the treatment plant includes both flocculation/sedimentation and activated carbon adsorption, a separate discussion of each of these recommended treatment processes for the full-scale plant is given below.

A series of jar tests were conducted on the raw waste. Different ferric chloride doses, polymer (anionic) doses, and pH combinations were tried. The best removal of suspended solids and color was noted under the conditions of: (1) final pH of 6.0, (2)  $\text{FeCl}_3 \cdot \text{H}_2\text{O}$  dosage of 200 mg/l, and (3) 4 mg/l of anionic polymer. The supernatant was clear yellow after filtering and the final TOC of

**Table 3.**  
**Non-Feasible Treatment Processes Reviewed for BROS Site Wastewater**

Candidate Process	Treatability Studies Conducted	Feasibility Status and Reasons for Inclusion or Rejection	Cost Estimates for 200 gpm Unit
Air Stripping	Laboratory-scale air sparging studies	Large proportion of the waste (approx. 35%) amenable to removal by air stripping. However, NJDEP regulatory requirements preclude significant VOC emissions.	< \$15,000
Biological Treatment	Bacterial acclimation to waste, toxicity oxygen uptake rates	Not considered feasible due to exceedingly slow rates of bio-oxidation, anticipated start-up delays, and substantial volatile emissions	Not performed due to lack of technical feasibility
Reverse Osmosis	None	Due to extensive pre-treatment required, influent quality to unit would have to be superior to plant discharge limit; thus unit would be extraneous	\$170,000 (with sand filter)
Ultrafiltration	Pilot-scale studies by vendor (CDM present)	Maximum organic removal approximately 50% TOC with highest reject membrane. Effluent not suitable for discharge-concentrated stream would require disposal.	Not performed due to poor performance noted.
Hydrophobic Resin Beads	Parallel test and control adsorption columns	No significant amount of organic material removed	Not performed due to lack of technical feasibility
Ultraviolet/Ozone Oxidation	Pilot-scale studies by vendor	Demonstrated effectiveness to reduce waste TOC concentration down to acceptable discharge levels. However, cost levels too high.	\$1.6 million for contractors and ozone generator; \$8 million for chemicals, power, etc.
Chemical Fixation	Pilot-scale studies by vendor	Chem-fix process gives solid acceptable for disposal under EP extraction test. However, no decrease in volume of material treated and limitations in on-site storage space of material.	\$2 - \$3 million
Ion Exchange	None	Organic chemicals in raw waste have high probability of fouling resin. Disposal proven for concentrated regenerant solutions. Metals can be removed in treatment process as part of other disposal techniques.	System not considered necessary -- no pricing attempted.
Off-Site Disposal (to treatment plant)			
By Truck	Preliminary treatability studies conducted by DuPont's Chambers Works	Temporary "quick-fix solution" no process equipment would remain for application to long-term clean-up. High cost.	\$750,000 water treatment \$750,000 waste transportation
By Pipeline	None	The nearest treatment plants are approximately two miles away. Thus, pumping and piping costs would be high. Treatment efficiencies are questionable and VOC emissions would be a problem.	Not priced due to lack of technical feasibility

the filtrate was 119 mg/l, a substantial reduction from the filtered (no flocculation) waste concentration of 175 mg/l.

It appeared highly unlikely, based on CDM's laboratory results, that this flocculation alone would be sufficient to meet discharge requirements. However, some additional process such as carbon adsorption or oxidation is necessary to remove soluble organic materials. One advantage of the use of adsorption technology would be that this process could be beneficial in removing dissolved metal species, especially where powdered activated carbon would be used in combination with a ferric hydroxide coagulation step.

Activates carbon can be applied to wastewater in two ways. The most common method of contact is through passage of the waste through a stationary bed of granular carbon. An alternate method of carbon contact is to add powdered carbon. Powdered carbon, due to the fact that most of the available surface area is on or near the external surface of the particle, results in quicker adsorption equilibrium since materials to be adsorbed only have to travel relatively short distances.

For evaluating columnar carbon adsorption for treatment of BROS wastewaters, CDM was fortunate in having the results of the on-site emergency response cleanup action which used USEPA's mobile physical-chemical treatment system. Based on these data, granular activated carbon adsorption, appeared unsuitable for treatment of the wastewater. Rapid exhaustion of the 16,000 lb of carbon in the unit was observed. Furthermore, actual achievement of an effluent concentration limit of 50 mg/l TOC was observed in only a few isolated instances.

Hydraulic surface loading rates in the physical-chemical treatment system were approximately 6 gal/min/ft<sup>2</sup> as opposed to a "normal" operating range of 2 gal/min/ft<sup>2</sup>. Such a high loading rate could have been responsible, to a certain degree, for the relatively rapid rise of TOC concentration in the effluent.

Independent of surface loading considerations, however, is the fact that, even at the very start of the run, effluent from the carbon columns was quite poor (greater than 40-50 mg/l TOC). Since the empty bed detention time in the columns was considerably greater than standard operating conditions of 15 min (through the use of three columns in series), this essentially immediate appearance of high effluent TOC concentration was indicative of the poor adsorbability of many of the compounds in the waste.

CDM suspected that the mediocre performance of the carbon treatment unit was related primarily to the high concentrations of oily materials in the wastewater, materials which are poorly diffusible and which can block the pores for penetration of other adsorbents.

Partial confirmation of the role of the oily materials in not-penetrating and/or blocking pores was obtained when it was noted that greater adsorption efficiency and better effluent quality was observed as more regenerated carbon was used in the columns. Since regenerated carbon generally has less surface area but larger pores than virgin carbon, the observed performance seemed to confirm CDM's supposition that carbon adsorption efficiency was primarily related to the actual availability of adsorbent surface area to the adsorbable species, rather than to total surface areas.

CDM, therefore, concluded that the poor performance of on-site carbon beds was probably due, in part, to the poor penetration of chemical species into micropores. As a consequence, any attempt to expand the area available for chemical species adsorption, either by increasing the diameter of the micropores or by maximizing external (i.e. non-intra-pore) surface area would increase performance. Furthermore, it was surmised that long contact times would increase carbon performance by allowing greater amounts of the pore penetration to occur and, to prevent pore blockage any removal of floating oils should be undertaken.

To investigate and/or confirm these suspicions, a series of laboratory scale treatability studies were carried out. Calgon Corporation was sent a sample of the wastewater and requested to perform adsorption isotherm at an acidic and neutral pH. These studies were conducted in a standard manner using powdered activated carbon, raw wastewater and a contact time of 17 hr. The

powdered carbon was quite successful in treating the raw waste, reducing TOC levels to less than 50 mg/l TOC at carbon concentrations of 500 mg/l or greater.

CDM conducted its own combined isotherm/jar test evaluation with powdered activated carbon and raw wastewater. Significantly greater amounts of carbon were required (in 2 hr) to reach the same TOC concentrations as had been observed in the Calgon data in 17 hr. CDM believes that better performance would have been observed in both cases had suspended materials and oils been removed before carbon treatment.

In addition, CDM conducted a small scale carbon adsorption column test at a hydraulic loading rate of 2 gal/min/ft<sup>2</sup>, and an empty bed detention time of approximately 15 min. Coagulated wastewater was used for this test. Only two effluent samples from the laboratory column study, taken 2 and 4 hr after commencement of the study, were analyzed. Both of these samples showed TOC values in the range of 20 mg/l. This relatively poor effluent from a new bed of carbon under normal loading, while within permit limits, suggests that breakthrough to 50 mg/l could be expected on the full scale.

In summary, therefore, granular activated carbon does not appear well suited to treatment of the lagoon water to a level of 50 mg/l TOC. Powdered activated carbon does, however, show great potential applicability, presuming sufficient times of contact and dosages (these two factors being inversely related) are allowed. Use of powdered carbon was strongly recommended for treatment of this waste for two primary reasons:

- The technology is applicable to the removal of a diverse variety of chemical components.
- By adjustment of carbon dose (or contact time) considerable flexibility of operation is insured, an important consideration for the expected variability in BROS lagoon wastewater characteristics.

Once candidate options were dismissed on the basis of their technical feasibility or cost effectiveness, two potentially feasible options remained. These were off-site disposal to DuPont's Chambers Works Plant or on-site treatment using flocculation and powdered activated carbon. Of these two, on-site treatment was considered the more desirable primarily because it could be easily incorporated into a long-term final site remediation.

The estimated costs of each alternative were roughly equivalent at \$1.3 million. An additional \$600,000 in operating expenses was predicted for the powdered activated carbon system.

Preliminary cost estimations showed that use of a granular activated carbon system could result in a savings of approximately \$400,000 to \$500,000 (primarily contributed by reductions in capital expenditure and reduced carbon usage). However, based on laboratory and full-scale studies previously described, CDM did not feel that granular carbon would be adequate to meet the 50 mg/l effluent discharge limit to Timber Creek specified by NJDEP. However, if the discharge limit were relaxed to 100 mg/l TOC, a granular activated carbon unit could reliably meet that standard. This was demonstrated by on-site application of USEPA's mobile physical-chemical treatment system under "worst case" conditions, that is, without pretreatment for the removal of oily materials.

NJDEP and USEPA are still reviewing the report. Until review is completed, CDM is not carrying out any design work for operation beyond the pretreatment step for oil removal.

## RECOMMENDED ACTIONS

For a 50 mg/l TOC discharge limit, CDM recommends construction of the powdered activated carbon system shown schematically in Fig. 3. The system is designed to provide "standard" detention times (i.e. 5-10 min rapid mix, 30 min flocculation and 1 hr of sedimentation) at a flow rate of 200 gal/min. A powdered carbon contact period of 6 hr was specified based on the results of isotherm testing (carbon dosages could be increased on an as-needed basis). Note that all process tanks will be covered to reduce volatile emissions. Final effluent will be sand-filtered to remove carbon granules



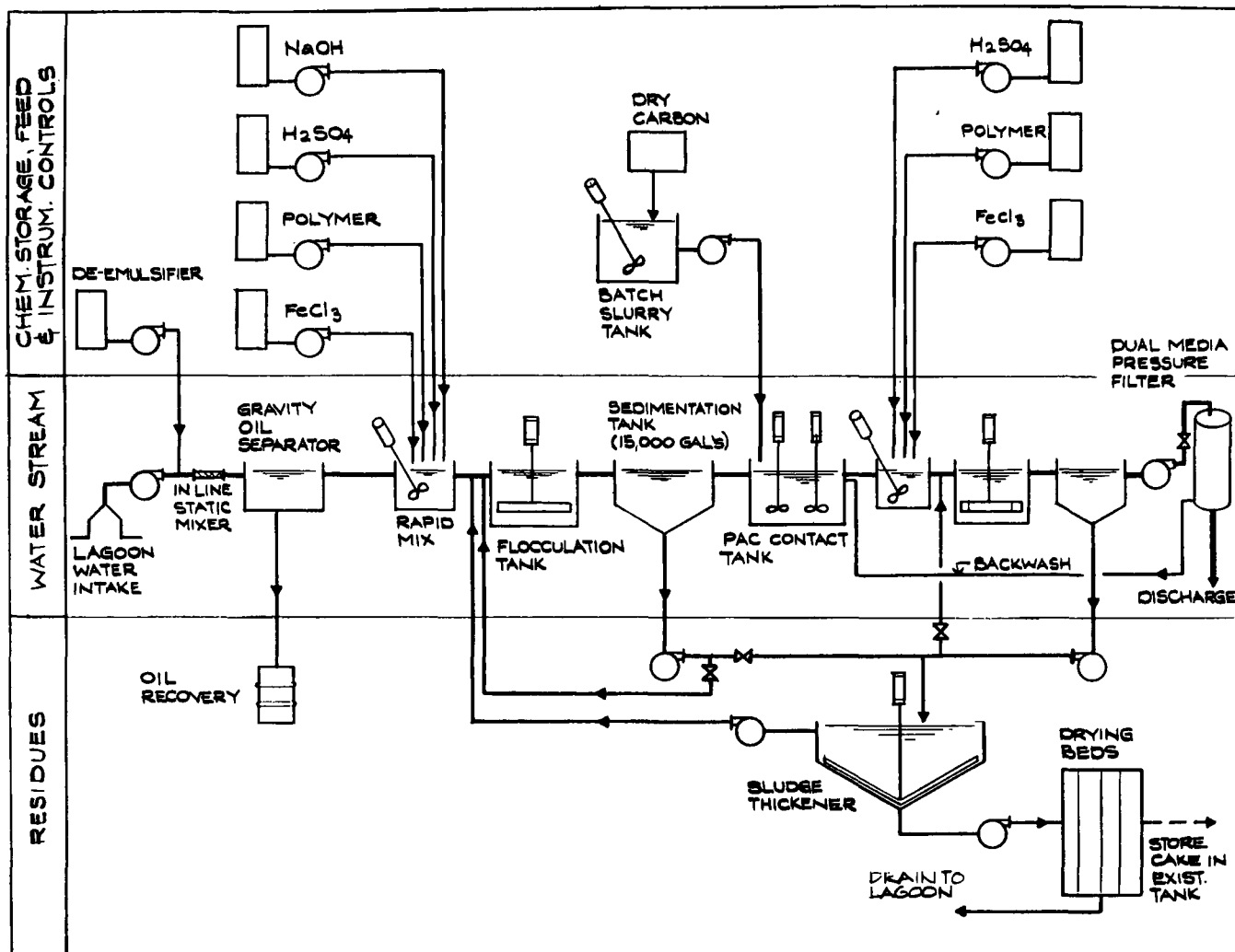


Figure 3.  
Recommended Treatment Process Flow Diagram

which could contribute to the TOC. CDM's decision to recommend this process train was based upon the following considerations:

- The system will be effective in treating most of the identifiable components in the lagoon liquid under a variety of flow, composition, and concentration conditions.
- Because the treatment will use only physical/chemical processes, very little time will be required to bring the plant up to a full operating condition.
- The treatment plant should be of great benefit in treating additional lagoon waters related to overall cleanup.
- The possibility exists for many treatment system components to be used at other sites once work has been completed at BROS.
- The proposed system is the least cost option that provides confidence in meeting discharge requirements.

To the maximum extent possible, CDM intends to specify package units for the treatment processes. Use of such pre-fabricated systems will achieve the following goals:

- Short construction time
- Low capital cost
- Ability to design the system in a short time (e.g. structural engineering effort to design concrete tanks will be avoided).

The packages to be specified will be expected to hold up for several years of continuous service, a period of time which USEPA estimates will be required for eventual site remediation.

Specification of a Granular Activated Carbon system would reduce capital outlay by approximately \$250,000 by obviating the need for all powdered activated carbon storage and contact tankage. Furthermore, due to greatly decreased sludge handling requirements (i.e. essentially limited to ferric hydroxide/oil sludges from pretreatment) CDM believes the thickener, sludge drying beds could be replaced by an automatic batch feed centrifuge.

#### SUMMARY

Upon direction by USEPA, CDM has specified and will design, a treatment system for waters drawn from a waste oil storage lagoon. Treatment processes were recommended on the basis of laboratory and full-scale treatability tests. CDM believes that the most cost effective treatment solution is the application of a combined flocculation/sedimentation oil removal, activated carbon adsorption treatment system. Pending review of this report, technical specifications for the appropriate treatment system will be prepared for formulation of site construction bidding documents under the combined direction of USEPA and the U.S. Army Corps of Engineers.

# PICILLO FARM, COVENTRY, RHODE ISLAND: A SUPERFUND & STATE FUND CLEANUP CASE HISTORY

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## HISTORY

In the fall of 1977, an explosion and fire alerted area residents and officials to the presence of a chemical dump site at the Warren V. Picillo Farm (Fig. 1). The Rhode Island Attorney General sued to enjoin Picillo from further disposal and to remove all hazardous wastes for proper disposal. The State attempted to secure legitimate disposal outlets for these wastes. When Picillo failed to comply with the court order, the Attorney General became involved in a lengthy court action which continues to this day.

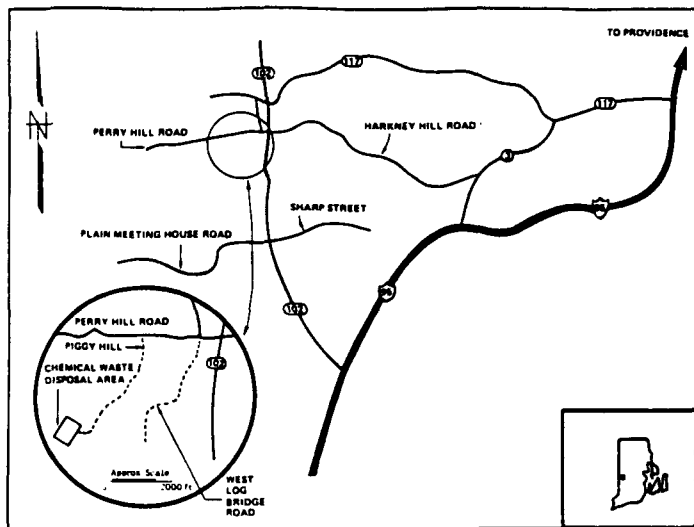


Figure 1.  
Location of Picillo Farm, Coventry, Rhode Island.

## CLEANUP BEGINS

In late 1978, the Rhode Island General Assembly passed an emergency appropriation to begin cleanup activities at the site. The Rhode Island Department of Environmental Management (RIDEM) retained the services of a consultant to conduct a hydrogeological assessment of groundwater contamination, assess the extent of wastes buried onsite and develop remedial options for resolution of the problem (Phase 1).

The remedial action options evaluated included:

- Encapsulation Of The Site**—This option considered the placement of an impermeable cover over and wall around the site to bedrock. It was rejected for the reasons that: (1) a significant sources of chemicals would remain in a liquid state as they were contained in deteriorating barrels, (2) the bedrock depth varied between 25 and 35 ft which would be costly insofar as liner placement was concerned, and (3) the bedrock beneath the site is highly fractured, i.e., too permeable for a secure bases.

- Interceptor Trenches**—This option considered the placement of trenches down gradient from groundwater and leachate flow. It was rejected for the same reasons, i.e., deep bedrock, irregular bedrock surface and fractured bedrock.

- No Action**—This alternative was examined since a swamp directly northwest of the site was found to contain significant quantities of leachate and acted as a “filter” or point of volatilization of many organics. It was rejected as the swamp could not be proven to be an adequate treatment mechanism for all wastes. Further, no control over this “mechanism” could be exerted since the disposal site itself contains a significant source and quantity of chemical wastes. In a purely social sense, the option of no action was ill-advised and posed significant consequences.

- Drum and Chemical Removal**—This alternative was considered to be the only viable one as it would insure the source of contaminants would be removed. Further dispersion of contaminants in the groundwater could be monitored.

Following receipt of the consultant’s recommendations, it was decided to excavate and dispose of all barrelled wastes and contaminated soil. In the spring of 1980, the RIDEM authorized excavation of the contents of the northeast trench, which was thought to be one of the smaller trenches (Fig. 2).

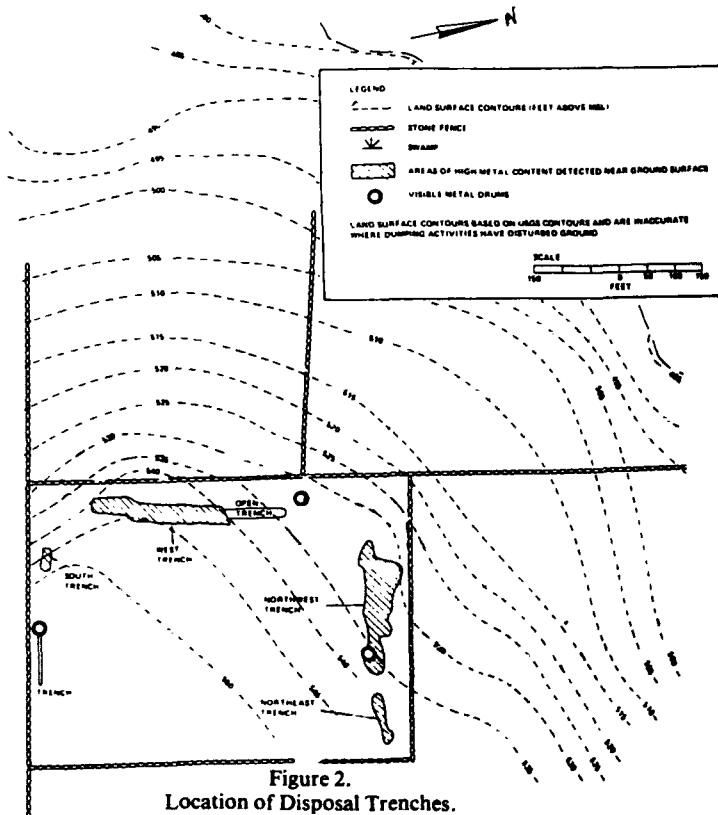


Figure 2.  
Location of Disposal Trenches.

Ground penetrating radar and metal detection surveys had been utilized to determine the extent of the trenches.<sup>1</sup> Unfortunately, these techniques could not predict either density of barrels or depth of the trench. When the excavation was completed, the depth from grade was 35 ft and the trench contained 2,300 barrels of wastes as compared to an estimate of 270.

It appeared from the condition of the barrels that this had been one of the oldest trenches since most barrels were leaking as they were removed. Many barrels in the upper layers had been crushed, generating large pools of leachate.

Several important lessons were learned from this first excavation:

- Barrels were allowed to leak during removal causing additional contamination of the soil. This soil which is contaminated with PCB<sup>2</sup> still poses a significant disposal problem.
- The State let a lump sum agreement contract for a specific number of barrels thought to be contained in the trench. When it was discovered that the amount of waste far exceeded the forecast, delays were encountered until additional funding could be procured. The lump sum agreement form was altered to a time and materials format.
- It was decided to combine the contents of many barrels of similar flammable wastes in the tanker prior to thorough final analysis. The result was 4,000 gal of wastes contaminated with PCB levels in excess of 1,500 mg/l. This waste was ultimately disposed of in the spring of 1981.

### CLEANUP CONTINUES

Following completion of disposal of the northeast trench wastes in the fall of 1980, RIDEM began planning for excavation of the northwest trench (Fig. 2). It was known from the metal detection survey and ground penetrating radar studies that the trench extended for 250 ft and at its widest was 50 ft. From previous experience in the northeast trench, the revised estimates for barrel content ranged from 8,200 to 22,400.

A Scope Of Work and Request For Proposal for excavation and disposal was distributed in Nov. 1980 (Phase 2). It specifically requested a response to the technical issues of drum removal, encountering leaking barrels, contaminated soil, site layout, personnel required, personnel protection, site decontamination zones and safety requirements.

Further requirements to be addressed included drum staging following subsurface removal, at which time leaking drums would be repackaged and records initiated. Other areas to be addressed were drum waste classification, sample analysis, on-site treatment, disposal, recordkeeping and reporting and surface water infiltration.

All interested bidders were directed to respond not later than mid-Nov. However, in early Dec. the USEPA announced that they had money available to fund the excavation portion of the project if the State would assume responsibility for disposal of the waste.

The State agreed to this option and transferred all bids to USEPA for evaluation. The State examined its bids for disposal capability and selected a contractor to perform disposal activities. USEPA chose another contractor to conduct excavation activity. In early Feb. 1981, USEPA began site preparation by constructing several diked storage and staging areas placed so as to effect an orderly material flow from the trench excavation area to pumping/staging area to final storage prior to disposal (Fig. 3).

USEPA constructed several areas in which a polyethylene liner was placed beneath the soil surface to prevent infiltration of chemical wastes from leaking or spilled drums. By the end of Feb., project mobilization was begun.

However, USEPA advised the State in mid-March that anticipated funding was not available and it would have to terminate its contract. The State decided to assume the excavation portion and dispose of as much waste as possible within its own funding constraints. RIDEM began preparation for the excavation requirements and mobilized all remaining equipment necessary on site. In

mid-Apr. actual barrel removal began.

The excavation of barrels from the northwest trench proceeded until the end of June, 1981 by which time 4,400 barrels of wastes had been removed and stored on site. At that point over \$800,000 had been expended, necessitating a curtailment in disposal options.

USEPA obtained emergency funding of \$250,000 to dispose of the hazardous liquid wastes and 2,600 barrels of solids material. By Nov. 1981 all barrels of liquid wastes had been disposed of with available funds.

### CLEANUP—PHASE 3

Throughout the summer and fall of 1981, RIDEM negotiated the complex requirements of a cooperative agreement with USEPA to obtain Superfund monies to continue the cleanup effort. Recognizing the long lead time required for funds to be awarded, RIDEM developed the scope of work and request for proposal (RFP) in the fall of 1981. The RFP was distributed to prospective bidders in early Dec. 1981 and a bidders conference followed to answer technical questions.

The Scope of Work and Request for Proposal was similar to that issued for the 1981 work, and addressed the same issues: regarding site preparation, layout, safety and work effort.

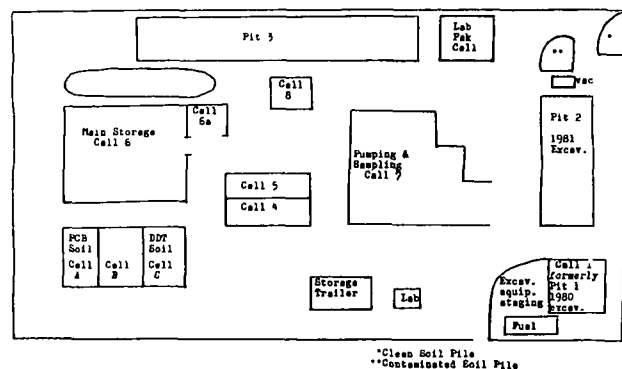


Figure 3.  
Operational Layout of Northwest Trench Excavation.

To enable quicker turn around time on unknown waste analysis, an on-site laboratory would be required. Additional ground penetrating radar work was required in order to both identify and confirm the south and west trench location as well as to insure that no other trenches or buried barrels were located on the site.

Negotiations between the State and USEPA continued when an acceptable Superfund grant proposal was submitted to USEPA in Dec. 1981. However, despite previous consultants' reports indicating that drum removal was the most viable cost effective technique to use at this site, USEPA required the state to conduct an additional cost effectiveness study. Its intent was to provide information necessary for the development of engineering design and contract documents for the excavation and disposal of hazardous waste buried at the site.

The State retained a consulting firm to provide the study and identify cost centers of the proposed excavation project.

In the meantime, several companies submitted bids for the cleanup of the wastes from the west and south trenches. It was assumed that given the overall size of the trenches as many as 8,500 barrels might be buried in these remaining trenches.

All bids were reviewed for technical approach and analyzed for specific cost requirements: mobilization, administration, site preparation excavation, staging and storage and bulking of wastes, analytical capabilities, transportation and disposal. Interviews with the top three companies were conducted to evaluate key personnel capabilities and responses to technical questions.

Final selection of the contractor was made in Mar. of 1982 and contract negotiations were completed in Apr.

The contractor began its work effort at the end of Apr. and by the end of May, 3,300 drums had been excavated from the site.

This in fact proved to be the extent of buried drums in these remaining trenches. Exploratory excavations, to confirm ground penetrating radar were conducted, but no more drums were encountered.

Throughout June and until mid-July 1982 final analysis, accumulation (bulking) and disposal of the excavated waste material was continued.

### BARREL HANDLING AND ANALYSIS

In both the latter two phases, the procedures for barrel removal and staging were discussed with contractor and subcontractor personnel and thoroughly understood prior to movement. As a barrel was unearthed, it was transferred to a pit staging area and examined for identifying markings or labels. Any barrels containing such markings were held aside as potential evidence drums.

If the barrel was leaking, it was placed in an overpack drum. Along with non-leaking drums, the contents were examined for physical state. Based on this preliminary examination, the barrels were transported to a liquid storage area, solid storage area or sludge storage area.

Leaking drums, which had been placed inside overpacks in the pit area, were retained in overpacks until the contents could be ascertained. The overpack was moved into a storage area. Before sealing the drum, the pumping crew sampled the contents for transfer to the laboratory.

Once analysis was completed, the drum contents were transferred to compatibility chambers. After the contents of the drum were transferred, the empty drum was inspected for residual materials content. If a significant amount of solids remained in the drum, it was transferred to the solids holding area. If not, it was placed in the empty drum pile.

Acid drums were repumped into polyethylene lined drums for storage. A sample of each acid waste was taken by the pumping crew, pH ascertained and transferred to the laboratory.

### Storage

All non-leaking liquid barrels extracted from the trench were directly transferred to the liquid storage area. A three man sampling crew opened each drum, sampled the drum and closed or secured the drum from the weather.

Each drum was sampled with a hollow  $\frac{3}{4}$  in diameter glass tube to allow a composite sample of the barrel. To avoid cross contamination of the samples, a separate tube was used for each barrel.

The characteristics of each sample were noted on a separate card. A number was assigned to each barrel and sample.

As each drum containing solid material was extracted from the trench, it was transferred to a secure solids storage area. Samples were extracted from several drums with a disposable scoop and delivered to the laboratory for analysis.

Non-pumpable liquids or sludges from the repumping area were staged in a sludge holding area when extracted from the trench. A glass tube was used for sampling if possible; a disposable scoop was used in cases of material too viscous for the tubing. Samples were collected, numbered in the same manner as the liquids and held pending collection for analysis.

During the sampling procedure, all wastes (solid, sludge and liquid) were examined and physical characteristics were noted (e.g., odor, fuming, color, etc).

### Laboratory Analysis

Upon delivery of liquid samples to the laboratory, samples were first examined for the previously noted physical characteristics (odor, fuming) to insure the protection of the personnel involved. All liquid and sludge examples were checked for pH. Those with a pH less than 3 were considered to be acid and greater than 12, basic. Following this test, a flammability analysis using a portable flash point tester was conducted. By hazardous waste regulation, if such test shows the material has a flash point of less than 140°F, it is considered to be flammable. Following this test, water reactiv-

ity was examined by dropping a minute quantity of the sample into distilled water.

Specific gravity was examined and samples were isolated into three groups: (1) those with specific gravity less than 0.9, (2) those with specific gravity ranging from 0.9 to 1.1, and (3) those with specific gravity greater than 1.1.

Following the specific gravity analysis, all samples with pH greater than 9 were checked for the presence of cyanide. Acids were examined for reduction/oxidation potential which measures the ability of an acid to be a reducer (water reactive) or an oxidizer (which when mixed with organics could cause an explosion). As an example, perchloric acid, a strong oxidizing acid, if mixed with grease or oil forms an explosive mixture. Physical characteristics such as fuming or sublimation were noted on the work sheets for those samples.

Upon receipt of solids samples in the field laboratory, samples were examined for extraordinary physical characteristics, e.g., fuming, odor, etc. Following this, distilled water was utilized to dissolve the solid, if possible, and pH was checked. Obviously, if water reactivity was a problem, it was noted in this phase. A portion of the mixture was then examined for cyanide and flammability/combustibility capability.

Based upon the analysis for both solids and liquids, drums were segregated into preliminary compatible groups or transferred to the compatibility chambers (e.g., flammables, acid, caustic, etc.). This minimized redundant drum movement until disposal was imminent.

### Disposal Analysis

Once the preliminary laboratory investigation was completed, samples of compatible wastes were combined in the laboratory to provide for disposal analysis. It was the intention to bulk as many compatible liquids as possible for disposal purposes to enable the most cost-effective means of transportation and disposal.

Once a significant group of compatible samples was developed (representing 80 to 100 barrels), a PCB analysis was conducted on subgroups (generally five drums). This proved to be the most time consuming, costly, but necessary analytical task.

PCB contamination poses difficult and expensive disposal options whenever concentrations exceed 50 mg/l. When a five barrel composite showed significant PCB contamination (>50mg/l), each uncombined sample would be examined individually for contamination. As can be imagined, time was a time consuming task which posed significant problems in turnaround time for composite analyses.

However, once a compatible group of samples had all PCB barrels identified and removed from the composite, a final disposal analysis on the remaining barrels was conducted. Combined with all preliminary tests, the disposal analysis consisted of those tests shown in Table 1. In comparing the analytical requirements of a variety of disposal facilities, these tests (Table 1) represent the analyses necessary prior to acceptance of unknown materials for disposal.

### AIR/SAFETY HAZARD MONITORING

As a result of improper storage, an unauthorized waste disposal facility can be a source of significant odors. In the Picillo case, an ongoing air pollution incident was created as a result of barrel excavation. Leaking or open barrels, pooled leachate, pumping and transfer operations and the storage of wastes awaiting disposal all contribute to the creation of objectionable odors.

The generation of odors creates problems from both a worker and community standpoint. While worker exposure was limited as far as possible with protective/respiratory equipment, community complaints occurred throughout the excavation and disposal operations.

### Monitoring Program

During Phase II an on-site pollutant monitoring program was designed and implemented to provide an assessment of the health

**Table 1.**  
**Analytical Requirements For Disposal.**

1. Flammability
2. pH
3. Specific gravity
4. PCB analysis
5. Thermal content (BTU/16)
6. Physical state at 70°F
7. Phases (Layering in liquids)
8. Solids (%)
9. Hydrocarbon composition
10. Pesticide analysis
11. Sulfur content
12. Phenols
13. Oil and grease (%)
14. Water (%)
15. Viscosity
16. Organochlorine percentage
17. Metals analysis
  - a. Liquids were analyzed for soluble metals.
  - b. Solids were extracted according to the EPA Toxicant Extraction Procedure (24 hr) which shows leachable metals.
  - c. Both liquid and solids were checked for concentrations of the following metals:
 

Arsenic	Mercury
Barium	Nickel
Cadmium	Selenium
Chromium	Silver
Copper	Zinc
Lead	
18. Both free and total cyanide content were checked.
19. Solids were checked for solubility in water, sulfuric acid and dimethyl sulfoxide.

hazards to personnel participating in the cleanup operations.<sup>2,3</sup> Its purpose was to provide an assurance that personnel protection and fire and/or explosion protection were sufficient and that the "clean" areas on site were indeed "clean."

The focus of this program was on-site operations. First, higher concentrations of contaminants would be encountered which would pose a greater threat as well as facilitating more reliable measurements. Second, the logistics of on-site sampling were easier to consider with respect to placement of monitors and the effects of local meteorology and topography on air contaminant movement.

The monitoring program was designed in three phases to provide:

- Identification of the chemical hazards over a range of conditions representative of site operations
- Assessment of the site operations, layout and personnel protection practices to define hazard levels and specific needs for continuing pollutant monitoring
- A continuing pollutant monitoring program focusing on personnel hazards

Initially a three day monitoring program was conducted in which critical operating personnel utilizing personal monitors and several fixed locations were examined. Samples from these personnel and area monitors were analyzed to identify and quantify exposures.

Once identification of all exposure components was made, air sampling using portable sample pumps and adsorbent composite cartridges was performed. Thirty-two highly volatile contaminants were identified. Of these, 13 chemicals were considered to have been present in significant quantities at one or more locations on site. The maximum concentration of any of these contaminants never exceeded 8% of the Threshold Limit Value (TLV).

The number and variety of volatile, flammable and/or explosive industrial solvents and petroleum products identified by the analyses underscored concern for the danger of fire or explosion. Although the concentrations detected did not warrant great concern,

several factors suggested that continuous explosion monitoring was necessary:

- Ignition sources are necessarily present during site excavation operations (metal grapplers scraping drum surface can create sparks)
- Depth of trench, combined with calm winds, and pools of volatile, flammable liquids could possibly result in conditions conducive to ignition

The program concluded that, in terms of individual TLVs, there was no significant risk to human health in the operational zones for personnel adhering to the required safety precautions. The concern that non-protected personnel outside the work area in the "clean" zones would be exposed to excessive levels was not supported since measurements of contaminants in the decontamination and clean zones indicated that in no instance were TLVs approached.

Nevertheless, odor complaints from area residents increased throughout the excavation phase and into the summer months. Presumably the complaints were based upon increasing quantities of exposed chemicals which tended to volatilize more readily in hot weather.

### Phase III—Air Monitoring

It was determined from the results of the personnel on site monitoring effort conducted in Phase II to expand the effort in Phase III to be as representative of on site ambient conditions as possible.

In Phase III, the excavation contractor assumed responsibilities for on-site monitoring to determine safe working conditions and whether adequate respiration protection was being maintained.

An effort was made to quantify population exposures by positioning an air monitoring station near private residences. Air sampling for this effort was tailored to meet requirements for sampling three classes of problem compounds and elements:

- Volatile organic compounds (VOCs)
- Semi-volatile organic compounds (primarily pesticides and PCBs)
- Metals (including complexed mercury)

To accomplish this, three media were used to collect the compounds or elements of interest:

- Glass tubes packed with Tenax-GC sorbent were used to collect vapor-phase VOCs.
- Hi-Vol samplers were set up with particulate filters to capture metals and PCBs and pesticides associated with particulates.
- Backing up the particulate filters in the throat of the Hi-Vol were two polyurethane foam (PUF) plugs used to collect vapor phase pesticides and PCBs.

Fig. 4 is a map of the area showing locations of the seven semi-permanent sites. Stations Nos. 1, 2, 4, and 5 are based around the perimeter of the site, Station No. 3 is the onsite station, Station Nos. 6 and 7 were sited in the predominantly downwind (northerly) area, and Station No. 8 (not shown) was set at one of three locations dependent on the morning wind direction for the sampling date.

During the monitoring the concentrations of metals, PCBs and pesticides did not vary markedly from background. After one month of data collection these samples were discontinued.

### Discussion

The air monitoring programs of Phase II and III provided data for both community exposure and worker safety. While odor complaints persisted throughout the excavation/disposal phases, the rural, remote location of the site provided for dispersion of contaminants.

In no instance did the concentrations of contaminants exceed threshold limit values. However, no synergistic effects of the combined pollutants were examined.

However, the continuous air monitoring data collected was an average of ambient concentrations, and not the maximum exposure levels. It is possible, therefore, that higher levels existed for short periods.

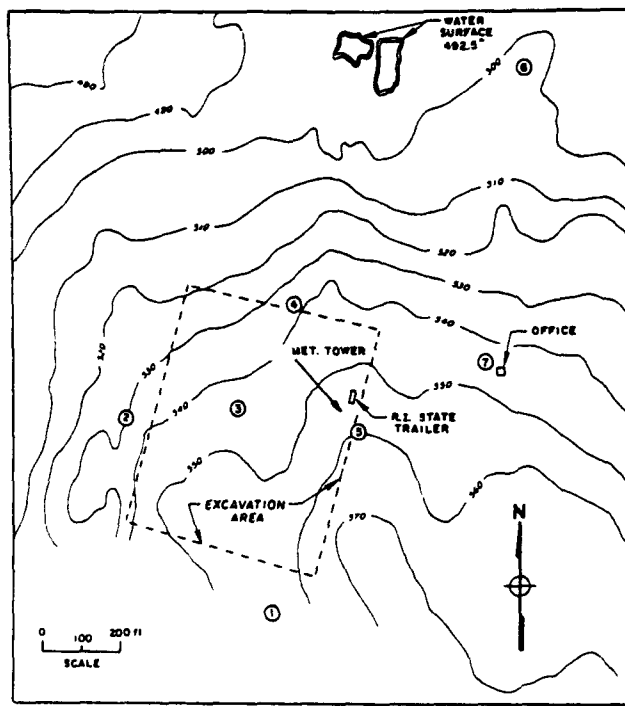


Figure 4.  
Air monitoring locations for the Picillo hazardous  
waste site, Coventry, Rhode Island.

## GROUND AND SURFACE WATER CONTAMINATION

Since site abatement efforts began in 1978, monitoring of both surface and groundwater has taken place. As a matter of policy it was determined to remove the source of contamination prior to proceeding to address the water contamination problem. Currently quarterly monitoring is taking place at the well network installed at the site.

It is RIDEM's intent to conduct an engineering feasibility study to determine if groundwater treatment can be successfully and cost effectively applied to the contaminated plume.

## OPERATIONAL PROBLEMS

### Analytical Backlog

In Phase II, one of the most important areas associated with the excavation and disposal of hazardous waste from this site involved the time required to collect, screen and analyze the samples, to allow for the disposal of the hazardous wastes at licensed hazardous waste treatment or disposal facilities. Typically this process took more than two weeks to complete, and backlogs for PCB analysis increased that time up to one month. Various schemes and methods were tried in order to reduce this turnaround time: additional personnel, overtime, various sample compositing schemes and providing the disposal companies with samples for their own analysis.

In Phase III, it was determined that an on-site laboratory would be a requirement for the project. In terms of overall work effort this significantly decreased the time frame between sample collection analysis and disposal.

However, certain requirements should be realized at the outset:

- Laboratory personnel should be familiar with the state's (clients) requirements and be capable of providing analysis which will allow for disposal of the waste. Since the State is the generator of the waste, disposal responsibility falls clearly on its shoulders.
- The sampling analytical requirements should be thoroughly developed prior to bidding the project so the contractors will provide for all the required equipment.

## Funding Logistics

A second problem area experienced by the RIDEM in regard to the effectiveness and timeliness of the cleanup effort at the Picillo site involved funding for the project. Funding has come from four sources to date and the availability of monies to continue the work effort on site had been sporadic until Superfund money was available. This presents obvious planning and scheduling problems in regard to long range plans for a phased removal operation.

Equally important is the question of cost efficiency which is raised when the on-site work cannot continue in a steady uninterrupted manner due to budget cuts and funding uncertainties. Considerable sums of money are required to mobilize a contractor at a remote location such as the Picillo site; earth moving equipment and pumping equipment fixed costs continue whether the equipment is operating or idle. These costs eventually are borne by the RIDEM either directly as downtime or indirectly in increased contractor rates.

## Contractual Agreement

Another concern of the agency/department responsible for the cost effective cleanup of a hazardous waste site relates to contract methods and procedures. As is customary in construction engineering practice, elaborate plans and specifications are produced spelling out in minute detail exactly what is to be accomplished and which standard methods are to be employed. The contractor is given little or no latitude as to construction methods or work schedule. Progress is easily measured and completion of the project is easily verified.

A hazardous waste cleanup project presents a different challenge. Standard methods are not in widespread use and while some standard laboratory procedures and safety standards are in existence, work plans must be developed for each site activity on a case-by-case basis and what hazardous materials are encountered.

Each contractor brings his own perspective and company policy and procedures in regard to working conditions and safety issues. The contractor's on-site work effort can be considered to be more in the realm of professional services as opposed to construction contract services. Thus, contract documents should be developed as a result of requests for proposals rather than bids. This creates basic problems of contract administration and cost control. A more specific scope of work would increase overall project and cost control but reduce flexibility and stifle contractor creativity in developing and implementing improved work methods and procedures.

## Safety

Safety issues are of primary concern as they relate to the excavation, sampling, storage, transportation and ultimate disposal of hazardous waste materials. If an unlimited supply of money were made available, ultimate safety procedures could be instituted. Every drum could be handled remotely by means of mechanical devices and robots. Continuous automated monitoring for explosivity, oxygen content, organic vapor content, and other known contaminants could be performed utilizing remote samplers and gas chromatography. Any automatic alarm system could be utilized and a cessation of the work effort and site evacuation could take place each time an alarm condition arose. But the pace would be agonizingly slow and experience to date has shown that the vast majority of the wastes at the site do not fall into the extremely hazardous categories of explosive, shock sensitive or extremely toxic which would require such careful handling and become excessively costly. The materials found are primarily: highly flammable waste solvents, acids, pesticides and PCBs.

Operating within the confines of a limited budget, safety must be addressed and every reasonable effort must be made to afford safe working conditions. However, in the field of hazardous waste cleanup a risk free environment is not possible. Even if ultimate safety measures were affordable and put into practice, risks would be reduced but not eliminated. The safety related practices and procedures put into effect at the Picillo site included: (1) remote

handling of all drums in the excavation area; (2) constant monitoring of the excavation trench area for explosivity and oxygen content of the work area utilizing various portable meters, including explosimeter, oxygen meter and portable organic vapor analyzer, periodic monitoring of the contaminated zone, decontamination zone, command post and off-site areas for airborne contaminants; and (3) utilization of self contained breathing apparatus for all personnel involved in excavation and material handling. Every person in the work area was equipped with chemically resistant coveralls, rubber gloves and boots, hard hats, goggles or other eye protection as well as a cartridge or canister type filter respirator.

In addition to this, tests have been completed attempting to define the effectiveness of personnel protection using chemical dosimeters which are available to measure exposure to a number of particular chemicals as well as total organic vapor exposure. All personnel were advised to adhere to strict decontamination and were included in a medical monitoring program.

### Contaminated Soil Disposal

An additional problem area involves the sampling logistics and costs associated with the disposal of contaminated soil generated primarily during the excavation of the northeast trench and to a lesser extent the excavation of the northwest, west and south trenches. Continuous leachate pumping unit greatly reduced the amount of soil contaminated during the northwest, west and south trench excavation. Much of the contaminated soil was disposed of during Phase II and III since it was highly contaminated.

Currently RIDEM is attempting to degrade 1700 yd<sup>3</sup> of soil contaminated with phenols. An ongoing landfarm/leachate program utilizing microbiological treatment to degrade the soil is in progress. Results of the program are unavailable to date.

Considerable quantities (approximately 3300 yd<sup>3</sup>) of soil contaminated with organic solvents and PCBs remain on site awaiting final disposition through disposal, on-site fixation or treatment. Estimates for off site transportation and disposal are approximately \$500,000. USEPA is funding a research project which is attempting to destroy the PCB content utilizing sodium polyethylene glycolate.<sup>4</sup>

### Citizen Involvement

Citizen participation, which was originally perceived as a problem, developed into an asset. The involvement of concerned citizens groups in the planning process and the dissemination of information as to the progress toward project goals is an absolute necessity when dealing with the sensitive and often emotional matters associated with hazardous wastes.

An informal community relations plan was developed including local input into the planning process, briefings at citizen group meetings, scheduled weekly access to the site for all interested community and press representatives as well as periodic briefings for local (town) officials and press releases. The concerned citizens group developed into a valuable resource with regard to developing site historical information and providing accurate lists of local affected population in addition to communicating information regarding progress and site conditions to the affected population.

### CONCLUSION

The cleanup of unauthorized hazardous waste sites presents varied operational and environmental problems. In this paper, the authors have attempted to provide insight into the chronology, operational techniques, air monitoring aspects, water monitoring and problem areas associated with the abatement of such a site situated in Rhode Island.

Field and off-site disposal analyses proved to be a problem in terms of turnaround time and procedural techniques. Particular attention must be paid to the analytical requirements so that they:

(1) keep pace with excavation efforts, and (2) provide the required disposal analyses in a timely fashion.

One of the primary operational constraints involves reducing the risk of injury and adverse health effects to personnel working on site and the surrounding population. A key aspect of this risk reduction strategy involved monitoring the atmosphere to assess the degree of hazard in the following areas: explosion, oxygen deficiency and exposure to contaminants. Much of this risk can be reduced by the use of self-contained breathing apparatus. But at some distance away from the contaminated zone, respiratory protection must be removed and the air considered to be clean. Unanswered questions at this point include the possibility of long term effects posed to those workers not utilizing respiratory protection (in the clean zone) as well as the effects on the local population.

Funding of a project of this scope must account for the significant unknown factors associated with hazardous waste cleanup, i.e., What is the amount and type of material to be excavated and disposed of? Every attempt must be made to closely monitor contractual obligations. Thorough negotiations and understanding prior to commencement of a project will reduce problems later on.

No hazardous waste disposal activity can be risk free. Therefore, safety precautions are paramount. Yet budget limitations are real and require consideration of the trade-off between risk immunization and performance efficiencies.

The generation of contaminated soil poses a significant disposal problem. Successful efforts were made to limit this problem in Phase II and III in terms of the smaller amount of generated contaminated soil. However, at some point, a disposal or treatment option must be chosen to deal with this problem.

Finally, and most importantly, all activities should be closely coordinated with any citizens organization or affected group that deals with the issues of hazardous wastes. An informed citizenry can aid procurement of funding and maintain the necessary interest in the issue that influences governmental decisions. Working closely with such organizations promotes cleanup effects, maintains good press relations and may accelerate completion of the job.

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# A COORDINATED CLEANUP OF THE OLD HARDIN COUNTY BRICKYARD, WEST POINT, KENTUCKY

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## INTRODUCTION

During Feb. and Mar. of 1982, a Superfund immediate removal operation occurred at an uncontrolled hazardous waste site at West Point, Kentucky, known as the Old Hardin County Brickyard. The purpose of the authors is to describe in this paper the events and activities of the operation, especially highlighting the coordination among federal, state, and local officials involved in the response.

The authors believe that this response was very successful and efficient, and that it sets a good example of cooperation, coordination, and communications among response personnel. By examining the response operation, we will identify those factors which we believe are keys to a successful and well-coordinated Superfund response action.

## SITE HISTORY AND BACKGROUND

The Brickyard Site is located in northern Hardin County, Kentucky, approximately 0.25 miles from the city limits of West Point, Kentucky (Figs. 1, 2 and 3). The facility was operated since the early 1900s to manufacture bricks; however, operations ceased in the late 1960s.

In Mar. 1977, an illegal chemical waste disposal operation at the Brickyard Site was reported to the Kentucky Department for Environmental Protection (KDEP). Subsequent investigations revealed that approximately 3,000-55-gal drums had been placed at the site by Mr. Donald Distler and Kentucky Liquid Recycling, Inc., who had leased the property from the owner. The wastes were various liquids, sludges, and solids characterized as corrosive, toxic, highly volatile and flammable.

Following initial investigations of the site, the KDEP began enforcement proceedings against the operator, Mr. Distler. On Jan. 19, 1979, Mr. Distler and Kentucky Liquid Recycling, Inc. were issued an order to abate and alleviate by the KDEP. A follow-up order and opinion was issued on May 24, 1979. Personnel from the USEPA, Region IV, visited the site in early 1979 during response operations at the nearby waste site known as the "Valley of the Drums"; however, since Kentucky enforcement activities were underway, USEPA took no further action at the Brickyard.

During Jan. and Feb. 1980, Mr. Distler relocated many of the drums on-site and removed several hundred non-hazardous sludge drums to a nearby landfill. This operation soon ceased, however, and on Apr. 5, 1980, a fire involving approximately ten of the drums occurred at the site. The fire was extinguished by the City of West Point Fire Department.

On June 30, 1980 a Settlement Order between KDEP and Donald Distler was signed. This order set a 150 day period (expiring Nov. 30, 1980) for final disposition of all materials on-site and site clean-up. Mr. Distler took no action, and this 150 day period expired with hazardous conditions remaining at the site.

The State continued to pursue an enforcement solution to clean-up, and on Feb. 24, 1981, KDEP filed a complaint in Franklin County Circuit Court against Donald Distler and Kentucky Liquid

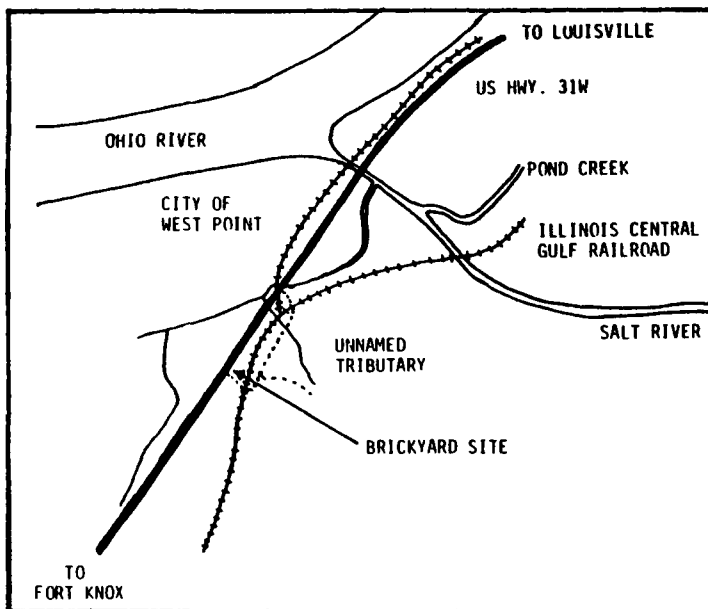


Figure 1.  
Location Map of Brickyard Site, West Point, Ky.

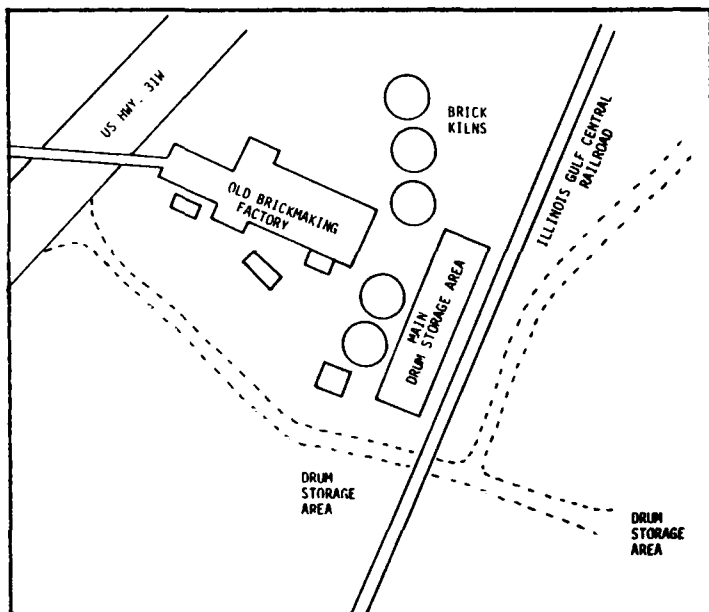


Figure 2.  
Overview of Brickyard Site, West Point, Ky.



Figure 3.  
Old Hardin County Brickyard, West Point, Kentucky

Recycling, Inc. No response or action occurred at the site as a result of the complaint.

As a final enforcement effort, KDEP filed a Motion for Summary Judgement in Franklin Circuit Court on Sept. 24, 1981, in order to bring the case to final resolution. At that time, KDEP expected that the case would be tied up in the courts for an extended period of time. (In fact, the Motion for Summary Judgement has still not been heard as of this writing.)

#### Environmental Health Concerns

In late 1981, with no enforcement solution in sight, conditions at the Brickyard continued to worsen. Many of the over 2,000 drums were leaking due to deterioration and vandalism at the site. The effects of the release of chemicals into the environment was readily apparent in the vicinity of the drums. Spillage had killed grass, trees and birds. In addition, irritating odors were immediately apparent within 0.25 mile of the drums. Material leaking from the drums had entered the ditch adjacent to the railroad tracks and had entered a tributary to the Salt River.

The Illinois Central Gulf railroad tracks run directly through the site. Complaints of dizziness due to odors had been received from railroad personnel when rail cars had been stopped for 15-20 min, while waiting for other trains to pass.

The entire population (2,000) of West Point was within a one-mile radius. A computer air model indicated that a four to six mile radius would have to be evacuated if a fire occurred. Since the drums were located in a valley, the air model predicted the fumes would linger in the area intensifying the problem.

There was also concern that the spillage from the drums had entered the groundwater. The water supply for Fort Knox Military Base came from a groundwater well field located 0.5 mile from the site. Also, the nearby town of West Point used groundwater as the major drinking water supply.

Because of these environmental health concerns, KDEP and EPA agreed to pursue immediate removal action under Superfund.

#### Request for Immediate Removal

On Jan. 4, 1982, USEPA Region IV received the State of Kentucky's written request for an immediate removal action at the "Brickyard". A copy of the letter was delivered to the USEPA attorney assigned to the site. Demand letters were prepared for the four parties that might be held responsible for the clean-up.

The OSC also requested the USEPA Environmental Response Team (ERT) to conduct an air monitoring survey on the site to: (1) provide documentation of air hazards, (2) determine material present on site and concentration of material, (3) establish levels of protection needed to conduct emergency cleanup, and (4) estab-

lish an air monitoring program to be conducted during clean-up activities.

On Jan. 20-21, 1982, the ERT conducted a total vapor/gas air monitoring survey. Based on results of the initial air survey, an air monitoring scheme was developed and the levels of protection proposed for the immediate removal action.

In the meantime, the USEPA On-Scene Coordinator (OSC) prepared the required ten-point document necessary to effectuate an immediate removal action. An estimated cost of \$300,000 was projected for the removal of all liquids, sludges, contaminated soil, and drums at the site.

In response to the USEPA demand letters, the four potential responsible parties decided that they would rather see USEPA do the cleanup. On Feb. 16, 1982, Mr. Distler, the primary responsible party, began serving a two year prison sentence for another illegal hazardous waste incident that occurred in Louisville in 1977.

The request for immediate removal action was submitted to USEPA Headquarters by the OSC. On Feb. 22, 1982, approval to commence Superfund immediate removal action at the Brickyard was received.

#### RESPONSE PLANNING

Upon approval of the immediate removal request, additional response planning commenced. Two important activities that occurred were selection of contractors and community relations.

##### Selection of Contractors

Two main contractors were selected for the removal action. One of the contractors (Resource Recycling Technology) was selected on the basis of analytical support and the capability to dispose of the liquids at the site. The other contractor (CMC, Inc.) was hired to provide heavy equipment for handling of the drums, liquids, and solids. In addition, it was planned for the OSC to arrange the contract for the disposal of any solid hazardous wastes generated at the site. These wastes would be disposed of at an approved hazardous waste facility. Both contractors were signed to "Superfund cleanup contracts" prior to commencement of removal activities on March 1, 1982.

##### Media and Community Relations

The media and community relations operations were coordinated through the KDEP Office of Communications and Community Affairs (OCCA) and USEPA Region IV Superfund Public Relations personnel. Upon approval of Superfund Money, the OCCA was contacted to provide support in the community relations area. OCCA contacted by telephone the Mayor of West Point, the County Judge, and the State Representative to inform them of the upcoming operations. A press conference was scheduled for the morning of the first day of activities at the site, and OCCA made all necessary arrangements, including the appearance of the highest ranking State Environmental official, Secretary Swigart of KDEP. Finally, a press release was prepared for review by USEPA Public Relations at the Regional Response Team meeting prior to the beginning of operations.

#### THE REGIONAL RESPONSE TEAM MEETING

Of all the many factors that contributed to the successful response at the Brickyard Site, perhaps the most important was the Regional Response Team Meeting that occurred on the day before the actual on-site operations began. This meeting brought together for the first time all of the main organizations and personnel to be involved in the response.

The Response Team Meeting was held on the afternoon of Feb. 28, 1982. Present at this meeting were the following personnel and organizations:

- USEPA On-Scene Coordinator (Stroud)
- USEPA Environmental Response Team Member (Gilbert)
- KY Superfund Coordinator (Burrus)
- KY Disaster and Emergency Services Personnel (DES)

- Prime Clean-up Contractor (CMC, Inc.)
- Prime Sampling/Analysis/Lab Contractor (Resource Recycling Technology)
- KY Office of Communications and Community Affairs
- USEPA Superfund Public Relations

The USEPA OSC conducted the meeting. At the start, a brief background of the site was covered and a basic scope of the work to be accomplished was presented. This gave everyone a common base and frame of reference for the site activity. There was also the opportunity for each group involved to get to know others on the team and get a feel for who was going to be on the team and what they would do. This was very important prior to commencement of activities and helped establish a working environment of trust and coordination from the beginning.

After the general introduction at the response team meeting, specific planning occurred on three basic concerns: safety, security, and public relations. The Site Safety Plan was reviewed and further developed. Responsibility for implementation of the Safety Plan was assigned to the USEPA Environmental Response Team Member (Gilbert). Site Security details were also developed and assigned to the KY DES with the responsibility to use local law enforcement personnel. Finally, the draft of the press release was reviewed by all, corrected, and returned to the KY OCCA contact at the meeting for release. When all these items, together with some final details for the first day, were completed, an excellent plan had been developed and shared. This meeting allowed the Regional Response Team to "hit the ground running" when operations commenced on the next morning.

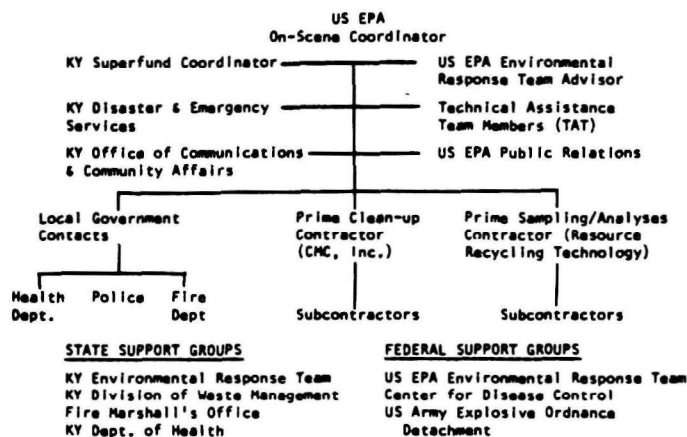


Figure 4.

Response Organization for Old Hardin County Brickyard

## RESPONSE ORGANIZATION

A key factor to a well coordinated Superfund Response is the proper organization and inclusion of the people necessary to do the job (Fig. 4). During the planning phase, the OSC began assembling these necessary individuals and groups. At the Regional Response Team Meeting, the basic organization crystallized so that we were ready to begin the next day. Other people and organizations were utilized during the response, and by having the basic organization established at the Response Team Meeting, these new people were able to quickly assimilate into the appropriate organization position.

One of the more important aspects of this response organization was the good integration of the State and Local personnel into the overall response organization. While USEPA did, of course, maintain the lead for the overall project, the State was fully involved in the response activities and coordination. This State and local involvement, encouraged by USEPA, was an important factor in the success of the response and enhanced effective communications during the response.



Figure 5.

Activities View of Brickyard Entrance



Figure 6.

Drum Grapppler and Compatibility Chamber

## RESPONSE ACTIVITIES

The immediate removal action at the Brickyard began on Mar. 1, 1982, and was completed on Mar. 27, 1982. The following sections describe some of the main activities that occurred during the response.

### Initial On-Site Activities

The contractors arrived at the site on the morning of Mar. 1, 1982, and began staging their equipment and personnel by 7:00 a.m. The hotline was established and security precautions were put into effect. To support field activities, a command post, decontamination trailer, mobile laboratory, and USEPA Region IV's van for air monitoring were positioned according to the plan (Fig. 5). Other support items for field activities included electricity, telephones, copy machine, "port-a-lets", typewriter, and a telecopier.

A press conference was also held at the site on the morning of Mar. 1, 1982. The OSC, Ms. Jackie Swigart, Secretary, Natural Resources and Environmental Protection Cabinet, and West Point Mayor Gene Smith outlined the removal action.

### Personnel Safety

Based on the initial air monitoring survey, personnel working on site were required to wear USEPA's Level C protection which included an approved air purifying mask with an organic vapor cartridge. Tyvek/Saran hooded disposable coveralls were required for heavy equipment operators, monitoring and surveillance activities, and observers. A safety boundary, or "hotline," was established and the Level C protective equipment had to be removed prior to exiting the "hot area".

When sampling of the drums began, Resource Recycling's personnel were using a bung wrench to open drums. The third drum they attempted to sample had a pressure build-up, and the person opening the drum was sprayed with liquid. Fortunately, he was protected by his protective gear and was not hurt. In order to make the drum sampling operation safer, the remaining drums were opened utilizing a punch on the bucket of a backhoe. When punching the drums, the operator of the backhoe was in an enclosed cab with a fresh air supply. No personnel were allowed in



the vicinity of the drums when they were being punched. This procedure worked well and there were no further incidents.

In order to maximize worker safety, a drum grapppler was utilized to relocate the drums. The grapppler provided a safe working environment for the operator (enclosed cab with fresh air), and no personnel were required to handle the drums. The grapppler was also used to empty the drums containing liquid wastes into the compatibility chamber (Fig. 6).

### Sampling Program

The contractor chosen to sample the drums and determine compatibility developed the sampling program for conducting this portion of the activities. The analytical scheme developed by Resource Recycling Technology that was utilized to segregate the drummed material into categories for disposal is shown in Fig. 7.

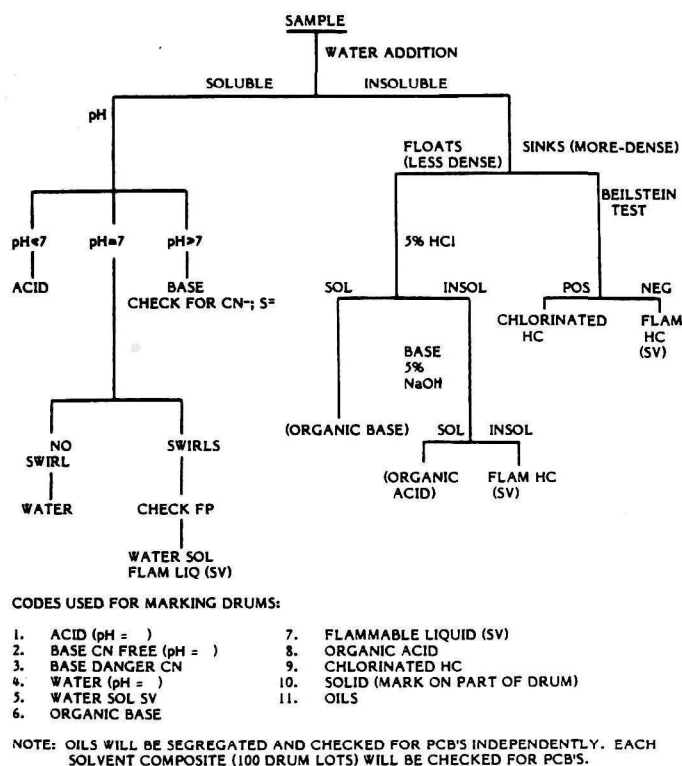


Figure 7.  
Analytical Scheme for Sampling/Categorization

### Air Monitoring

Air monitoring surveys were conducted utilizing the Century Organic Vapor Analyzer (OVA) twice a day in order to determine what impact cleanup operations had on the ambient air conditions. In addition to the gross OVA readings, air samples were collected utilizing personnel sampling pumps and Tenax collection tubes (Fig. 8). The samples were collected over a two to three hour period. The tubes were desorbed and analyzed utilizing the OVA. These samples provided a time weighted average concentration and an estimate of how many compounds were in the air. All air monitoring was conducted to justify the level of protection being worn by on-site personnel or to indicate that a change in the level of protection was warranted.

The air sampling indicated that during the time that liquids were being poured into the compatibility chamber and the solids were being dumped that the concentration of the organics in the air went up substantially in the areas of dumping. However, the ambient conditions on-site were not affected by the dumping operations.



Figure 8.  
Collection of Air Samples

### Disposal Options

The most cost-effective and environmentally sound method of disposal was to be used for each type of waste that was generated at the site. Once the drums had been staged into solids and liquids, they were sampled and marked according to the category code and description (Fig. 7). This eventually led to eight different disposal options.

Everything that was considered contaminated water was transported to the analytical contractor's waste water treatment plant for disposal. Liquids that were classified reclaimable solvents were dumped into the compatibility chamber provided by the contractor, and a suitable reclaimor subcontracted to remove these liquids. Other organic liquids of no economic use were incinerated at an approved facility within the State of Kentucky. Empty drums and contaminated soil on the site that were deemed nonhazardous by the State were disposed at a local landfill.

The remaining sludge and solids were stabilized with fly ash and sand to produce a "mixed solids" waste pile, and these mixed solids were disposed at an approved hazardous waste disposal facility. Two drums of lab packs and three drums of oil containing PCB's were redrums on-site and properly disposed by a subcontractor at approved hazardous waste facilities.

### COMMUNITY RELATIONS DURING RESPONSE

The community relations were excellent during the response. The Mayor and Police Chief of West Point were kept informed frequently of the progress being made. Since the police were providing nightly security at the site, there was involvement of the local community in site activities which helped promote good community relations.

During the second week of activities, a new press release was developed by KY OCCA, checked with on-scene personnel, and issued as a status report to the press. Additional media inquiries were answered promptly and effectively by the OSC.

At the end of the response, the Mayor of West Point was so pleased with the cleanup, that he contacted several media and press personnel and issued very positive statements about the operations. This provided a good, positive final touch to the community relations aspects of the response at the Brickyard.

### PROBLEMS ENCOUNTERED

Several problems were encountered during the response. Due to continuing effective coordination among members of the Response Team, all these problems were successfully resolved. The problems are described in the following sections.

### Utilities

In order to operate the mobile laboratory and the command post, temporary power service was required. The local power company was contacted, but they were not accustomed to dealing with emergency hook-ups, and the service was delayed. The Kentucky Department of Emergency Services (DES) contacted the power company and asked them to expedite the power hook-up due to the emergency. Once DES contacted the power company, the power was installed the following day.

### Air Episode

During the liquids dumping operation, foggy conditions caused a heavy vapor build-up on the evening of Mar. 11, 1982. This condition began after the close of business that day. Around 10:00 p.m. the OSC received a call from the West Point Police reporting that many town residents were complaining about the vapors emitting from the Brickyard.

Two Response Team members returned to the site to conduct an air survey. By the time they arrived, the police chief reported that the odors were not as bad as before. The air surveyed indicated higher than normal organic concentrations around the compatibility chamber, the sludge pile, and an area of empty drums. To reduce the vapors emitting from these areas, they were covered with plastic.

Since the Police Chief was aware of the activities being conducted at the "Brickyard," he was ready to handle problems like this. When people started complaining, he advised them to stay indoors and shut all windows. He also contacted the OSC to determine the extent of the problem. This cooperation was a result of the coordinated planning process prior to work being initiated.

### Explosive and Radioactive Materials

When the contractors encountered drums that were marked explosive and radioactive, experts were called to help assist defining the problems. An Explosive Ordnance Disposal Team (EOD) from the U.S. Army at Fort Knox was brought in to examine the material marked explosive. After examining the material the EOD determined that the material did not represent an explosion problem and the material was disposed of as sludge.

Two drums were encountered that had markings indicating the possibility of radioactive material. A complete radioactive survey was conducted over the site by the Kentucky Department of Health Radiological Survey Team and the Jefferson County Department of Health. Neither group found any radioactive material.

### Disposal

The major problem encountered during the entire response operation concerned the disposal of the mixed solids and sludge generated at the site. The planned strategy on handling solids and sludge was to composite it in a large pile on the concrete pad at the site and mix with fly ash (Fig. 9). Because of the nature of the wastes at the site, the plans were to declare this waste as hazardous and ship it in bulk to a hazardous secure landfill. Several contacts were made and finally one disposal contractor appeared to be the most cost effective while providing the quickest response; therefore, arrangements were made to begin shipment of this mixed solid waste, totaling about 400 tons, to the facility.

Major problems always seem to happen at 4:30 p.m. on Fridays, and that is exactly when this one developed, at the end of the second week of operation! That is when word was received that the State Agency responsible for regulating this out-of-state facility had questions about accepting this waste and needed more information. Because of the time of day, clarification of the problem could not be obtained; it was Monday before the responsible State Agency official could be contacted.

During that weekend, USEPA began examining other disposal options, including disposal in Kentucky by classifying the waste as non-hazardous. Testing of samples from the sludge pile had indeed shown that the waste was not hazardous by any of the four



Figure 9.  
Mixed Solids Pile

RCRA characteristics (i.e., ignitability, corrosivity, reactivity, or EP toxicity) and did not contain PCBs. Kentucky State personnel, on the other hand, held the opinion that the waste should be declared hazardous under the mixture rule since 12 compounds from those RCRA listed wastes numbers F001, F002, F003 and F005 were detected at significant levels in the samples of the mixed solids. Thus, on-site personnel reached an impasse as to the hazardous/non-hazardous waste issue on the mixed solids, and it was necessary to get further clarification from EPA personnel.

At USEPA's request, the Kentucky coordinator submitted a letter on the following Tuesday giving justification for classifying the waste as hazardous. This letter was forwarded immediately to USEPA Region IV RCRA personnel and later checked out with USEPA Headquarters in Washington, D.C.

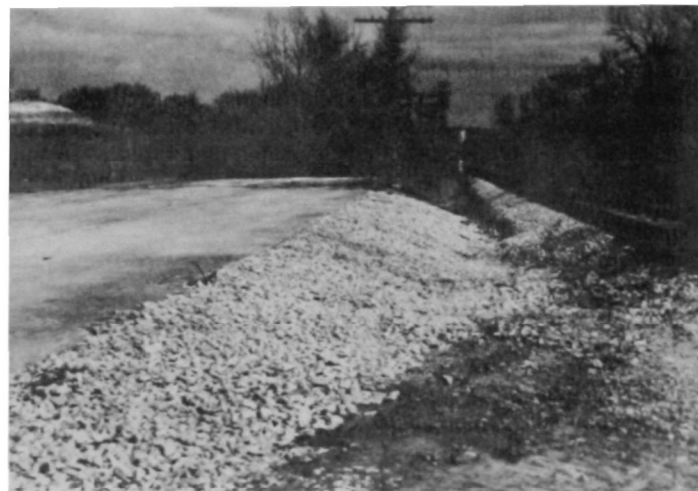


Figure 10.  
Response Completed at Drum Storage Area

In the meantime, all other operations had been completed except the mixed solids disposal, so operations at the site were completed and all personnel left the site. The prime cleanup contractor was on stand-by as a decision was awaited on the disposal of the mixed solids.

Two days later, USEPA Region IV RCRA personnel ruled that the waste would be classified as hazardous since it contained sludge that had been in contact with hazardous liquids that had been shipped under USEPA hazard numbers F003-F005; therefore, because of the mixture rule, the entire 400 tons of mixed solids was classified as a hazardous waste. This ruling hastened the negotiations with the potential disposal contractor and the other State Agency. An additional clarification letter on the waste was sent by the Kentucky Coordinator to the other State Agency requesting disposal as a hazardous waste.

As several days passed without hearing further word from the other State Agency, a new disposal alternative was presented by another disposal contractor for a facility in a different state. On further checking by the USEPA OSC, this new alternative appeared more cost-effective and offered rapid response; therefore, in conjunction with Kentucky personnel, the decision was made to go with the new disposal option. A contract was signed the following day, and removal operations for the mixed solids began. In three days, the operation and total response was finished (Fig. 10).

Two important lessons can be learned from this problem and its solution. First, even though a major difference of opinion occurred between on-scene USEPA and State personnel over whether the waste was hazardous, coordination had been developed successfully enough by that time so that the problem was effectively resolved and completed. The second lesson is that it is never too late to implement a better solution!

## REMEDIAL INVESTIGATION

With the completion of the immediate removal response, attention was focused on potential remedial action at the Brickyard Site. There were several local reports of buried drums of waste at or near the site; however, follow-up magnetometer inspections and interviews have shown no presence of buried wastes. The primary remedial concern, therefore, has been potential groundwater contamination.

During Mar. 22-26, 1982, The Field Investigation Team (FIT) of USEPA Region IV conducted resistivity surveys of the Brickyard Site in order to approximate the horizontal and vertical extent of any groundwater contamination.<sup>1</sup> Results of this testing indicate that there is some contamination of groundwater below the site, but that the contaminated plume has not moved off-site.

As a result of this initial testing, a program has been initiated to install 10 groundwater monitoring wells at the site to better define

the groundwater conditions. This work is in progress and should be completed in the Spring, 1983.

## CONCLUSIONS

At the completion of this response, those who had been associated with it realized that it was one of the most effective they had seen. It was natural, then, to ask the question—"Why did this response go so well?" The general answer is that this response was coordinated well. In other words, people, equipment, and activities were managed in such a way that they were effectively integrated to get the desired results.

Some of the key factors that we believe led to this successful and well-coordinated Superfund Response are the following:

- Effective communications and working relationships between the primary USEPA person (OSC) and the primary state person (Superfund Coordinator) prior to and during the response
- Good response planning prior to the response, especially in the areas of contractor selection and community relations
- The Regional Response Team meetings
- The integration of the State and Local team members into active involvement and coordination of the response
- Utilization of proper equipment and techniques for handling and disposing of hazardous wastes

These factors, together with a spirit of cooperation and commitment, led to the successful cleanup of the Brickyard.

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# SILRESIM: A HAZARDOUS WASTE CASE STUDY

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## INTRODUCTION

The Silresim Chemical Corporation's chemical waste reclamation facility in Lowell, Massachusetts was abandoned in Jan. 1978; approximately one million gallons of hazardous material were left behind in drum and bulk storage. The five-acre reclamation facility, established in 1971, had been accepting approximately three million gallons of oil wastes, solvents, chemical process wastes, plating wastes, heavy metal containing sludges and other materials yearly. The facility was designed and licensed for the ultimate disposal or recycle of these chemical wastes. Site investigations conducted in 1977 revealed license violations; the license was revoked when Silresim declared bankruptcy later that year.<sup>1</sup>

The Commonwealth of Massachusetts, Department of Environmental Quality Engineering (DEQE) initiated efforts to clean up the site and by Sept. 1981 all stored materials had been removed. In Oct. 1981, Perkins Jordan began a two-part study to characterize the nature and extent of soils and groundwater contamination caused by the hazardous materials and to recommend actions to remedy the contamination problem.

## HYDROGEOLOGIC INVESTIGATION

The site is located at the edge of an industrial area south of Lowell's central business district (Fig. 1). The Lowell Connector, Boston and Maine Railroad tracks, River Meadow Brook, and several residential areas are all close to the site. To assess the extent of surface and subsurface contamination, investigations of the surficial soil, surface water, subsurface soil, and groundwater were conducted at both on-site and off-site locations.

Twelve backhoe dug test pits—eight located in on-site, high-use areas and four in adjacent surface runoff areas—were sampled for shallow soils analysis (Fig. 2). Five borings were installed for deep soils exploration; one was in the center of the site and four at various locations around the perimeter of the site (Fig. 2).

A deep monitoring well was installed at each boring location and shallow wells were positioned at four borings. The monitoring wells served two purposes. The physical characteristics of the groundwater regimes were determined by means of *in-situ* permeability measurements and groundwater level measurements. The level and extent of chemical contamination in groundwater was determined by means of gas chromatography/mass spectroscopy (GC/MS) analyses of organic constituents.

Surficial soil samples were collected in or near the closer residential areas to assess the extent of airborne contaminant migration. Surface and groundwater samples were obtained from surrounding areas including the River Meadow Brook. A subsurface metal detector survey was also performed at the site to identify any underground storage tanks.

## RESULTS

The visual effects of contaminants in surface runoff were evident at the site itself: vegetation was dead or nonexistent and the soil was discolored and emitted an odor. Laboratory analyses of the surface soil, shallow subsurface soil, and groundwater samples collected during the study indicated that approximately 6,000 gal of volatile organic compounds were in the soil and groundwater beneath the Silresim site.

The zone of maximum soil contamination (1,000,000 ppb of volatile organic substances) is limited to on-site high use areas in the central portion of the site and along the northern perimeter. Maximum soils contamination levels were found at 10 ft or less below the surface (Fig. 3). The zone of maximum groundwater contamination levels occurs at depths of 20 ft or less (Fig. 4). The rate of horizontal groundwater flow beneath the Silresim site is approximately 16 ft/yr. The direction of groundwater flow is toward the north.

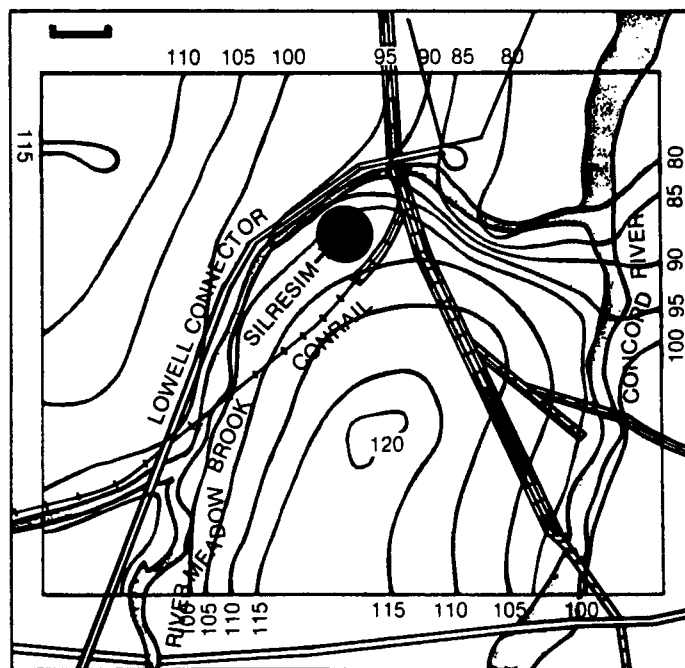


Figure 1.

The five-acre Silresim Site is located approximately 500 ft east of River Meadow Brook and the Lowell Connector in Lowell, Massachusetts. The contours represent approximate groundwater elevations in the vicinity of the site. Scale bar is approximately 1000 ft.





Figure 2.

The heavy dashed line indicates the borders of the five-acre Silresim Site. Explorations are indicated by squares (test pits) and circles (borings with monitoring wells). Contours represent the distribution of volatile organic substances in surface soils as determined by a photoionization meter survey. The 50 ft sampling grid is superimposed on the figure.

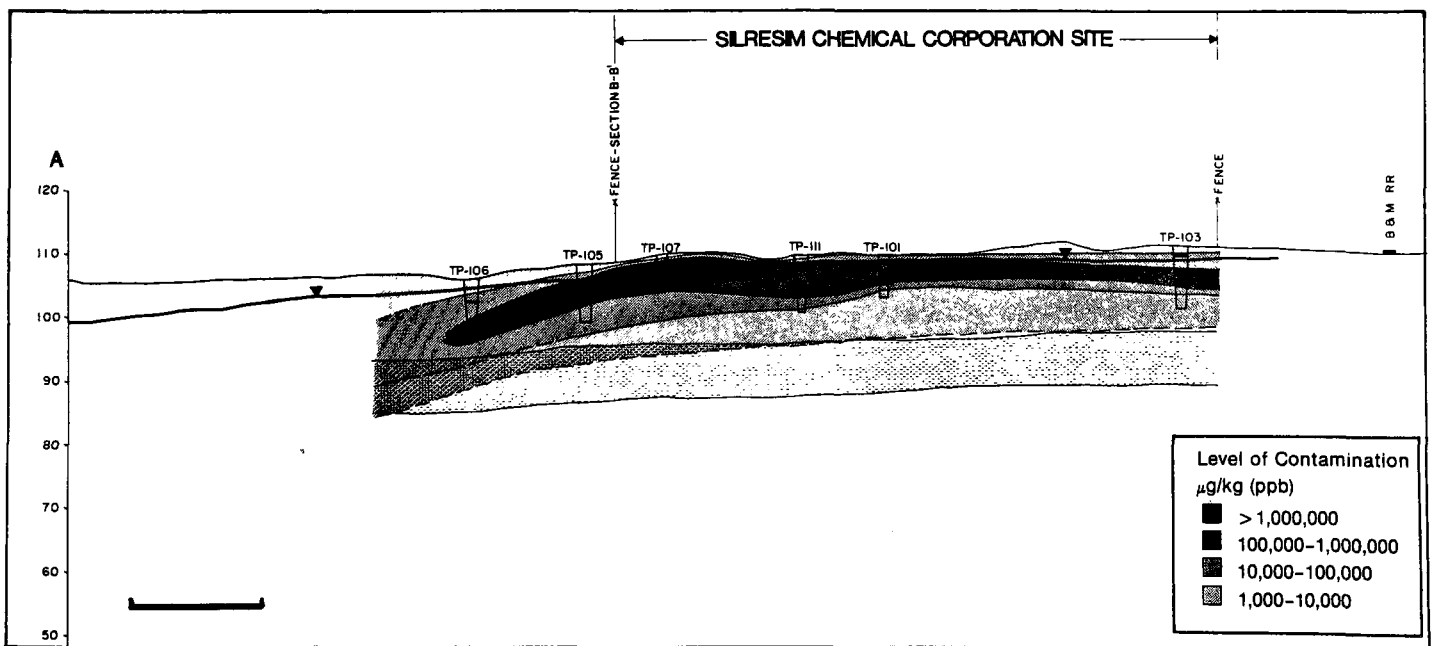


Figure 3.

Contours represent the vertical distribution of volatile organic materials in soils at the Silresim Site. A 10 ft thick silt stratum is located at a depth of 15 ft. Scale bar is 100 ft.

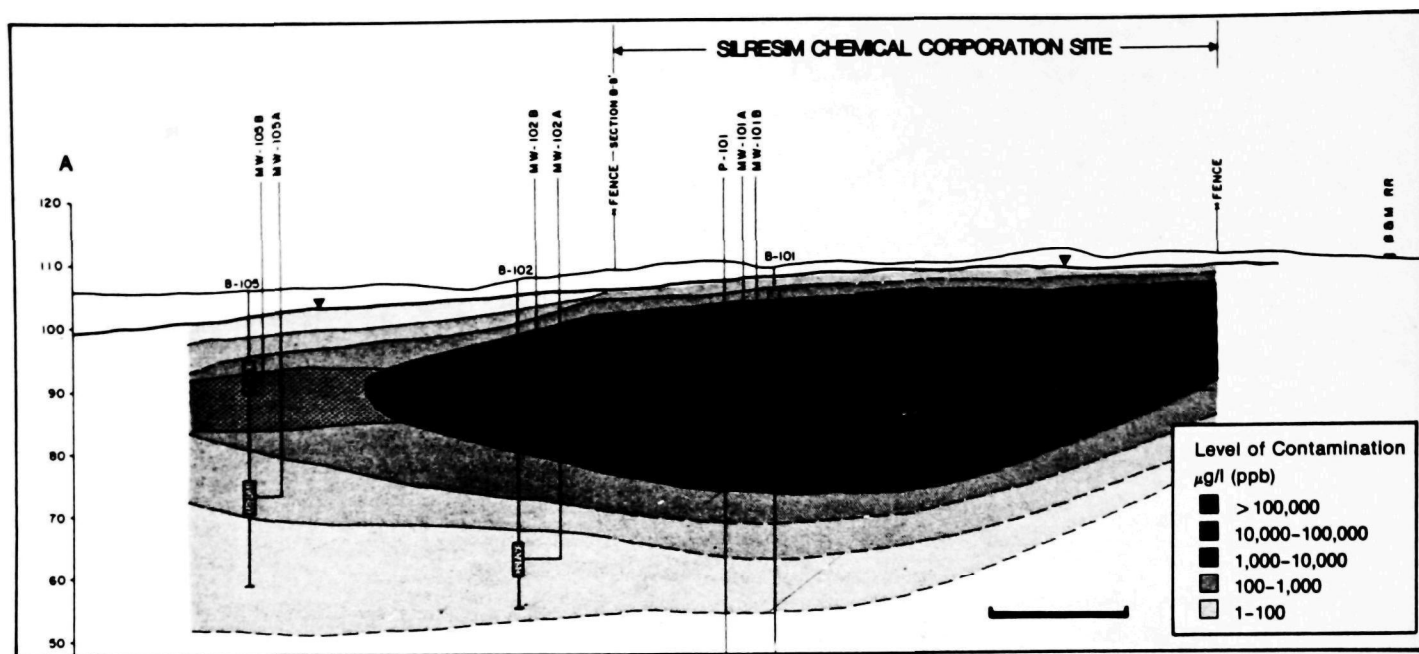


Figure 4.

Contours represent the vertical distribution of volatile organic materials in groundwater at the Silresim Site. Scale bar is 100 ft.

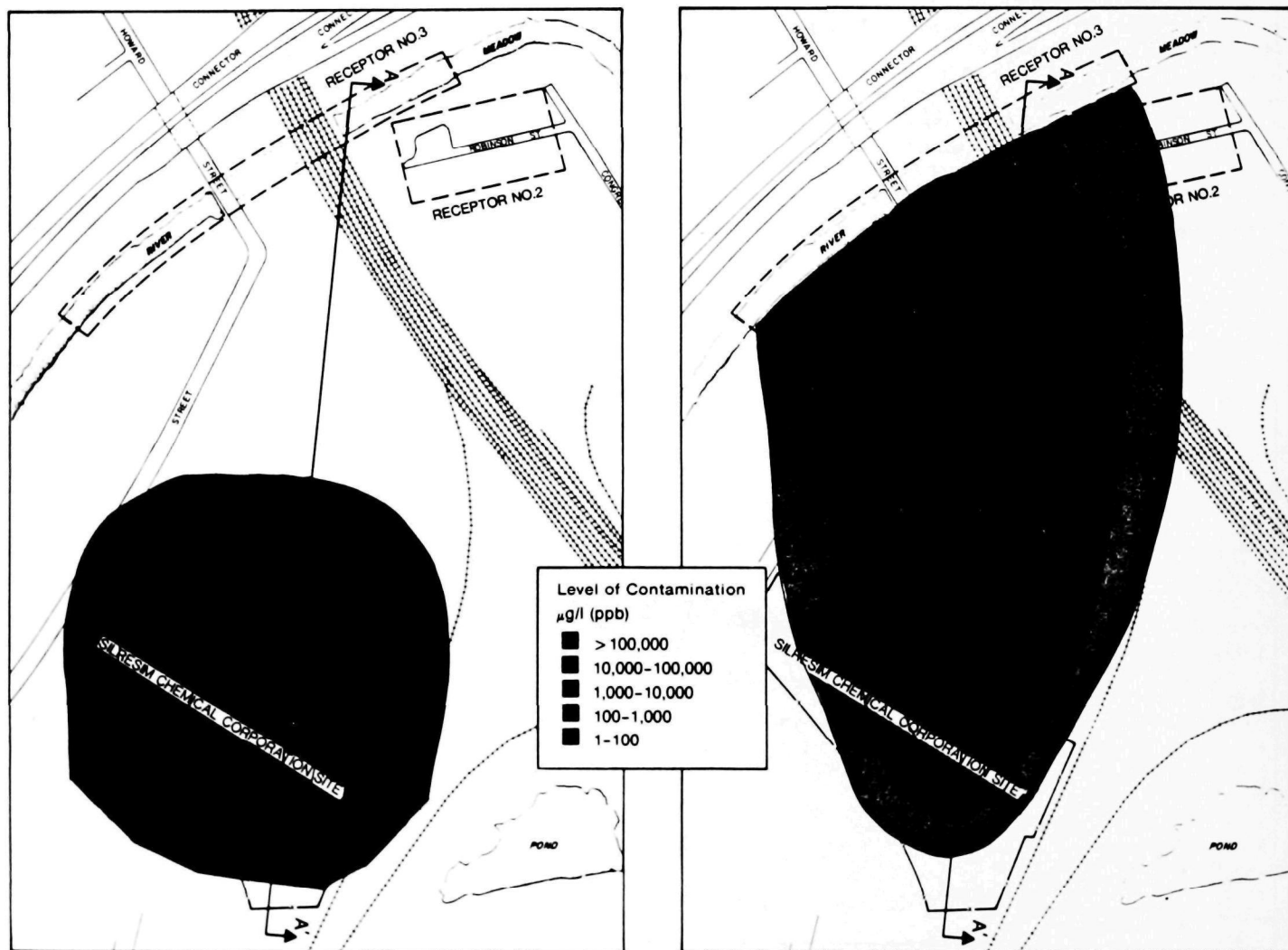


Figure 5.

The contaminant plume that presently exists in groundwater at the site (left) was determined by means of the hydrogeologic study. The migration of the contaminant plume in groundwater as a function of time (right) was determined by means of predictive modeling of the groundwater regime. The illustration on the right depicts the estimated extent of the plume in the year 2006 if no remedial action is taken. Three potential receptors are identified in the figure.

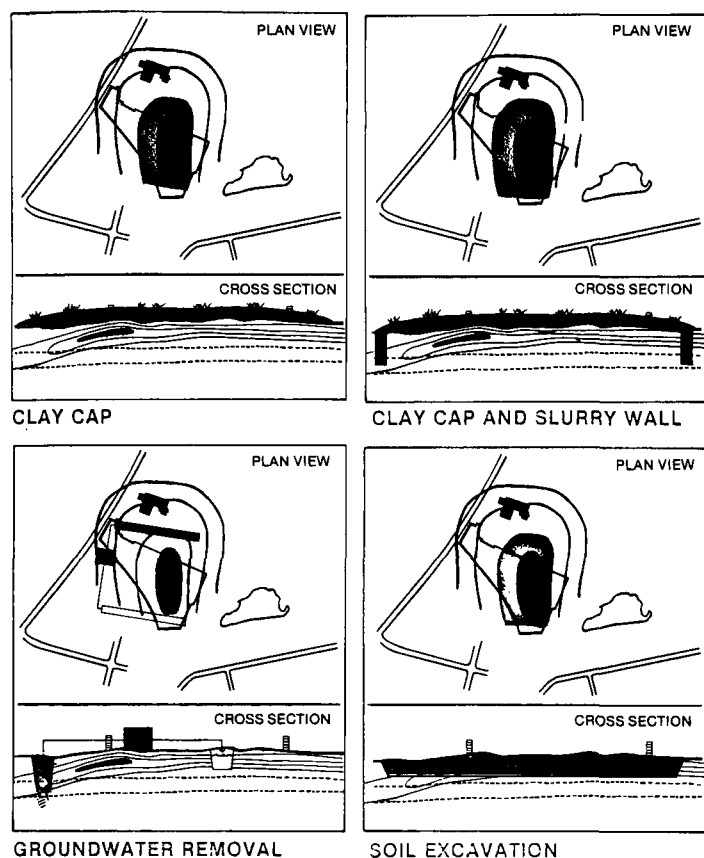


Figure 6.

Each of the four remedial actions is shown at 70% level of implementation (i.e., 70% of subsurface contaminants are contained or removed). Cross-section views depict levels of contamination in soils as depicted in Fig. 3. Contours in plan view represent contamination levels in soils that exist approximately 5 ft below the surface.

The horizontal contamination plots for soils and groundwater indicate that subsurface contamination exists beyond the boundaries of the site to the north, in the direction of surface runoff and groundwater flow. Groundwater samples obtained from up-gradient monitoring wells located south of the site show little or no evidence of contamination.

Most of the chemical contamination occurs in the shallow soils and groundwater: about 8% of the waste volume is dissolved in the groundwater while 92% is held in the soils. Contamination levels in soil and groundwater decrease as distance from the site increases.

Dilution of chemical contaminants in groundwater occurs by means of dispersion through groundwater flow and molecular diffusion. Unless the contaminants are removed from the subsurface, or their movement is inhibited, they will continue to migrate away from the site, either in the form of air emissions from the soil or through groundwater flow.

## LONG-TERM EFFECTS AND REMEDIAL ACTION

How will contamination affect the areas surrounding the site 10, 15, or 50 years from now? The second phase of Perkins Jordan's study was directed toward determining these long term effects and recommending methods of inhibiting contaminant migration.

Mathematical models were used to predict future migration through air emissions and groundwater flow and discharge (Fig. 5).<sup>2,3,4</sup> The models were applied to three potential receptors of the contaminants: 1) the Lowell Iron and Steel plant, the closest occupied structure to the site in the path of groundwater flow, 2) the Robinson Street area, the only residential area within the anticipated bounds of the contaminated groundwater flow, and 3) the River Meadow Brook, which is the ultimate discharge area for groundwater flow from the Silresim site.

Five remedial conditions were considered: 1) "no action", 2) clay capping, 3) clay cap and slurry wall, 4) groundwater removal and treatment, and 5) soil excavation and removal (Fig. 6). The groundwater and air transport models were used to evaluate each alternative remedial action in terms of the contamination levels that could be expected to reach the three receptors over the next century.

If no corrective action is taken at the site, the first evidence of contaminated groundwater (1 ug/ml) is estimated to reach the three receptors in five, 20, and 27 years, respectively. Maximum air contaminant levels (8 ug/ml) are estimated to arrive in 25, 75, and 90 years. These levels neither exceed OSHA air quality standards nor USEPA drinking water criteria. In addition, there are no known users of the groundwater along the expected pathway of the contamination plume. Based on these factors, no remedial action is considered to be warranted to specifically reduce contamination via groundwater flow.

However, air emissions emanating from the contaminated soils and groundwater are a concern. The ability of the four remedial actions to reduce air emissions was evaluated based on the concentration levels and amount of exposure expected at each of the three designated receptors. The cost of construction and/or operation of the four alternative remedial actions at three levels of implementation (20, 70, and 90%) and the duration of contaminant levels at the site were also evaluated in order to assess the effectiveness of the remedial schemes.

The clay cap and slurry wall, groundwater removal and treatment, and soil excavation and removal options each involve excavation which will aggravate air emissions. Clay capping alone was the most cost-effective, positive control option evaluated and was recommended for implementation in order to reduce the effects of contamination at the Silresim site. Air and groundwater monitoring were recommended in order to verify the findings obtained from air emissions and groundwater modeling.

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# CLEANUP AND CONTAINMENT OF PCBs—A SUCCESS STORY

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## INTRODUCTION

The General Electric Company owns a 24-acre site in Oakland, California that serves as a location for an apparatus service shop and a short-term storage facility for various company products. From 1924 through 1975 the site was used for the manufacture of transformers, motors, and switchgear and for some maintenance and repair work.

Polychlorinated biphenyls (PCBs) were used as a dielectric in the manufacture of transformers at the site from 1940 to 1968. Pyranol-filled (a blend of approximately 50% trichlorobenzene and 50% Aroclor 1260, a PCB) transformers were serviced at the Oakland facility until 1975.

During the manufacturing process, Pyranol was pumped to tanks, tested, stored, reprocessed by filtering, and transported by vehicle and pipes. Accidental leaks and spills occurred resulting in PCB accumulation in surface and subsurface soils, and detectable levels of PCBs were found in shallow soils in 1979.

Shortly thereafter the State of California requested General Electric to submit a plan of correction. General Electric retained Brown and Caldwell to conduct a preliminary site investigation to determine the extent of the problem. General Electric closely coordinated initial project activity with the regional USEPA office, the California Department of Health Services (DOHS), and the Regional Water Quality Control Board (RWQCB). Eventually, the DOHS was designated lead agency in the project, simplifying subsequent coordination for General Electric.

The preliminary site investigation was expanded into another phase, and a conceptual design for the immediate correction of the problem was developed by Brown and Caldwell. After the expanded preliminary site investigation was completed, the RWQCB, in conjunction with the DOHS and USEPA, issued a cleanup and abatement order requiring: (1) a Phase II study providing historical and current information on plant operations, geohydrologic information on the site, and additional data on the extent of site contamination, and (2) development and implementation of an immediate correction plan for control and removal of subsurface oil and prevention and containment of storm water runoff.

The Phase II study was completed in June 1981 concurrently with plans and specifications for construction of "an immediate correction project." The project was bid in Aug. 1981. Construction began the same month and was essentially complete in Dec. 1981. The immediate correction program, now operating successfully, includes an underground oil and groundwater collection system, an extraction sump, a treatment system for removal of PCBs, and an extensive site sealing and drainage system.

The oily groundwater treatment system was started up in Dec. and began discharging cleaned effluent to the local utility district sanitary sewer system in Jan. 1982. Long-term monitoring of the treatment system, the surface sealing system, and the shallow groundwater system has continued since startup.

In this paper, the authors describe the methodology employed in meeting the requirements of the regulatory agencies and the Gen-

eral Electric Company; specific aspects of the project approach and correction plan that may have application to other sites are also discussed. Unique components of the corrective plan are described that contributed to the project receiving first place in the 1982 California Competition of the Consulting Engineers Association of California, an honor award from the American Consulting Engineers Council, and a certificate of merit from the California Water Pollution Control Association.

Significant features of the project are: (1) the extent and nature of PCB concentration at the site were determined, (2) PCBs were found in subsurface oil and absorbed to soil particles but were not found in the shallow groundwater, (3) the potential of PCB migration in shallow soils to deeper confined aquifers was determined to be insignificant, (4) PCBs are being effectively removed from oil groundwater extracted from the site, (5) PCB loadings leaving the site through storm water runoff are being kept below acceptable limits, and (6) the direction of shallow groundwater movement has been effectively altered to reduce the potential for PCB migration off site.

## SITE INVESTIGATION

The site investigation or problem definition activity for the Oakland Site Project was conducted in three phases: Phase I, Phase Ib, and Phase II. The Phase I investigation was performed in response to an order dated Nov. 29, 1979, from the California DOHS. Work involved a brief review of existing site characteristics and plant operations, a field investigation including soil borings and monitor well construction to obtain data on PCB distribution in the soil and the quality and movement of shallow groundwater, and development and evaluation of alternative correction programs.

The Phase Ib investigation included collection of soil boring and surface grab samples in an unsampled area of the site, construction of additional monitor wells, including a multicased well through a subsurface free oil zone, and sampling and analysis of PCBs and volatile organics.

The Phase II site investigation was performed in response to a Cleanup and Abatement Order issued by the Regional Water Quality Control Board and concurrently ordered by the DOHS and USEPA. This work expanded upon the previous investigations by detailing site history and operations, describing the existing site drainage pattern, providing additional information on PCB distribution and water quality through more soil borings and monitor well construction and completely characterizing the shallow groundwater system.

The multiphase site investigation was comprehensive. After the final phase was completed, the State of California acknowledged to General Electric in writing that the Phase II Definition Study adequately addressed the issues raised in the Cleanup and Abatement Order and at subsequent meetings, and fulfilled the intent and requirements of the order. Highlights of the site investigations are presented below.

## Soil Sampling and Drilling Techniques

Soil samples were collected using a California split spoon drive sampler through a hollow-stem, continuous-flight auger. For the soil borings and shallow monitor wells, the first three samples at 0, 5, and 10 ft below grade were initially analyzed. If these samples had detectable levels of PCBs (more than 0.1 ppm), additional samples were analyzed until a depth of nondetectable PCBs was found. If samples from 0 to 10 ft had nondetectable PCBs, no additional samples were analyzed. For deep monitor wells drilled adjacent to shallow wells, samples at 25, 30, and 35 ft were initially analyzed and the same procedure described above was used to determine the need for any additional analyses.

During the investigation, it was necessary to construct three multicased wells. These wells were drilled through PCB-contaminated soils. To prevent downward movement of contaminants while drilling and to collect representative soil samples below a shallow zone of high PCB concentration in soil, it was necessary to seal off the contaminated zone before constructing the monitor well. To meet these requirements, the multicased wells consisted of a series of concentric steel casings of decreasing diameter. A drillable grout plug was placed at the bottom of each casing and each casing was cleaned and sealed to prevent contamination of the next lower casing. After installing each casing, a cement-bentonite grout seal was emplaced between the well casing and borehole.

## Extent of PCB Contamination

PCB concentration in soils at the site ranges from nondetectable to 11,000 ppm, with high concentrations centered in the area where pyranol was stored. PCB concentrations in soils attenuate to nondetectable levels at a depth of 10 ft over most of the site with some exceptions attenuating at 25 ft in the tank farm area and one boring having measurable PCB concentrations to a depth of 35 ft in the old PCB storage area. Detectable concentrations of PCBs were not found in groundwater samples.

## Monitor Well Construction

The multiphase investigation involved drilling 89 soil borings and constructing 76 monitoring wells. Over 800 soil samples and 70 fluid samples were collected and analyzed for PCBs. Over 300 water level measurements and 30 permeability tests were made to help characterize the groundwater system.

## Free Oil

Free oil contaminated with PCBs was found in several monitor wells, screened in thin layers of sand strata located at a maximum depth of 32 ft below grade under an oil tank storage area (tank farm). The free oil measured in the monitor wells was a maximum of 8 in thick.

## Groundwater Mound

Groundwater flow in the shallow strata of the site, defined as the upper 60 ft, tended to be away in all directions from a groundwater mound in the vicinity of the tank farm. The source of the groundwater mound was identified as the diked area of the tank farm.

## Hydraulic Continuity

A detailed flow net evaluation was made of the shallow groundwater system; the potential for vertical migration of PCBs in shallow soils on the site to deeper confined aquifers was determined to be negligible.

## DESIGN

The design involved preparation of bidding documents, plans, and specifications. In addition, pilot tests were conducted on a small scale oil-water separator for verification of performance expectations. Permits and approvals were arranged with various regulatory agencies, and as-built drawings were prepared after construction. The facilities designed included:

- A surface sealing system of bentonite and soil overlaid with a permeable gravel layer
- Surface runoff control facilities including curb and gutters, catch basins, drainage piping, drainage channels, and a monitoring and sampling station
- A three-trench French Drain system with central collection sump and mechanical extraction system
- A groundwater treatment system and storage facilities for treated groundwater, sediment, and PCB-contaminated oil
- Modification of the existing tank farm (tanks previously used for oil storage and mixing) for approved temporary bulk storage of PCB fluids and drummed storage of sediments.

## Groundwater Collection and Extraction System

A plan and section of the French Drain collection system and extraction sump is shown in Fig. 1. The system was located in the central area of the subsurface free oil area to facilitate oil collection. Three levels of 6 in diameter perforated pipe were designed for each French Drain arm to provide flexibility in collecting oil and groundwater.

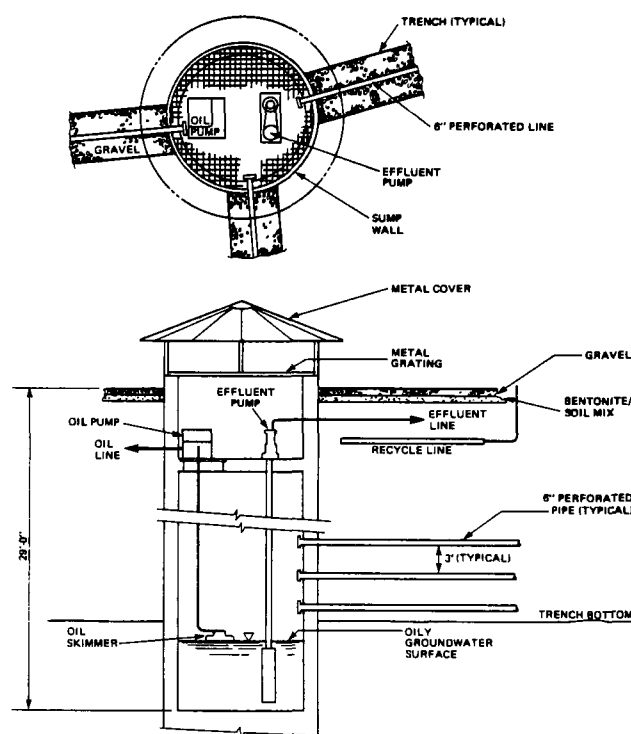


Figure 1.  
Plan and Section of French Drain and Extraction Sump

## Oily-Water Treatment System

A schematic of the oily-water treatment system is shown in Fig. 2. Oil collected via the surface skimmer is pumped directly to a storage tank. Oily groundwater is pumped to an oil-water separator consisting of a rectangular fabricated steel box approximately 20 ft long, 6 ft wide, and 6 ft high containing a series of vertical and horizontal coalescing plates that are hydrophobic and oilphilic. The plates cause coalescence of the fine oil droplets into larger globules which more readily float to the surface for easy collection via a static skimming pipe.

Solids settle in the separator, dropping into sludge hoppers for collection by periodic pumping. Clean effluent passes under a baffle and over a weir and flows by gravity through a monitoring station and then into the sanitary sewer collection system of the local utility district. Polymer may be added to the oil water separator influent to enhance coagulation and separation of solids. The effluent can be pumped to a storage tank for testing before discharge to the sewer.

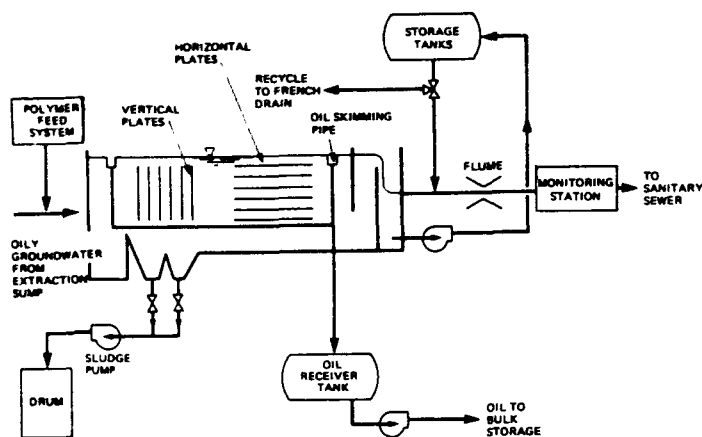


Figure 2.  
Oily Groundwater treatment system

### Surface Sealing and Drainage System

The Oakland plant site and the surface sealing and drainage system are shown in Fig. 3.

The design provided two types of soil sealing systems: (1) a bentonite-soil mixture covered with permeable rock, and (2) asphalt-concrete paving and base rock coated with a surface sealant. The bentonite (a natural low-permeability clay) soil mixture was applied using 4 in. of imported soil and 4 lb of bentonite/ft<sup>2</sup> to achieve a final permeability not greater than  $1 \times 10^{-7}$  cm/sec when compacted to 80% at optimum moisture content. Six inches of crushed drain rock was spread over the bentonite-soil mixture. This surface sealing system was used over portions of the site containing high concentrations of PCBs, where vehicular traffic would be prohibited, and where no facility expansion plans existed.

Part of the site was sealed with asphalt-concrete paving over an aggregate base. A seal coat was applied at a rate of 0.10 gal/yd<sup>2</sup> to both new and existing paving.

The site investigation showed that the western portion of the property had so little PCBs that sealing appeared unnecessary. Therefore, with concurrence from the regulatory agencies, this section was left in its natural state except for some grading to provide a holding basin for accumulation of runoff during severe storms.

The design contains three separate, structured drainage systems: (1) roof runoff, (2) paved area runoff, and (3) bentonite seal area runoff. The discharge of all three structured systems is combined and passed through a monitoring station before discharge to a storm sewer.

Having three systems provides the flexibility of system isolation if monitoring results indicate abnormally high PCB levels in the combined discharge. Part of the storm water collected in the unpaved area runs off the site overland in a northwesterly direction, while remaining storm water collected in this area drains to the monitoring station.

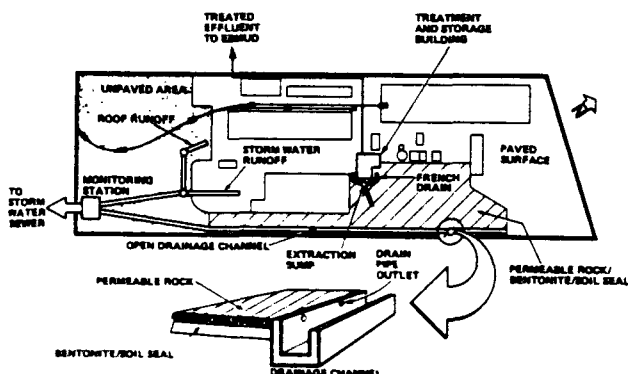


Figure 3.  
Surface Sealing and Draining System at Oakland Plant Site

### PERMITS

One agency approval and three agency permits were required for construction and operation of the Oakland site project. Approval was necessary from the Alameda County Flood Control and Water Conservation District (District) for discharge of storm water collected on site to the storm sewer system. An approved connection point, flow calculations, and a drainage system design drawing with plans for a short-term holding basin were needed to satisfy requirements of the District.

A building permit was required from the City of Oakland to construct a structure over the tank farm. Securing this permit did not permit any difficult problems.

An Authority to Construct and a Permit to Operate was required from the Bay Area Air Quality Management District. This permit was necessary due to the potential for volatile organic emissions from the oil-water separator escaping to the atmosphere.

The most complicated permit required was a wastewater discharge permit from the East Bay Municipal Utility District (EBMUD). Under the provisions of this permit, treated groundwater from the oil-water separator could be discharged to the EBMUD sanitary sewer system. Permit provisions require flow monitoring of the treated groundwater discharged to the sewer and periodic (every 8 weeks) analysis of total suspended solids, filtered chemical oxygen demand, oil and grease, and PCBs from a 16 hr composited samples. The PCB discharge requirement is for a maximum of 2.3 µg/l and an average of 1.4 µg/l.

The flow measurements are used to compute a sewage disposal service charge. Quarterly reports are required documenting flow readings and quantities of oil and solids stored on site or off-hauled.

Provisions of the Resource Recovery and Conservation Act and the Toxic Substances Control Act were explored for permit requirements applicable to the Oakland facility. No specific requirements were found and it was therefore concluded, with concurrence of the State of California, that no additional permits were required.

### CONTRACTOR PROCUREMENT AND CONSTRUCTION

Prospective bidders for the Oakland site project were solicited by issuing a request for qualifications which contained a brief description of the project. A pre-bid conference was held at the project site to familiarize prospective bidders with the proposed project.

Subjects covered included a description of the project, contract requirements, safety with respect to PCBs, and the contractor selection process. Major items of concern expressed by the prospective bidders were containment of extracted groundwater and safety provisions in working with PCBs. Key safety provisions discussed were equipment cleaning, personal protective equipment, and control of excavated materials.

Six bids were received for the Oakland site project. The bids were evaluated based on: (1) submitted project activity schedule, (2) qualifications of key project personnel, (3) submitted safety program, (4) extent of subcontracting planned, (5) any special conditions of the bid, and (6) bid price. Underground Construction Company of San Leandro, California, was selected as the successful bidder for the project.

### Construction

Construction work on the Oakland site began in Aug. and ended in Dec. 1981. A particularly important feature of the construction phase that facilitated maintaining a tight construction schedule was the assignment of a full-time project manager to the site by General Electric. This individual had personal knowledge of the site history and ongoing operations and had complete authority to execute contract change orders and make field decisions for the company.

### Prepurchased Equipment

The oil-water separator and five pumps were prepurchased by General Electric and furnished to the contractor. While attractive in concept, this approach did cause problems. Equipment deliv-

eries were delayed. When the equipment finally arrived, parts and installation instructions were occasionally missing, and in some cases, specifications had not been followed. Numerous hours were spent by Brown and Caldwell and General Electric expediting pre-purchased equipment deliveries. As a result, the contractor was delayed and the project schedule suffered.

A total of 49 change orders were executed during the project. All but three of these change orders increased the contract price.

### Construction Problems

**Sheet Piling.** The contractor drove sheet piling to prepare for excavation of the extraction sump and French Drain trenches. The sheet piling was to be driven 20 to 30 ft to prevent soil cave-in during excavation and to afford some degree of groundwater isolation. Unfortunately, neither a pneumatic pile driver nor a diesel pile driver would drive the piles through the site soils. Piles shifted and the ends buckled. Use of newer and thicker piles may have resulted in more success. Eventually, a 24 in.-diameter auger was used to drill several deep holes in the extraction sump, permitting the piles to be driven.

**The French Drain lateral trenches** were excavated to the required depth in sections by backhoe with sheet piling added after, rather than during excavation. Very little groundwater was encountered in the lateral trenches or the extraction sump during construction. Excavation of the extraction sump and lateral trenches required three times longer than the contractor expected, which proved very costly and resulted in the entire project falling behind schedule.

**Monitoring Wells.** The 76 monitoring wells installed on site during the site investigation phase all had to have well-casing extensions installed so the site grading crew could see them. Even then, approximately one third of the wells were damaged by impact with earthmoving equipment and had to be repaired. Fortunately, none of the multicased wells were damaged. In retrospect, it would have been better to have extended each monitoring well a few feet above the ground surface during initial construction, brightly colored the well casings, and surrounded them with temporary fencing.

**Buried Pipes.** Since operations had been occurring at the Oakland site for a long time and as-built drawings of the facility were not available, location of underground piping and utility lines proved to be a problem. The recollection of General Electric personnel and numerous "potholing" expeditions were necessary to locate buried pipes and lines. This situation caused considerable delay in construction and many change orders but prompted careful preparation of as-built drawings for the newly completed construction.

**Wipe Tests.** The contract specifications required that all construction equipment leaving the site must be inspected and cleared by the resident engineer. This provision was designed to ensure that PCB-contaminated soil material did not leave the site and contaminate another location. A wipe test was used; it consisted of wiping a 1 ft<sup>2</sup> area with a swab coated with acetone and analyzing the swab material for PCBs. Equipment was cleared to leave the site if the wipe test analysis had a PCB concentration of less than 100 µg/ft<sup>2</sup>.

Cleaning equipment to this specification required dirt scraping, water washing, and detergent steam cleaning. The process proved to be very time consuming and expensive for the contractor, particularly with rented equipment.

### OPERATION AND MAINTENANCE

Operation and maintenance activities for the Oakland site project involved basically the extraction system, the oil-water separator, and the material storage systems. An operation and maintenance manual was prepared covering key aspects of these systems, including relevant construction features, operational theory, and equipment maintenance.

Training sessions were conducted by Brown and Caldwell operator specialists to provide instruction to General Electric person-

nel on proper operation of the treatment plant. Startup assistance, including process adjustment, was provided during the first few weeks of plant operation with hands-on training for General Electric personnel. Long-term operating assistance is being provided by Brown and Caldwell specialists for the first year of operation. This assistance involves solving process-related problems, making system modifications, and assisting in monitoring performance.

Operating problems and solutions resulting from the first few months of operation are described below.

**Groundwater Quantity Extracted.** It was predicted that as much as 16,000 gal/day of groundwater might be extracted from the French Drain system. Operating history has shown close to 1,000 gal/day of groundwater is being extracted. Because of the low flow rate and General Electric's desire to man the treatment plant during the same time period each day, automatic operation of the groundwater treatment system was discontinued. The system is now operated in batch mode.

**Oil Skimmer Operation.** The oil skimmer in the extraction sump is designed to efficiently operate only if sufficient oil is present to completely wet the skimmer membrane. Without sufficient oil, water leaks into the skimmer, tripping an alarm. To overcome this problem, the skimmer is removed when the thickness of the oil layer in the extraction sump is less than 1 in. When the oil layer becomes thick enough, the skimmer is dropped to the water surface briefly for oil removal to bulk storage.

**Solids Buildup.** Solids have accumulated in the oil-water separator downstream of the horizontal and vertical oil coalescing plates. These solids are believed to have entered the system during start-up and they have been removed. If continued buildup occurs, it may necessitate adding foam filter pads to the oil-water separator between the vertical and horizontal banks of coalescing plates.

**Flowmetering System.** The ultrasonic flowmetering system consisting of a flume, ultrasonic transducer, and display panel malfunctioned repeatedly during the early months of operation. The problem was finally traced to a hairline crack in the transducer that presumably occurred during installation. After transducer replacement, the system is performing reasonably well.

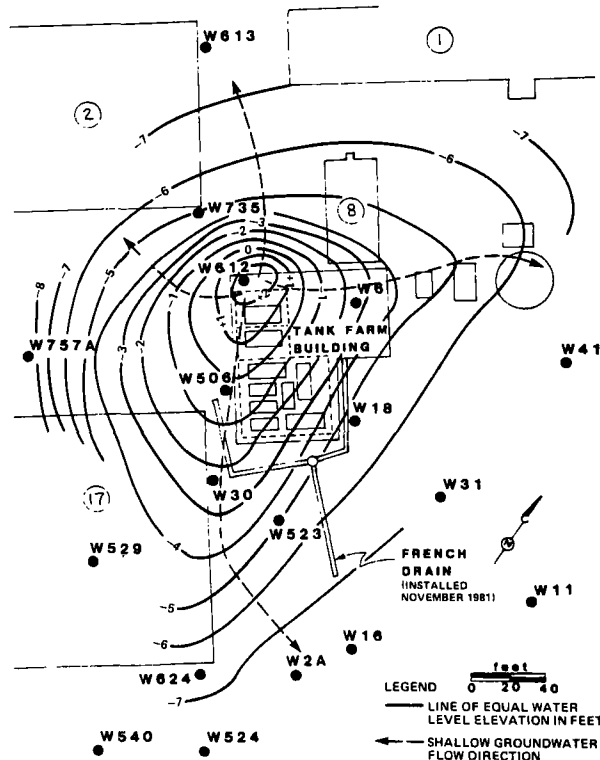


Figure 4.  
Water Level Contour Map in September 1981



**Ultrasonic Level Probe Fouling.** During startup of the plant, the ultrasonic level probes in the oil-water separator, which activates the effluent pump, fouled and the unit flooded the building with extracted groundwater. The fouling substance consisted of a sticky, viscous material suspected of being packing around the coalescing plates. After probe cleaning, the problem has not recurred.

**Steam Condensate Sidestream.** A steam condensate sidestream from the General Electric apparatus service shop with high concentrations of solids, chemical oxygen demand, oil, and arsenic was initially added to the oil-water separator influent flow. This action proved to be problematic as the sidestream contained surfactants which reduced the coalescing of oil droplets in the oil-water separator. Eventually, the sidestream was split off and handled separately.

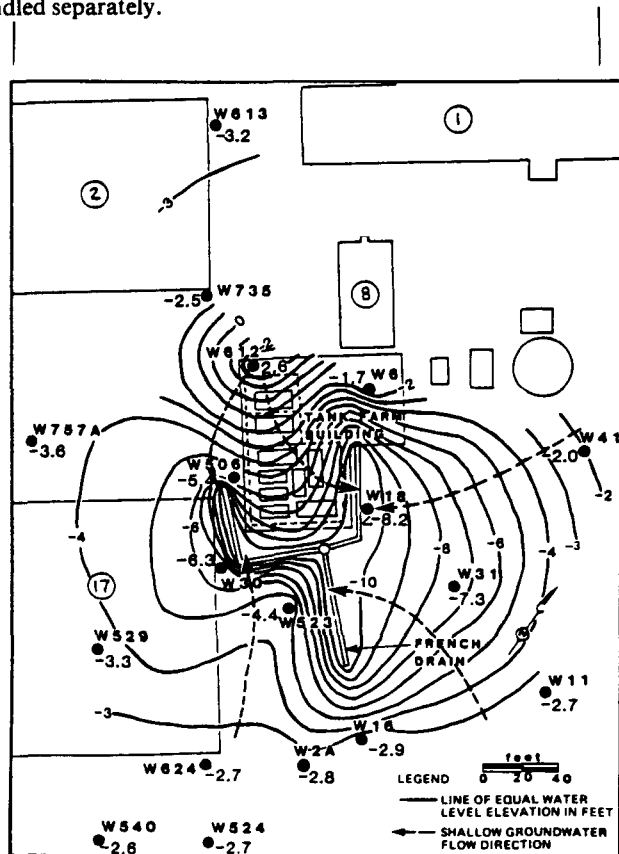


Figure 5.  
Water Level Contour Map in August 1982

## LONG-TERM MONITORING

In response to a request by the RWQCB, a long-term monitoring plan was developed to monitor: (1) groundwater, (2) recovered, treated groundwater, (3) recovered sediment and oil, and (4) storm water runoff.

### Groundwater

Monitoring of the groundwater is done to identify any PCBs in groundwater and to determine changes in the groundwater levels. Monitoring consists of water level measurements in all 76 on-site

monitor wells and sampling and chemical analyses from 19 selected wells. Analyses are to be made for: water levels, PCBs, and oil and grease.

A water level contour map prepared immediately before construction of the French Drain is shown in Fig. 4; the water level contour map 8 months after startup of the French Drain and groundwater extraction system is given, for contrast, in Fig. 5. Note the reversal of groundwater flow that has occurred and the influence the French Drain extraction system has had on the shallow groundwater system water levels.

### Recovered, Treated Groundwater

The recovered, treated groundwater (effluent from the oil-water separator) is monitored to evaluate the unit performance and to confirm that the discharge to the sewer system is meeting the requirements of the receiving utility. Determined are flow rate, PCBs, total identifiable chlorinated hydrocarbons, oil and grease, and total suspended solids. Average values for weekly measurement of these parameters during the first 8 months of plant operation are shown in Table 1.

### Recovered Sediment and Oil

Solids and oil recovered by the oil-water separator are sampled and analyzed to determine the PCB concentration of these wastes. Sediment and oil PCB concentrations measured on one occasion during the first 6 months were 27 ppm for dry sediment and 870 mg/l for oil.

### Storm Water Runoff

Storm water runoff is monitored to detect any PCBs, permitting an evaluation of the effectiveness of the bentonite and asphalt sealing systems. For the period Nov. 1981 through Apr. 1982, PCBs in the runoff averaged 2.4 µg/l.

Table 1.  
Recovered, Treated Groundwater Monitoring Results

Parameter	Average value	
	Influent	Effluent
Flow, gpd	-	1,100
PCBs <sup>a</sup> , ppb	6.5	0.1
Oil and grease, ppm	9.2	7.1
Total suspended solids, ppm	5.8	5.8

<sup>a</sup>Actually total identifiable chlorinated hydrocarbons.

Note: For first 8 months of operation.

# IMPLEMENTATION OF REMEDIAL ACTIONS AT ABANDONED HAZARDOUS WASTE DISPOSAL SITES

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## INTRODUCTION

In this paper, the authors describe current efforts to study, design, and implement remedial actions at abandoned hazardous waste disposal sites in USEPA Regions VI through X. They also discuss the legislative background and enabling authorities to provide such remedial activities, the provisions of Black & Veatch's contract with USEPA, issues related to the objectives of Superfund, and investigations and feasibility studies at an abandoned site.

## LEGISLATIVE BACKGROUND

There are three major laws that cover remedial activities at abandoned hazardous waste disposal sites. These laws include the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response Compensation and Liability Act (also known as Superfund).

Section 311 of the Clean Water Act required the preparation of the National Contingency Plan to provide for emergency response to discharges of oil or hazardous substances. RCRA provides the overall legislation governing the management of hazardous wastes including standards for generators, transporters, and owners/operators of treatment, storage, or disposal facilities. Regulations promulgated under RCRA and the Consolidated Permits Program provide facility design guidance, outline closure and financial requirements, and set general operating standards.

The most important legislation governing abandoned sites is Superfund, which provides \$1.6 billion for cleanup. Superfund also established a Postclosure Liability Trust Fund and required revision of the National Contingency Plan while establishing liability provisions for cleanup costs. Superfund provided the basis for a USEPA contract to provide design services for remedial actions at abandoned sites.

## CONTRACT BACKGROUND

Under the provisions of Superfund, last year USEPA procured engineering services to provide remedial actions at abandoned disposal sites. The country was divided into three zones: Zone 1 is Regions I, II, and IV, Zone 2 is Regions II and V, and Zone 3 is Regions VI through X. Black & Veatch was selected to perform engineering services in Zone 3. The contract is a cost plus fixed fee work order type contract and calls for provision of certain services at abandoned disposal sites where the USEPA takes the lead to clean them up.

The scope of work calls for five separate areas of service to be provided including initial field investigation, feasibility study, design, construction management, and general technical support. The objective of the initial site investigation is to establish the degree of contamination, sources, possible remedies, and impacts to public health and environmentally sensitive areas.

### Field Investigation

Typical tasks associated with the field investigation include:

- Determination of the amount and composition of hazardous substances
- Determination of the extent of contamination
- Groundwater and air quality monitoring and modeling
- Collection of additional data required by subsequent activities
- Identification of environmental pathways
- Characterization of potential exposure
- Preliminary data processing and storage
- Preparation of reports and participation in project review meetings

## FEASIBILITY STUDY

The feasibility study incorporates a review of problem history and the results of field investigation to analyze and compare remedial options. The comparison is based on technical feasibility, expected duration, cost effectiveness, economic reliability, O&M considerations, and public acceptance. Typical tasks included in the feasibility study are:

- Processing and review of data collected during the remedial investigation and definition of additional data requirements
- Analysis of complete data base
- Definition and analysis of discrete problems impacting the development of remedial options
- Definition of alternative remedial measures, phasing options, and consequences
- Performance of treatability, compatibility, and pilot scale studies
- Performance of cost effectiveness and risk analyses
- Performance of preliminary environmental assessments and economic impact analyses
- Recommendation and approval of preferred options
- Preparation of conceptual design of the selected options
- Identification of discrete work packages for an integrated design-construction approach
- Development of preliminary cost estimates, cash flow requirements, and schedules for subsequent activities
- Performance of detailed environmental assessment and economic impact analysis
- Preparation of reports and participation in project review meetings

## Engineering Design

The engineering design phase defines the selected remedial action in sufficient detail to permit direct implementation. Depending on site-specific conditions, a wide range of potential design solutions are available, including:

- Construction plans for berms, dikes, ditches, dams, and other runoff diversion structures
- Underground and surface pipelines for short distance pumping and transfer of wastes on site
- Lagoon training, chemical fixation, neutralization
- Provision for incineration of wastes on site
- Ground water interceptor well networks

- Ground curtain, curtain wall, and sheet piling cutoff wall emplacement
- Dike stabilization
- Temporary and permanent holding tank or reactor tank construction
- Temporary and permanent biological and physical/chemical treatment plants
- Construction of alternative water supply pipelines
- Specifications for off-site disposition of wastes, including thermal destruction, chemical treatment, and land disposal

Typical tasks involved in engineering design include:

- Acquisition of additional data required
- Procurement of applicable federal and local permits and rights-of-way
- Monitoring availability of suitable disposal sites
- Preparation of engineering designs and specifications, including post-closure, resource replacement, and relocation plans
- Integration of containment and cleanup feasibility considerations
- Preparation of cost estimates and schedules
- Preparation of bid documents for construction and cleanup and technical support in reviewing and evaluating bids
- Preparation of procedures and forms
- Preparation of operation and maintenance manuals
- Development of operator training programs when needed
- Preparation of reports and participation in project review meetings

#### Construction Phase

Construction phase services typically include the following:

- Answer questions during the bidding period by the Contracting Officer regarding meaning or interpretation of the drawings and specifications and prepare the required changes
- Assist the Contracting Officer in analyzing and evaluating proposals and bids
- Check and recommend approval action on shop drawings, material samples and proposals submitted by the construction Contractor
- Be available for consultation and advice during the planning, construction, and final inspection of the project
- Prepare any additional details or detailed drawings as required for clarification of construction
- Revise the original drawings to show construction as actually accomplished
- Visit the construction site to review and record the progress of the work and to inspect all aspects of the work for conformance with the plans and specifications
- Prepare plans and specifications for any changes to the contract that may be required
- Check the validity of all invoices for payment submitted by the construction Contractor
- Review claims submitted by the construction Contractor and make recommendations for their settlement to the Government Project Manager

#### ISSUES RELATED TO SUPERFUND

The implementation of remedial actions is a complex process. There are several issues that relate to the success of Superfund programs including:

- Site specific variables
- “How clean is clean?”
- Communications

Site specific variables can influence the ultimate choice of remedial options for implementation. Some of these variables include:

- Site geotechnical and hydrological characteristics
- Extent and magnitude of contamination
- Local political situation
- Proximity to off-site disposal facilities
- Proximity to experienced contractors

The issue of “how clean is clean?” is related to cost since the incremental cost of achieving “complete” cleanup can be prohibitive. It is necessary during the feasibility study to determine which remedial alternative results in an acceptable reduction of risk and also an acceptable level of contaminant reduction. This is dependent on the characteristics of both site and wastes and represents the most difficult engineering decisions in the entire cleanup process.

Communications between state officials, regional USEPA, and USEPA Washington are critical because overall program management comes from Washington, whereas each Region assigns a project monitor to each specific site. It is essential that the concerns of state officials are adequately addressed during cleanup activities.

#### CASE HISTORY

One of the sites under this contract is the MOTCO disposal site located near Texas City, Texas. This site is an 11-acre tract of land that contains approximately 7 acres of abandoned lagoons. The lagoons were originally used for storage in a waste styrene tar reclamation operation. For several years the facility was also used as a dumping ground for various waste products, including vinyl chloride bottoms, acids, metallic catalysts, and elemental lead and mercury. The waste materials are contained in unlined lagoons that vary in depth from approximately 12 to 30 ft. Several attempts were made to recycle the waste materials for commercial purposes, but all of them failed. It was determined by the USEPA and the U.S. Coast Guard that the site was posing a serious threat to navigable waters and, thus, an action under Section 311 of the Clean Water Act was taken. The immediate threat was eliminated by the construction of dikes and fencing. However, the extent of subsurface contamination was not investigated.

Black & Veatch conducted initial and supplemental field investigations to determine the nature and extent of contamination. A site-specific safety plan was prepared and samples were taken from air, surface water, surface soils, ground water, subsurface soils, and the waste pits. Analytical data cannot be released due to pending litigation, but offsite contamination has been discovered.

In addition to reporting the results to USEPA, Black & Veatch developed some preliminary order of magnitude costs for eight potential remedial action alternatives. The next level of investigation will be a feasibility study to determine the recommended remedial action. This study will include a detailed cost analysis that will replace the order of magnitude cost figures derived prior to beginning the feasibility study.

Work is also progressing at other sites throughout Zone 3 including:

- Ellisville, Missouri—Preparation of bid package in drum removal and feasibility study for cleanup of three sites
- Council Bluffs, Iowa—Preparation of Remedial Action Master Plan (RAMP) and feasibility study for site cleanup
- Commerce City, Colorado—RAMP preparation
- Tucson, Arizona—RAMP preparation and monitoring well installation
- Globe, Arizona—RAMP preparation
- Tacoma, Washington—Remedial investigation and feasibility study in contaminated municipal well field. Remedial investigation in South Tacoma Swamp
- Denver, Colorado—Feasibility study for radium sites. RAMP for abandoned chemical site

After feasibility studies are completed, the Corps of Engineers will manage design and construction (implementation) contracts while USEPA will approve the appropriate remedial alternative.

It is evident that through the Superfund program, the country has taken significant steps toward protecting public health and welfare. The cleaning up of abandoned hazardous waste disposal sites is a well directed program which will be recognized as producing benefits for exceeding expenditures.

# PROPOSED CLEANUP OF THE GILSON ROAD HAZARDOUS WASTE DISPOSAL SITE, NASHUA, NEW HAMPSHIRE

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## INTRODUCTION

The Gilson Road Hazardous Waste Dump site is located in Nashua, New Hampshire, near the New Hampshire/Massachusetts State line. The 6 acre site is located in a residential area of the city with two large mobile home parks directly adjacent to it (Fig. 1).

The site was developed as a sand borrow pit by the owners, with substantial quantities of sand having been removed over several years of operation. The sand excavation at many locations extended into the ground water table underlying the site. At some point in the late 1960s, the owner decided to discontinue the sand mining operation and began the operation of an unapproved and illegal refuse dump with the apparent intent of filling the pit left by the sand mining.

Household refuse and demolition materials were the initial components of the wastes dumped at the site. Eventually, chemical sludges and aqueous chemical wastes were also dumped there. The domestic trash and demolition material were usually buried while the sludges and liquid chemicals were disposed of in several ways: mixed with the trash and buried, placed in steel drums and either buried or stored on the surface, or dumped into a makeshift leaching field and allowed to percolate into the ground.

It was estimated that the site was used for the disposal of hazardous wastes for approximately five years. During the last eight months of operation at the site, Jan. to Oct. of 1979, over 800,000 gal of aqueous wastes were known to have been disposed of there. With the dump having been used for at least five years for aqueous waste disposal, the total volume of liquid waste dumped there is likely substantial.

Cleanup activities began in 1980, as soon as legal access to the site could be obtained. During May and June of that year, 1,314 drums, which were accessible, were removed by a contractor and disposed of at approved secure landfills in the States of New York and Ohio.

Immediately following removal of the drums, a ground water exploration and monitoring program was initiated to determine the magnitude and extent of the contamination. In July of 1981, an engineering report prepared by another consultant stated that there were high concentrations of heavy metals, volatile organics, and extractable organics in the ground water under the site. The metals and much of the extractable organics could be traced to the domestic refuse while the volatile organics likely originated from the makeshift leaching field used for the disposal of most of the aqueous wastes.

The concentration of organics, measured as total organic carbon, was found to be over 4,000 mg/l. Total metals concentrations, in the most contaminated portion of the plume, were in excess of 1,000 mg/l. Some of the major organic contaminants included methylene chloride, methyl ethyl ketone, toluene, benzene, chloroform, tetrahydrofuran, and acetone. The metals found at the site included iron, manganese, nickel, zinc, barium and arsenic.

The ground water plume of contaminants extended over an area in excess of 20 acres and was moving at a rate estimated at 0.8 to 1.6 ft/day. The plume was moving toward the Nashua River and contaminants from the upper portion of the plume had already entered Lyle Reed Brook, a small stream tributary to the Nashua.

The primary remedial measure recommended by the initial consultant was the encapsulation of a 12.5 acre site with a slurry trench cut-off wall and an impermeable surface cap. For that portion of

the ground water plume outside the containment wall, a treatment system would be installed which would intercept and treat the groundwater. The treatment process would consist of air stripping, biological oxidation, and activated carbon adsorption (Fig. 2). Chemical precipitation of the metal contaminants was considered to be an optional treatment step.

Following cleanup of the aquifer outside the slurry wall, all further activities would be terminated and the site would be left with the slurry wall to permanently contain the 12.5 acres of contaminants.

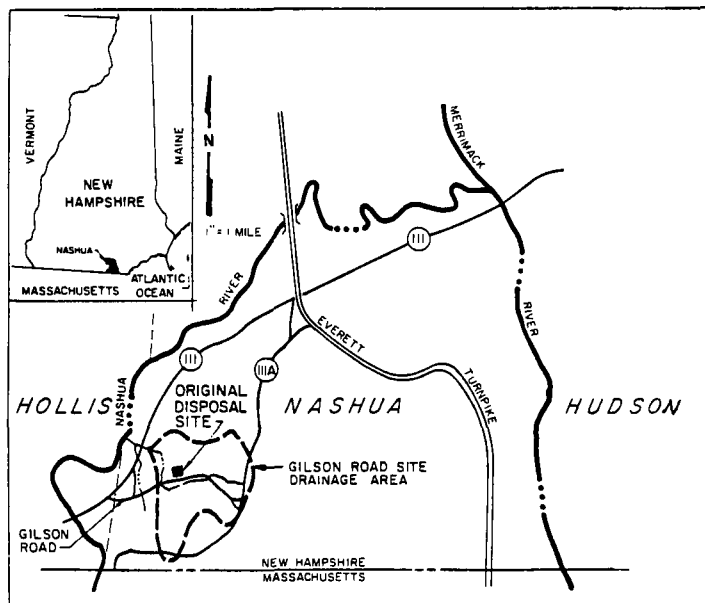


Figure 1.  
Location Map

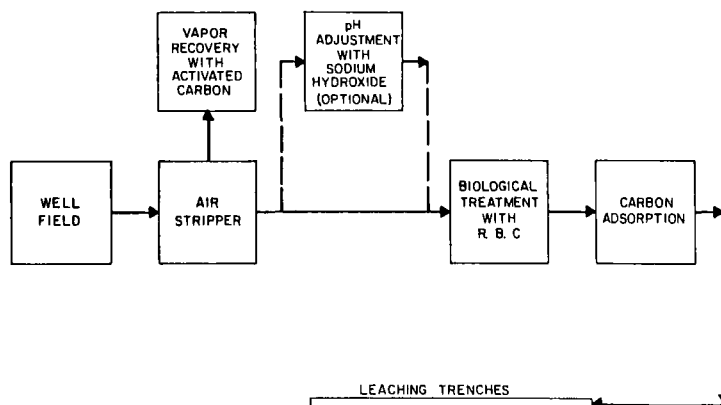


Figure 2.  
Proposed Treatment System in Initial Report

## FURTHER INVESTIGATIONS

Shortly after the completion of the report in 1981, the State of New Hampshire received a grant from the USEPA, funded under

the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, for the cleanup of the site. A condition of the grant called for the preparation of an interim report dealing with the feasibility of groundwater treatment.

WESTON was retained by the State of New Hampshire to prepare this report. Among the concerns raised by the State and USEPA were: the effects on the environment of taking no action at the site, the long-term integrity of the slurry wall, and the cost-effectiveness of the proposed treatment system.

#### No Action Alternative

WESTON's investigation found that taking no action at the site would have impacts both locally and some distance from the site. A small brook borders the site (Fig. 3) and, as previously mentioned, it was found that upper portion of the plume had migrated to the brook and low levels of contamination were being detected downstream.

Several municipalities in Massachusetts draw their drinking water directly from the Merrimack River and provide service to a combined population of over 100,000. Through direct surface water flow and groundwater seepage into the Nashua River, a no action alternative would result in exceeding suggested USEPA Water Quality Criteria for a lifetime cancer risk of 1 in 1,000,000 for methylene chloride and chloroform and exceeding 50% of the levels for trichloroethylene, benzene, and 1,2-dichloroethane in those downstream communities. Based upon soils flushing experiments and the current rate of natural groundwater flow through the site, it was likely that the cumulative effects of the

concentration of organics at the downstream water supplies would exceed USEPA Water Quality Criteria for a minimum of 20 years.

The effects on the aquatic communities within the Nashua and Merrimack Rivers were anticipated to be significant during low flow periods. Long-term effects are unknown since there is little if any research into the effects of the organic contaminants on species found in the receiving waters.

Locally, adjacent to the site, substantial volatilization could be expected as the Lyle Reed Brook flowed to the Nashua River. Although the predicted airborne concentration of the organic vapors would not be toxic, they would, cumulatively, exceed the recommended long-term exposure limits for a cancer risk of 1 in 1,000,000 by a factor of 100 for residents of the mobile home park located some 30m from the brook. Expected odor levels adjacent to the brook, as well as in the mobile home park, were expected to be high, in some instances more than 400 times the odor threshold.

#### Containment

A second major concern was the long-term integrity of the slurry wall and the potential seepage of contaminants through the wall or into the underlying bedrock. The wall in the previous consultants' recommendations, would be used to permanently contain the contaminants within the 12.5 acre site. It was found through a review of the literature, discussions with contractors, and laboratory work by a hydrogeological consultant to the state, that the integrity of the wall would be suspect because of the contaminants contained within the plume. Bentonite has a tendency to shrink

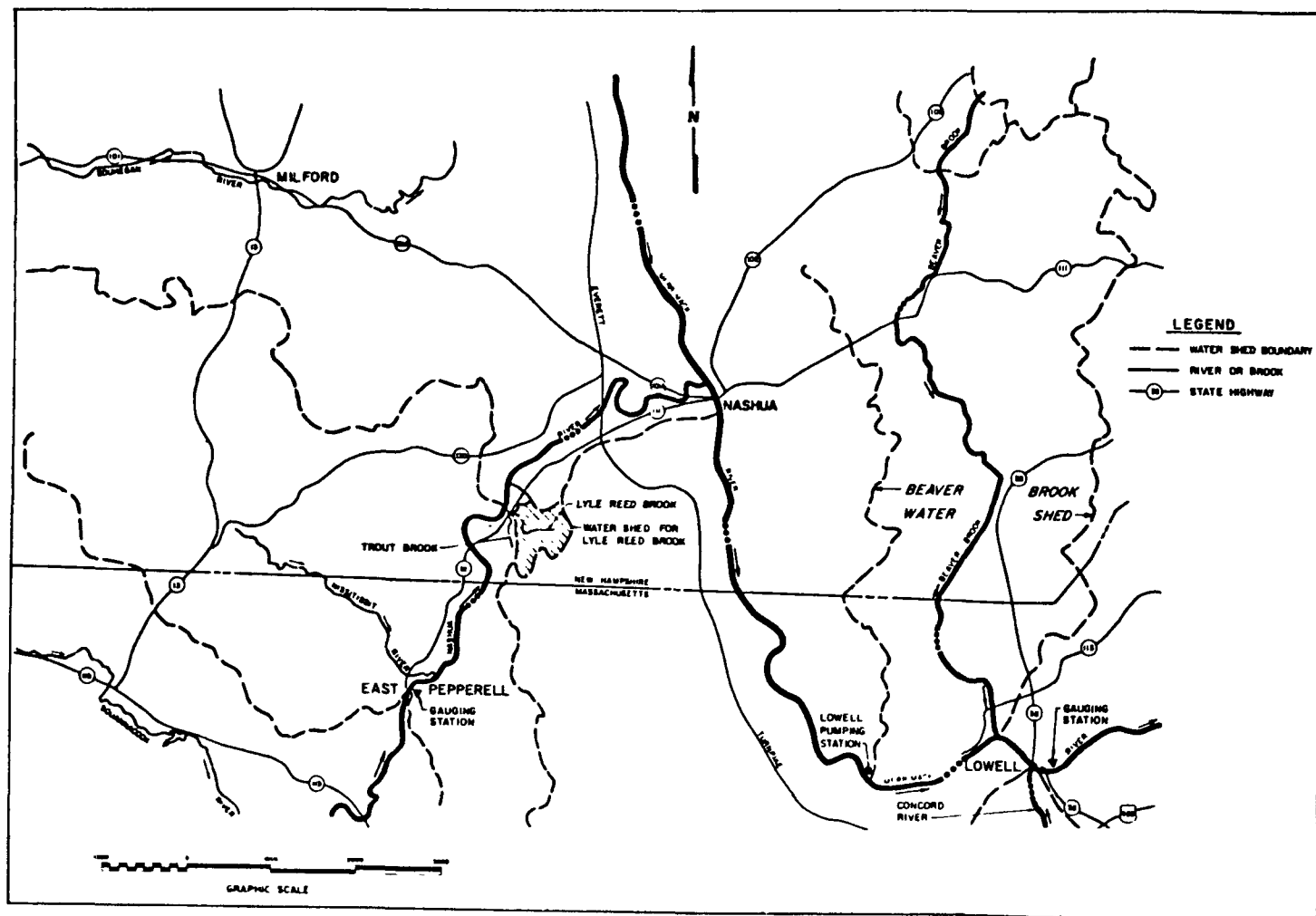


Figure 3.  
Location Map

when subject to some of the chemical contained in the plume, thereby increasing the permeability of the wall. The laboratory results indicated an increase in permeability from  $10^{-7}$  to  $10^{-5}$  cm/sec when the bentonite was exposed to the contaminants contained within the ground water.

In addition to the concern with the integrity of the wall, there was also concern with seepage of contaminants into the underlying bedrock. Even with an ideally constructed slurry wall and cap containment system, there will be flow into the site through the cap and underflow of the wall by way of the fractured bedrock. The combined volume of flow from these sources was estimated at 5,000 gal/day. This uncontaminated flow would displace an equal volume of contained groundwater which would exit the site through the bedrock. This would then be expected in time to enter the Nashua River. Even at a rate of only 5,000 gal/day, the combined concentration of the contaminants would equal the USEPA Water Quality Criteria for a cancer incidence of  $10^{-6}$ .

Because of these concerns, long-term use of the slurry wall for containment of the contaminated groundwater was not recommended. However, a slurry wall and surface cap system could be used quite effectively as a "clean water exclusion system." With such a concept, the wall and the cap would be constructed not to contain the contaminants but to exclude uncontaminated ground water from entering the contained site. Such a system would be used in conjunction with a groundwater treatment process.

Wells, located within the slurry wall, would pump contaminated water, treat it, and return it for recharge within the wall. This system would significantly reduce the volume of contaminated groundwater leaving the site since there would be induced flow into the site from the bedrock because of the pumping from within the wall. It was recommended to utilize this system to surround a 20-acre area of highly contaminated groundwater. A schematic of the recommended system is shown in Fig. 4.

#### Investigation of Treatment Alternatives

Various treatment alternatives were investigated to determine if the recommendations contained in the initial report were cost-effective. Because of the three distinct components of contamination in the groundwater, the alternatives for treatment had to address each of the contaminant groups. Heavy metals removal was the first process investigated.

The chemical analyses of the groundwater had indicated high concentrations of iron and manganese, averaged 350 mg/l and 80 mg/l respectively. Although not toxic or known to be carcinogenic in these concentrations, these compounds could severely affect the operation of a treatment processes. It had been found both in the laboratory and by personnel working at the site, that

the introduction of air into the contaminated groundwater would cause immediate precipitation of these metals. Failure to remove them would likely result in plugging or fouling of any process where air was introduced.

Four alternatives were reviewed which could be effective in removing the heavy metals component of the plume. These consisted of: chemical precipitation, ion exchange, electrodialysis, and reverse osmosis. Because of the high content of organics in the groundwater, only chemical precipitation with lime was determined to be a reliable, cost-effective alternative. In the laboratory, this process removed virtually all of the iron and manganese and provided a secondary benefit by removing about 65% of the other heavy metals.

From the standpoint of both health and environmental effects, the volatile organics fraction of the contaminants is the most significant component of the groundwater plume. Some of the analyses of the groundwater taken from wells on the site had shown concentrations of volatile organics of over 1,800 mg/l. Groundwater from one well, located directly adjacent to the former "leaching field", had a volatile organic concentration of 11,200 mg/l. This high concentration of low molecular weight organic compounds has a significant effect on the selection of treatment alternatives.

Carbon adsorption, which is effective for the removal of high molecular weight insoluble compounds, had produced poor results in treating the groundwater from this site. Breakthrough of the volatile organic fraction occurred after operating only a short period of time. Because of this situation, activated carbon was not considered a viable treatment alternative. After reviewing six other treatment alternatives, the two most effective processes appeared to be steam stripping and biological treatment.

Air stripping of the volatile organics, recommended in the previous engineering report, was found to be only partially effective in removing the contaminants. With an initial TOC of the groundwater of 4,000 mg/l, the best result in bench scale tests produced a stripping column effluent of 3,400 mg/l.

Steam stripping, in which the groundwater was preheated to 85-90°C, produced significantly better results. This process takes advantage of the high volatility of most of the compounds at elevated temperatures. The results from the bench scale test indicated that the TOC of the waste stream could be reduced from 4,000 mg/l to 1,400 mg/l. Nearly all of a selected number of representative volatile compounds were completely removed. As might be expected, this process was only moderately effective in removing the non-volatile fraction of the organic compounds.

Biological treatment (activated sludge or rotating biological contactors) was very effective in removing both volatile and extrac-

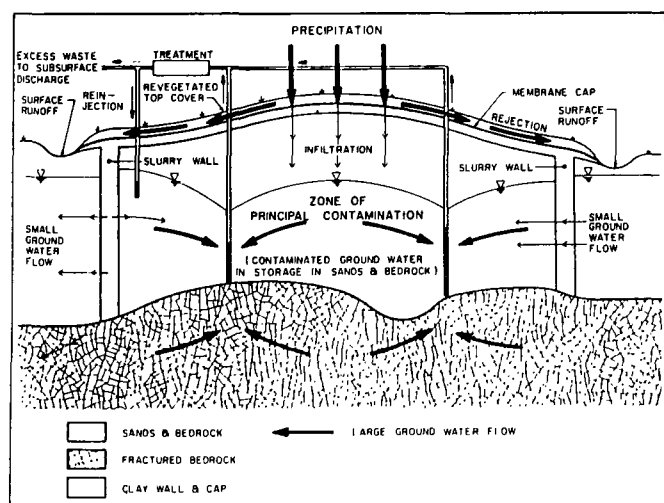


Figure 4.  
Proposed Containment/Treatment System

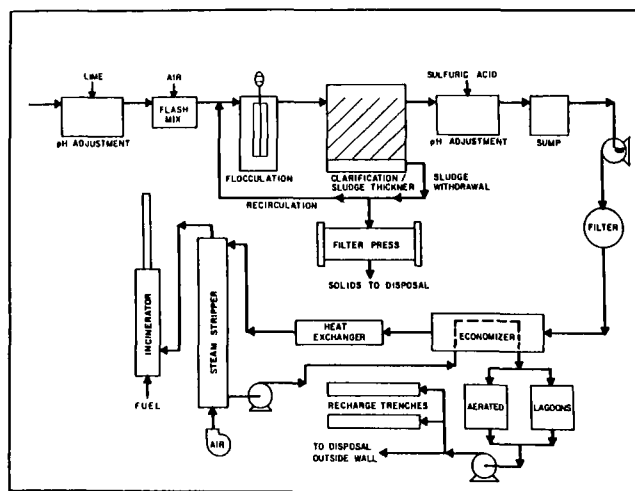


Figure 5.  
Proposed Groundwater Treatment System,  
Gilson Road Hazardous Waste Dump Site

table organics, eliminating nearly 90% of the total organic carbon. However, because of the need to add substantial quantities of nutrients and the relatively high capital cost of the process, compared with steam stripping, biological treatment alone was determined to be too costly for this application.

Biological treatment in the form of an aerated lagoon was found to be cost-effective in removing the remaining extractable organics following the steam stripping process.

Because of the reduced levels of organics entering this process and the resolubilizing of some of the nutrients as the biological sludge decomposes within the lagoons, lower levels of nutrient addition would be expected than with other forms of biological treatment.

The recommended treatment process would consist of chemical precipitation of the inorganics followed by pressure filtration to remove any remaining metallic floc. The waste stream would then be preheated to 85-90°C and then passed through a stripping column. Air would be passed counter-currently through the column and the off gasses would be burned in a fume incinerator.

The effluent from the stripping column would then be pumped to an aerated lagoon for removal of the remaining extractable organics. Nutrients in the form of ammonia and phosphoric acid would be added to the lagoon to insure adequate biological treatment. The lagoon effluent would then be pumped to recharge trenches located within the bentonite slurry wall. A diagram of the treatment process is shown in Fig. 5.

In addition to establishing the most cost-effective treatment process, it was also necessary to determine the design treatment flow rate and the length of operation of the treatment system.

Soil flushing experiments indicated that 90% of the contaminants could be removed from the soil after two full clean water flushes. Seepage of the remaining contaminants, when diluted with the surrounding groundwater and down-stream surface waters, was not expected to cause any health problems. The 20 acre slurry wall would hold approximately 137 million gal of contaminated groundwater. The estimated clean-water flow into the site from the bedrock and through the slurry wall was estimated at 23,000 gal/day.

Capital and operating costs and salvage values were developed for five different flow rates of the recommended treatment process. These rates ranged from 25 to 400 gal/min. After preparing a plot of the capital, operating, and salvage costs of the system (Fig. 6), it was found that the optimum treatment rate was approximately 300 gal/min, dependent upon rate of return used in the analysis. At this rate, it is expected to take 1.74 years to provide the two full flushes of the site necessary to remove 90% of the contaminants retained by the soil. The estimated capital costs would be \$4,920,000 and the annual operating costs are anticipated to be \$1,380,000.

#### CURRENT STATUS

In late 1981, a groundwater recovery and discharge system was installed in an effort to "freeze" the position of a major portion of the plume. This system appears to have been effective. A contractor began installation of the surface cap and slurry wall in Aug. of this year and is expected to complete the wall by Dec.

A pilot plant will be constructed to accurately determine specific design parameters and fine tune the operation to minimize O&M costs. This experimental work will be followed by the design and construction of the treatment facility which should be on-line in early 1984.

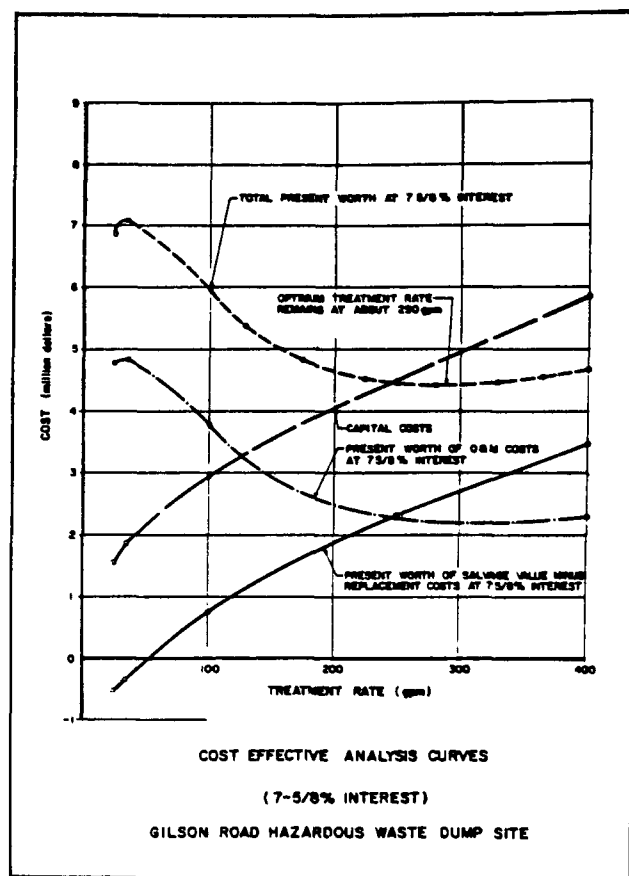


Figure 6.  
Cost Effective Analysis Curves

#### ACKNOWLEDGEMENTS

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# REMEDIAL ACTIVITIES AT FLORIDA'S UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Florida's water resources are not limited to its expansive 1200 mile coast line and over 7000 freshwater lakes. It is also blessed with an abundant supply of groundwater. The Floridan Aquifer underlies the majority of peninsular Florida and supplies most of the potable water needs of north and central Florida. The Floridan Aquifer is at the surface in many areas of central Florida. In coastal areas where the Floridan Aquifer is saline, surface aquifers are used for potable drinking water. The majority of the state has very pervious soils which allow for rapid transport of contaminants to the shallow surface aquifers; hence the groundwater is extremely vulnerable to contamination.

Toxic materials are finding their way into groundwater from various sources: hazardous waste dumps, waste lagoons and pits, sanitary landfills, accidental spills, mining operations, and storm water runoff. A recent assessment funded by the USEPA<sup>1</sup> showed over 70% of Florida industries using unlined impoundments for waste disposal. This is particularly alarming when 98% of the 6000 impoundments were located over useable drinking water aquifers. Florida's prominent position on EPA's Interim Priority List of uncontrolled hazardous waste sites is due, in part, to the susceptibility of the state's groundwater to contamination.

## SUPERFUND SITES

Florida recognizes that an integrated effort is needed to protect the state's ground and surface waters, fauna and flora, and inhabitants from exposure to hazardous wastes. In 1981, approximately 200 potentially dangerous uncontrolled hazardous waste sites were identified in the state. Twenty-seven of the most dangerous sites were ranked based on their relative hazard potential using USEPA's model. Sixteen of these sites were listed among the initial 115 USEPA interim sites eligible for funding under Superfund<sup>2</sup>. Twenty-four additional sites were ranked in 1982 and nine of these are being considered for addition to the priority list.

Florida's 16 sites (Table 1) are located throughout the entire state which emphasized both the extent of the problem and vulnerability of the environment. Very few areas of the state can be considered unsusceptible to potential hazardous waste contamination.

Principal contamination sources at Florida's uncontrolled hazardous waste sites (Table 1) include: municipal and industrial waste disposal facilities, fuel and solvent spills, battery casings, and industrial wastes from drum recycling, galvanizing, wood treating, electroplating, solvent extraction, battery salvaging, agricultural chemical manufacturing, polyester resin manufacturing, and solderless terminal manufacturing. Contaminants from these operations include both heavy metals and synthetic organic compounds. These toxic contaminants have been found in groundwater and/or surface waters and soils at these sites.

Activities at these hazardous waste sites fall into five main categories: enforcement by USEPA, Florida Department of Environmental Regulation (DER), or local programs, monitoring studies by responsible parties or DER, USEPA funded remedial action master plans or studies, USEPA/DER cooperative agreements

under CERCLA, and cleanup by responsible parties. Enforcement is taking place where viable responsible parties have been identified. USEPA guidance<sup>3</sup> currently specifies that before CERCLA cooperative agreement activities can proceed, the enforcement avenues must be pursued. Monitoring studies are underway where the extent of the site contamination is not known.

In the remainder of this paper, the author will discuss joint USEPA/DER CERCLA efforts. As of Sept. 1982, two sites have USEPA funded remedial action master plans (RAMPs) in preparation, three sites have USEPA/DER cooperative agreements for remedial investigations, and one site has an USEPA zone contractor study ongoing.

## REMEDIAL ACTION MASTER PLANS

The USEPA has authorized the preparation of RAMPs for the Hollingsworth and American Creosote sites. The purpose of a RAMP is to provide a general planning document for a hazardous waste site. A RAMP can be used to initiate work by a USEPA Zone Contractor, be the basis for a cooperative agreement with USEPA, or provide a plan of action for the site to assist with negotiations with responsible parties by the State and USEPA enforcement programs. The RAMPs will summarize available information for these sites and scope out remedial activities following the procedures established by the National Contingency Plan.

### Hollingsworth

The Hollingsworth Solderless Terminal Company, located in Broward County, Florida, was a manufacturer of electrical solderless terminals. As part of the manufacturing process, the parts were heat-treated in molten salt baths, degreased in trichloroethylene, and electroplated. Over the years, Hollingsworth disposed of its wastes in several ways. Machine parts were routinely cleaned on site and the solvents used were washed into the ground. Oil, grease and other unknown materials were routinely dumped into the septic system. Waste trichloroethylene was dumped routinely into a shallow drain field. The final mode of waste disposal was via an unauthorized injection well into the Biscayne Aquifer. The well was initially used to provide water for the plant cooling system. Approximately three to five years ago the use of the well was modified to inject solvent wastes into the ground.

Several Broward County public water supply wells and a major City of Ft. Lauderdale wellfield are all located within five km of the Hollingsworth site. One Broward County well is only about 120 m from the site. It has been estimated that more than 10,000 people are served by groundwater in this area.

The unauthorized disposal practices were not discovered until Hollingsworth contacted the Broward County Environmental Quality Control Board to report that oil was bubbling up out of the ground in the area surrounding the disposal well. Subsequent groundwater monitoring has shown the presence of trichloroethylene, and cis and trans 1,2-dichloroethane at the site. High levels of copper, nickel and tin were also found. Monitoring is underway to determine if the two public water supply wells are contaminated.

**Table 1.**  
**Florida CERCLA Sites**

<u>Site</u>	<u>Location<sup>1</sup></u>	<u>Ranking<sup>2</sup></u>	<u>Contamination Source</u>	<u>Action</u>
Biscayne Aquifer	Dade	2nd		EPA zone contract study
58th Street Landfill			Waste disposal facility	DER Enforcement/groundwater Monitoring
Miami International Airport			Fuel and solvent spills	Monitoring study
Miami Drum Services			Drum recycling wastes	EPA Cooperative Agreement for surface clean-up and groundwater study
Picketville Road Landfill	Duval	3rd	Industrial wastes	Monitoring study
Reeves Southeast Galvanizing	Hillsborough	3rd	Wastes from galvanizing operation	County Enforcement/groundwater monitoring
American Creosote	Escambia	4th	Wastes from wood treating facility	EPA RAMP/DER Enforcement
Taylor Road Landfill	Hillsborough	4th	Waste disposal facility	EPA Enforcement
Davie Landfill	Broward	5th	Waste disposal facility	Monitoring study
Pioneer Sand	Escambia	5th	Electroplating waste disposal landfill	DER Enforcement
Timberlake Battery	Hillsborough	5th	Battery casings	DER Negotiation
Whitehouse Oil Pits	Duval	5th	Waste oil and acid sludge pits	EPA Cooperative Agreement for Phase I investigation
Coleman-Evans	Duval	6th	Wastes from wood treating facility	DER Enforcement/groundwater monitoring
Hollingsworth	Broward	6th	Wastes from solderless terminal manufacturer	EPA RAMP/County Enforcement
Alpha Chemical	Polk	7th	Wastes from polyester resin manufacturer	Monitoring study
Zellwood Groundwater	Orange	7th	Wastes from agricultural chemical or drum recycling operations	Monitoring study
Gold Coast Oil	Dade	8th	Spills from drum storage and solvent extraction operation	Responsible party cleanup
Sapp Battery	Jackson	8th	Wastes from battery salvage operation	EPA Cooperative Agreement for Phase I investigation
Tower Chemical	Lake	8th	Wastes and spills from agricultural chemical manufacturer	Judgement/EPA Enforcement

Notes:

1 County

2 EPA ranking groups of 10

#### American Creosote

The American Creosote site comprises approximately 6 ha. American Creosote Works is an inactive wood treatment facility located in a densely populated residential/commercial area of urban Pensacola, Florida. The facility had been treating wood from

1901 to 1982 and discharged contaminated wastewater into two unlined percolation ponds. The facility utilized the "Rurping process" for treating wood with pentachlorophenol and creosote. The condensate water from this process was discharged into the unlined ponds. This wastewater contained entrained oils, preservatives, and

wood carbohydrates. Bottom sediment sludge from the treatment process was also discharged into the ponds.

Sampling of soils and waters at the American Creosote facility has revealed the presence of numerous substances including pentachlorophenol, oils and greases, phenol, 2,4-dimethyl phenol, 4-methyl phenol, fluorene, pyrene, fluoranthene, phenanthrene, and numerous other compounds. These contaminants have percolated through the highly permeable soil into the shallow groundwater table. The groundwater beneath the site is moving in a southerly direction. Contaminants from the American Creosote facility have been found in the groundwater 100 m south of the facility. Pensacola Bay is approximately 500 m south of the facility, in the direct path of the leachate plume.

### USEPA ZONE CONTRACTOR STUDY

The USEPA funded a zone contractor study of the Biscayne Aquifer site in Apr. 1982. The purpose of this study was to identify the extent of contamination of the Biscayne Aquifer in northwest Dade County by examining existing data and to propose further monitoring if warranted. The Biscayne Aquifer site is Florida's highest priority site for Superfund assistance, since this aquifer is the sole source of fresh water utilized for water supply in Dade County. It is a highly permeable, wedge-shaped unconfined surface aquifer composed of limestone and sandstone which underlies the entire county. It has an approximate thickness of 30 to 50 m along Biscayne Bay, and is less than 3 m thick along the western edge of Dade County. The Biscayne Aquifer is considered the most productive shallow non-artesian aquifer in Florida and one of the most permeable aquifers in the world. Average transmissivity of the aquifer is about 60 million l/day per meter, the storage is about 0.20, and the permeability is approximately 2.5 million l/m<sup>2</sup>.<sup>4</sup>

Several major wellfields are in the general vicinity of potential contamination sources in northwest Dade County. These wellfields include: Miami-Springs (80 mgd), Preston (70 mgd), and Medley (47 mgd). In addition to these public water supply wells, over 400 private wells are present in this area. The identified sources of contamination to the aquifer in this area of Dade County include: the Northwest 58th Street Landfill, the Miami International Airport site, and the Miami Drum Services site.

#### Northwest 58th Street Landfill

The Northwest 58th Street Landfill consists of a 260 ha area. The landfill began operation in 1952 as an open dump. Through July 1982 the estimated disposal rate for garbage and trash was about 90,000 tons/month and for liquid wastes was about 1 million l/month. Resistivity investigations by the U.S. Geological Survey and Technos, Inc. have determined that, leachate from the landfill has infiltrated the Biscayne Aquifer beneath and adjacent to the landfill site.<sup>5</sup> The infiltration is in the form of a groundwater plume moving in an easterly direction along with the natural groundwater gradient. The close proximity of wellfields to the landfill has stimulated much concern regarding contamination of these drinking water sources. The landfill is less than 5 km upgradient of the Miami Springs and Preston wellfields a 2 km from the Medley wellfield.

This site is not permitted as a sanitary landfill by DER. According to preliminary close-out plans for the landfill, it is classified as an open dump and is operating in violation of a 1979 consent order between DER and Dade County. Final close-out plans for this landfill are now being prepared and this facility is expected to be closed by the end of 1982.

#### Miami International Airport

Miami International Airport is located less than 1 km south of the Miami Springs wellfield. Industrial operations associated with a typical commercial airport have resulted in hydrocarbon contamination of surface and ground waters over the past years. Since 1966 approximately 15 spills and leaks have been recorded.

The total discharge of hydrocarbon materials is estimated to be 7.5 million liters. This includes the loss of an estimated 5.5 million

**Table 2.**  
**Summary of Potential Contaminants by Site**  
**for the Biscayne Aquifer**

Site	Vol Org. Comp	Heavy Metals	PCBs	Pesti- cides	Phenols	Cyanide	Base/ Neutral Extrac Priority Pol'ts	Oil & Grease
NW 58th St Land- fill	A	A	B	A	A	B	B	A
Miami Drum Site	A	A	A	B	A	A	B	A
Miami Int'l Airport	B	A	B	C	A	A	C	A

A—Presence detected in groundwater sampling

B—No groundwater analytical data available but the nature of activities at the site indicates that the contaminant may be present

C—No groundwater analytical data available and the nature of activities at the site indicates that it is unlikely that the contaminant is present

liters of Varsol (a petroleum-based cleaning solvent) discovered at the Eastern Airlines maintenance base. Recovery operations have removed less than 10% of the estimated spills. No testing has been done to measure the dissolved fraction of hydrocarbons in water around the airport. The proximity of the airport to the water supply wells and several major canals is reason for concern.

#### Miami Drum

The Miami Drum Services site is approximately 0.5 ha in area. The site is an inactive drum recycling facility located in a predominantly industrial area. About 5,000 drums of various chemical waste materials including corrosives, solvents, phenols, and toxic metals were observed on the site while the company was operating. Drums were washed with a caustic cleaning solution, and the waste solution was disposed of on-site.

Recent electromagnetic studies indicate a groundwater contaminant plume associated with the site. Preliminary results from five shallow monitoring wells indicate that the plume contaminants may include PCBs, trichloroethylene, dichloroethene, and other halogenated organic compounds, as well as heavy metals, oil, and grease. The plume is moving toward the Miami Springs wellfield and toward the Medley wellfield which is less than 400 m away.

#### Biscayne Aquifer Study Results

The first phase of the zone contractor study<sup>6</sup> concluded that the toxic contaminants of particular concern include volatile organic compounds, heavy metals, phenols, cyanides, pesticides, and PCBs (Table 2). Although no indications were found of contaminant plumes containing high levels of toxic materials, there is a general lack of groundwater monitoring data for the area. Further sampling may indicate the presence of a high-level contaminant plume at any of these sites. A unified, planned, and intensive sampling effort is needed to determine the magnitude of groundwater contamination in order to protect Dade County's drinking water.

### COOPERATIVE AGREEMENTS

CERCLA allows USEPA and states to enter into cooperative agreements for taking remedial actions at hazardous waste sites on the Priority List. Cooperative agreements allow cost sharing of appropriate remedial activities which are consistent with the National Contingency Plan. The agreement assigns specific responsibilities to the state and USEPA for each phase of a site's response actions. Three phases have been identified for response actions. Phase one involves investigation and feasibility activities, phase two includes final design of appropriate remedial alternatives, and phase three allows for actual implementation of the selected remedial alternatives.

### Miami Drum

The USEPA and DER have entered into a cooperative agreement for surface cleanup and a groundwater study at the Miami Drum Services site. In 1981 Dade County obtained the Miami Drum Services site through eminent domain proceedings to use the property for construction of a maintenance yard for the county's rapid rail transit system. The county contracted in Dec. 1981 for excavation and off-site disposal of contaminated soils. The "how clean is clean" issue had to be addressed. The amount of contaminated material to be removed was based on analyses of extensive soil-core borings at the site. Initially, a quadrant of 25 3-m cores spaced over the site was used to identify contaminated soils. The soil cores were analyzed every 0.5 m for suspected contaminants. The determination of the amount of soil removal was based on an assessment of the soil contaminant data and EP toxicity tests.

In addition to removing obviously contaminated soils based on bulk analyses, soils displaying EP toxicity parameters concentrations in excess of 10 times the state of Florida "minimum criteria" for groundwater were excavated. Excavation removed the first 2 m of soil and up to 3 m of the contaminated portion of the underlying limestone. Approximately 8,000 m<sup>3</sup> of material were removed. Contaminated soils were transported to and disposed of in the secure USEPA approved hazardous substance disposal facility in Emelle, Alabama. A portion of this material was below the water table; therefore, treatment of the contaminated water encountered during excavation was performed prior to on-site disposal. The total cost of this remedial activity was \$1,600,000.

A \$50,000 remedial investigation and feasibility study of remedial alternatives for cleanup of groundwater contamination is planned for the site. Preliminary evidence suggests that contaminants have entered the groundwater underlying the site. A groundwater monitoring study will be implemented in order to determine the extent of contamination and to identify alternatives for dealing with the subsurface contamination.

### Sapp Battery

The USEPA and DER have entered into a cooperative agreement for \$236,000 for a remedial investigation and feasibility study for the Sapp Battery Salvage site. The Sapp Battery Salvage site is a 12 ha site located in Jackson County, Florida. Prior to the closing of the facility in 1980, Sapp Battery Salvage was engaged in recovering lead from spent case batteries. During the period of operation, wastewater containing lead, zinc and sulfuric acid was discharged into settling pits which overflowed to an unlined pond. Spent battery casings were disposed of in several on-site fill areas. The pond, along with runoff from the Sapp property, discharges through two culverts into a natural creek system. Dead and stressed vegetation, as well as strong sulfuric odors, were noted along the drainage route from the site. Significant levels of metals including lead, magnesium and zinc have been found in sediments several miles downstream from the site.

The USEPA conducted a partial cleanup of the site in Aug. 1980. The efforts were geared toward raising the extremely low pH of the pond and berming certain areas to prevent contaminated runoff. Despite these efforts, runoff continued to move off-site. Since the shallow groundwater is closely connected to surface waters in this area, there is a strong likelihood of groundwater contamination.

In order to permanently solve the environmental problems associated with the Sapp Battery Salvage site, a phased program has been implemented. Phase one will consist of a remedial investigation and feasibility study. The remedial investigation will consist of groundwater and soil testing to define the extent of contamination. The feasibility study will identify the most cost effective long-term solution.

### Whitehouse Oil Pits

The USEPA and DER have entered into a cooperative agreement for \$265,000 for a remedial investigation and feasibility study at the Whitehouse Oil Pits site. The site is located in the community of Whitehouse which is west of Jacksonville in Duval County,

Florida. The oil pits were owned and operated between 1958 and 1968 by Allied Petro-Products, Inc., which used a sulfuric acid process to recycle used petroleum products. Waste from this operation was dumped into the pits and included acid sludges as well as waste oil containing PCBs. The pits were abandoned in 1969 when the company went bankrupt.

The Whitehouse site was given national attention when it was identified on an ABC television presentation.<sup>7</sup> On several occasions the pit levees have ruptured and spilled contaminants onto adjacent private property and into a creek. Chemical contaminants included heavy metals, PCBs and other halogenated organic compounds. Since the water table is generally within 1.5 m of the land surface, the oil pits pose a threat to the shallow aquifers used for water supply purposes.

The City of Jacksonville, DER, and USEPA have attempted to control pollution from the site by reinforcing the pit dikes, dewatering the pits, and capping with clay and soil. Recent efforts have included: liming to increase pH; rerouting of a perimeter drainage ditch; lining another ditch with clay to prevent leachate migration; and surface revegetation. Recent site inspections indicate that leachate continues to seep from the covered pits despite these efforts.

Additional efforts will be needed to achieve a stable site condition and prevent further migration of contaminants. An initial remedial measure and an investigation-feasibility study are planned. The initial remedial measure will be an effort to reduce the leaching of contaminants into surface water. This will reduce the dangers to public health and reduce further release of contaminants into the environment during the course of the remedial investigation-feasibility study. Additional work will consist of field investigations including groundwater monitoring. The feasibility study is designed to identify the most cost-effective long term solution.

### CONCLUSIONS

Florida has recognized the need for an integrated effort to protect the state's environment and inhabitants from the exposure to hazardous wastes. Superfund remedial activities initiated by DER and USEPA during the past year should lead to the cleanup of at least five of the 16 Florida priority sites. Ongoing enforcement activities will result in remedial actions at other priority sites in 1983. In order to meet the growing demands of hazardous waste remedial activities in the state, increased state funding is needed for staff, equipment, and matching funds for USEPA-funded cleanups.<sup>8</sup> The mitigation of the adverse effects associated with uncontrolled hazardous waste sites will require a multimillion dollar annual expenditure.

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# SAFETY AND AIR MONITORING CONSIDERATIONS AT THE CLEAN UP OF A HAZARDOUS WASTE SITE

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## INTRODUCTION

Effective management of a hazardous waste site cleanup requires realistic integration of safety concerns into all operating procedures. Decisions must continuously be made that not only minimize the risk to workers and the public, but also promote operational expediency. Experience is often the best teacher in making these decisions.

In this paper, selected decision-making factors and elements essential to the management of a safety and air monitoring program are critically reviewed with respect to the practical experience gained at the General Disposal Co. clean up, a major removal action of a drummed waste facility. Positive features of the safety program are addressed, as are logistical and organizational difficulties that arose during the clean up. It is hoped that this review will help clarify realistic options available to decision-makers when developing future safety programs.

In the paper, the authors specifically address site background, organizational management, levels of personnel protection, decontamination procedures, health surveillance, evacuation procedures, operations safety and air monitoring. Selected hazard assessment criteria are presented, as are other decision-making criteria used to justify program elements.

## BACKGROUND

On July 10, 1981, a fire erupted at the General Disposal Co. facility in Santa Fe Springs, Ca., burning nearly half of the estimated 18,000 drums of assorted paint wastes and unidentified chemicals stored on the one acre site. A series of explosions prevented control of the three alarm blaze until the next morning and the site continued to smolder for nearly two weeks after the incident (Fig. 1).

Numerous local, state and federal agencies responded to the scene, supported by a private clean up contractor. Based on concerns over the continued threat posed by the site, USEPA Region IX submitted a request to USEPA-Headquarters and was granted funding for emergency removal action under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA or "Superfund").

A unique situation developed after two months of intensive cleanup effort, when a generator of products found at General Disposal assumed financial responsibility for completion of the clean up. This led to the termination of USEPA's clean up contractor in early Oct. and replacement by a second contractor selected by the generator.

The familiarity of the generator and their contractor with the majority of products on the site and the USEPA experience on site allowed for significantly modified operations and a greatly reduced work crew. The modifications effectively allowed the second contractor to implement less stringent personal protection requirements. The relationship between site safety monitors and clean up contractor personnel also varied significantly over the two phases of clean up operations. The sequence of significant events as they occurred at General Disposal is shown in Table 1.



Table 1.  
Sequence of Significant Events at General Disposal

Date	Event
7/10/81	First at General Disposal
7/11-23/81	Site stabilized; fire watch maintained
7/24/81	Superfund implemented; cleanup efforts begin
8/14-27/81	Work shutdown due to lack of further funding approval
8/28/81	Cleanup begins after shutdown
9/10/81	Work again shutdown
9/28-10/8/81	First contractor demobilization
10/19/81	Second contractor stages equipment and begins work
1/6/82	Site work completed

The brief summary provided below is intended to highlight some of the technical operations which occurred over the duration of cleanup efforts. A site map showing cleanup operations is found in Fig. 2.

## Summary of Technical Operations

- Runoff and sediment from firefighting efforts was collected from residential streets and returned to the site. Drums and debris scattered offsite by explosions were also consolidated onsite.
- Site security was provided by the L.A. County Sheriff's Department. Temporary fencing was constructed around the site. A fire watch was maintained by the Santa Fe Springs Fire Department until the site ceased to smolder.

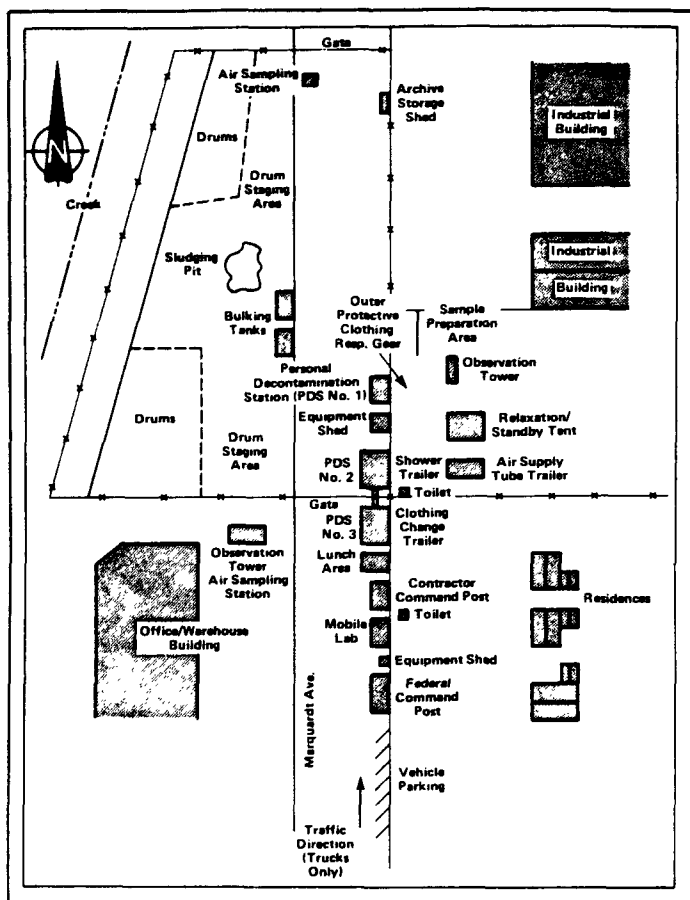


Figure 2  
Site Sketch of General Disposal on August 14, 1981

- Staging areas were cleared by removing non-chemical debris, including old trucks, trailers and dumpsters.
- Drums containing liquid were moved to a staging area and opened with hydraulic drum handling equipment mounted on a hydraulic excavator. The drums were numbered and sampled with one sample being characterized for compatibility and one being supplied to USEPA site monitors for documentation and storage. After the drum contents were characterized by an on-site laboratory, liquid products were batched in tanks for disposal. Basic characterization distinguished between flammable/combustible organics and neutral products and in some cases specific compounds. Any drums found to contain product requiring special handling (e.g., PCB, acids, bases or oxidizers) were isolated for further analysis and overpacking. This process was employed by the first contractor; the second contractor's familiarity with the material at General Disposal allowed them to simplify compatibility testing procedures. Only materials that were unfamiliar to site personnel were subjected to detailed analysis.
- Drums with solid materials or those containing charred residues were ripped open by a backhoe and dumped into a sludging pit. Sand was mixed with the solid residues and loaded into lined trucks for disposal.
- USEPA site monitors maintained a photographic log of each drum to accompany written descriptions. Samples were documented, packaged and stored in a secured shed for possible future enforcement actions. These samples were later transferred to the custody of the California Department of Health Services.
- Empty drums were crushed with a bulldozer (first contractor) or hydraulic drum crusher (second contractor), placed in lined dumpsters or trucks and disposed of as solid waste. All drums and liquids were disposed of at California Class I disposal sites.
- Following removal of all drums, including the overpacks, 6 in. of topsoil was removed from the entire site. Soil samples were

collected by the California Department of Health Services prior to the installation of a 6 in. clay cap on the site. Subsequent analysis of the soil samples indicated the presence of heavy metals and polychlorinated biphenyls which may preclude any future development of the property.

- Costs and site activities were monitored by the USCG Strike Team and Ecology & Environment, Inc. USEPA expenditures between July 24 and Oct. 8, 1981 reached approximately \$1.3 million; the generator spent approximately \$1 million to complete the cleanup by Jan. 6, 1982.

## ORGANIZATIONAL CONSIDERATIONS

A well-defined organizational hierarchy is probably the single most important factor for instilling a strong safety ethic into operations during the cleanup of a hazardous waste site. Recognizing the need for such an organization at General Disposal, USEPA and the other agencies represented at the site delegated explicit safety responsibilities to the Federal On-Scene-Coordinator (OSC) and, in addition, created the rather unique role of the Operations/Safety Advisor (OSA).

In accordance with the National Oil and Hazardous Substances Pollution Contingency Plan, the OSC is to direct and coordinate all Federal pollution control efforts at the scene of a discharge or potential discharge. With respect to safety, the OSC at General Disposal also had specific responsibility for:

- Assuring that appropriate personnel protective equipment was available and properly used by USEPA, USCG and contractor personnel in accordance with the site safety plan
- Assuring that personnel were aware of the provisions of the safety plan, were instructed in the work practices necessary to ensure safety and were familiar with the planned procedures for dealing with emergencies
- Assuring that personnel were apprised of the potential hazards associated with site conditions and operations
- Supervising the monitoring of safety performance by all personnel to ensure that required work practices were employed
- Correcting any work practices or conditions that would result in injury to personnel or exposure to hazardous conditions

To assist the OSC in carrying out those duties, the OSA served as the daily contact for operational advice and safety monitoring between the cleanup contractors and the OSC. The OSA did not directly supervise or manage contractor personnel, but rather provided advice and oversight. The OSA had responsibility to:

- Identify tasks and activities to be performed by the contractor with respect to the daily work order issued by the OSC
- Provide advice to the drum removal contractor and the OSC on operational and logistical options
- Conduct or request to be conducted site monitoring of personnel hazards to determine the degree of hazard present
- Recommend the proper and necessary clothing and equipment to ensure the safety of operating personnel
- Evaluate chemical hazard information and recommend to the FOSC and cleanup contractor necessary modifications to work and safety plans
- Monitor the safety performance of all personnel to ensure that the required practices are employed

Although the OSA did not have direct line authority, his visible interaction with the cleanup contractor and ready access to the OSC encouraged cooperation and adoption of recommended safety procedures (Fig. 3). The practical advantages of an intimate advisory role are numerous: (1) the OSA position may be filled by a technical consultant rather than an empowered government agent, (2) the OSA is generally more technically oriented than the OSC, who must deal more in policy-related matters, and (3) the OSA can provide succinct recommendations on significant technical issues and refer policy issues to the FOSC.

Additional safety support was provided at General Disposal by representatives of the USCG-Pacific Strike Team. An informal



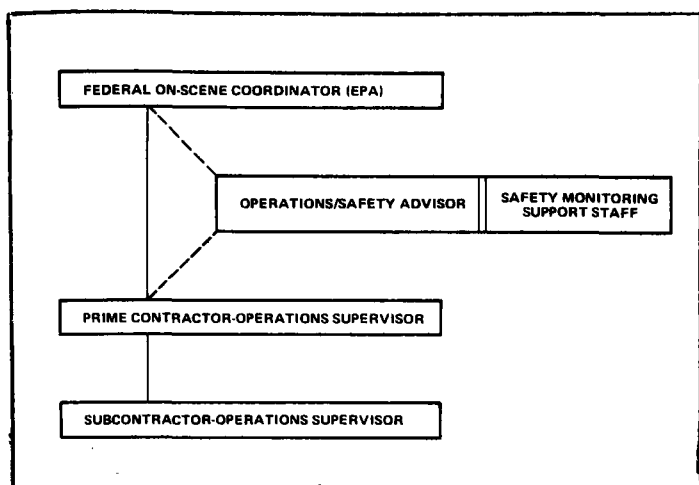


Figure 3

Organizational Structure at General Disposal (July through October 1981)

communications relationship was implemented where safety violations observed by USCG personnel were referred through the OSA for discussion with the contractor and/or OSC. Supplemental support such as that provided by the USCG greatly enhanced the overall effectiveness of the safety program.

During the period when USEPA was funding the cleanup effort, the OSA role remained dominant and influential. However, after responsible parties assumed funding, the OSA's influence gradually deteriorated. During the latter phase recommendations could be made, but without a management incentive the contractor was not compelled to adopt them. The more detached presence of the OSC during the final 2-3 months of the cleanup also contributed to the decreased effectiveness of the advisory role.

For future remedial actions, the management organization as applied at General Disposal is only recommended for Superfund cleanups where there is a strong Federal or state agency presence so that the OSA can function between the funding source and the cleanup contractor. The role of the OSA as discussed above essentially ceases to exist when a third party is funding cleanup activities. In that event, a safety supervisor with direct line authority may be necessary.

### SAFETY PLAN ELEMENTS

Obviously, personnel and public safety is of paramount concern whenever remedial actions are undertaken at a hazardous waste site. However, integration of a realistic safety program into a major cleanup effort requires constant trade-offs between operational efficiency and expediency and the protection of worker and ultimately public health. In general, the best safety program can only be expected to minimize, and not eliminate, the risks inherent in a site cleanup.

The development of a comprehensive safety program is typically the end result of a democratic process involving numerous interested parties. Pragmatically, however, a single individual or agency must initiate and present a flexible outline upon which refinements can be made. In the case of General Disposal, safety plan development involved input from USEPA Region IX, USEPA Environmental Response Team, USCG-Pacific Strike Team, Los Angeles County Sheriff's Department, City of Santa Fe Springs Fire Department, California Department of Health Services, the prime and subcontractors, and E & E. E & E provided the fundamental format upon which each agency, at various times throughout the cleanup, contributed or refined selected elements.

The safety program is also one of the first components of the cleanup that needs to be definitized as soon as the operational scope evolves. In planned remedial actions, this is not too difficult. However, in emergency actions of the magnitude of General Disposal, circumstances often dictate an evolutionary approach to safety planning. Long before a definitive document can be pro-

duced and distributed, safe operating procedures should be verbally discussed with the contractor as well as local agencies that may be involved in an evacuation. A hard copy, however, should immediately follow, which tends to legitimize the safety protocols and is a valuable reference for the numerous management personnel on duty rotations.

A safety plan should be specific yet broad enough to accommodate the dynamic and unanticipated events that will certainly occur. A safety plan for a drummed waste removal action should contain clarification of the following fundamental elements:

- **Applicability**—to all site personnel, contractors, government agencies, government agents and visitors (assumption of liability should be discussed)
- **Responsibility**—definition of roles, organizational hierarchy, site supervision, government liaison, safety requirements, contractor hierarchy (accommodate rotating supervisory personnel, flexible definitions, integrate safety responsibilities into management roles)
- **Site description**—configuration, size and type of contamination; services, materials and equipment within contamination zone, contamination reduction zone, standby zone, clean zone (consider space constraints, hazard assessment, utility and transportation access, weather variables, security and emergency response)
- **Personnel/Equipment decontamination**—contaminant specific, sequence of stations, manpower support (consider reuse and storage of protective gear, wet/dry decontamination, laundry, on-site/offsite cleaning, discharge of contamination wash water or materials, frequency of use)
- **Levels of protection**—description of protective clothing and respiratory gear for drum handlers and samplers, equipment operators, ancillary personnel (consider exposure potential, job function, work station by zone, level of site activity; allow for case-specific modifications and input from air monitoring results)
- **Operations safety**—daily safety meetings, buddy system, health monitoring and first aid capability, weather conditions, fire suppression, safety observers, incident log, heavy equipment, etc.
- **Air Monitoring**—on-site, perimeter, and off-site; mobile and stationary, real-time or time-weighted (address objectives, agents, background influence, onsite operations, episodes, worst case scenarios, instrument selectivity and sensitivity, monitoring locations, frequency, duration, recordkeeping)
- **Emergency evacuation**—on-site personnel and public (consider worst case and likely events, signal techniques, action levels, fire department notification, rescue techniques, first aid and emergency equipment, communications, emergency transportation and routes, hospital/poison control centers, use of mobile laboratory for rapid chemical identification).

### DECISION CRITERIA

For anyone who is routinely in the position of making decisions that influence the health and safety of other people, the concept of acceptable risk is not new. Such decisions require constant juggling of dozens of factors, few of which are sufficiently quantified or clarified in a timely fashion for the decision-maker. The consequence of lacking complete knowledge, particularly when addressing work practices at a hazardous waste site, is a very conservative approach to worker and public safety.

In few cases is this dichotomy between conservative and expedient approaches more apparent than in the cleanup of a hazardous waste site comprised of thousands of charred, bulging, and cryptically-labelled drums. Uncertainty over the wastes present, coupled with the potential for an accident, demands a conservative approach, as adopted in the first phase of the General Disposal cleanup.

At General Disposal two distinctly different approaches to safety were implemented based on the confidence the two funding sources, USEPA and the generator, had in knowing what the barrels contained. The urgency placed on the cleanup and the level of effort expended are two other factors that contributed to the dif-



ference in the scope and sophistication of the safety programs.

## LEVELS OF PROTECTION

The selection of appropriate respiratory protective equipment and protective clothing can be accomplished after practical consideration of a series of interrelated hazard assessment factors broadly categorized under two groups—toxicity and exposure potential. Although semi-quantified decision trees are often applied to this selection process, the authors prefer a more flexible format consisting of two lists of considerations subjectively prioritized on the basis of specific site conditions, manpower constraints or logistical concerns (Table 2). Subjective weighting of the factors by a safety professional will generally yield a conservative selection of safety gear or procedures because of the strong likelihood that all toxicity or exposure factors are not accurately known for all substances.

**Table 2.**  
**Decision-making Considerations for Selection of Levels of Personal Protection**

Toxicity-Related Factors	Exposure Potential Factors
•chemical agents	•job function
•concentrations (background, episodic)	•proximity to zones of contamination (work station)
•dose-response relationship	•accident/major release potential
•physiologic/synergistic consequences	•level of site activity
•TLVs, ceiling limits, STELs	•physical properties of agents
•odor thresholds	•frequency of exposure
•percutaneous characteristics	•route of exposure
	•atmospheric dispersion characteristics

At General Disposal, the basic set of protective equipment was selected on the basis of two dominant criteria, job function and proximity to zones of contamination. Because the contents of the drums could not be confirmed and the potential for a major accidental release remained high, the highest level of respiratory protection (positive-pressure self-contained breathing apparatus) was selected. Similar rationale was followed for selection of the acid resistant, PVC, full body coverall. These universally-applied levels of protection, however, represented a conservative compromise over what was originally considered adequate.

Initial efforts to apply more exposure criteria and reduce the clothing and respiratory requirements for selected non-contact personnel resulted in confusion for the safety monitors and disgruntlement among the workforce. Primarily to avoid misunderstandings and encourage a spirit of cooperation all personnel in the contamination zone were subsequently required to wear the same basic outfit regardless of job function or work station (Fig. 4).



Figure 4

Case-specific exceptions to the basic protection levels were made by the OSA through application of the subjective exposure potential factors in Table 2. For example, at the end of a work day when all activity had ceased, organic vapor emissions on-site had dropped to background levels and winds were picking up, a quick foray onto the site to retrieve some forgotten equipment could be done with an air purifying respirator and a lightweight disposable coverall.

## PERSONNEL DECONTAMINATION PROCEDURES

Large scale remedial efforts generally require a different approach to decontamination than those applied at short duration investigative activities such as initial site entries. Procedures must still be representative of the hazard potential presented by the on-site materials, however few long-term remedial actions are able to accommodate personnel decontamination stations of buckets, shuffle pits, brushes and soapy water.

General Disposal presented several obstacles to such procedures because of the large number of workers onsite (up to 20), frequent movement on and offsite (every 25 min), the unavailability of a sewer discharge or holding pond and the severely restricted space.

Fortunately, there was no evidence of extremely hazardous materials onsite that would require extraordinary decontamination precautions. Consequently, a "dry" decontamination procedure was applied consisting of four stations: outer protective clothing removal, shower trailer, dressing trailer and standby zone (Fig. 5). As teams moved offsite, SCBAs and reusable clothing were "dropped" at the first PDS station, after which the worker immediately moved to either the standby zone or through the shower and dressing trailers to the lunch/break area. A pipe rack was used to hang garments labelled with the workers' names. Most workers found it advantageous to tape outer gloves and neoprene boots to the PVC coverall for quick donning.

Two sets of cotton coveralls were issued to each worker. At the end of the day the coveralls were bagged and sent for laundering.

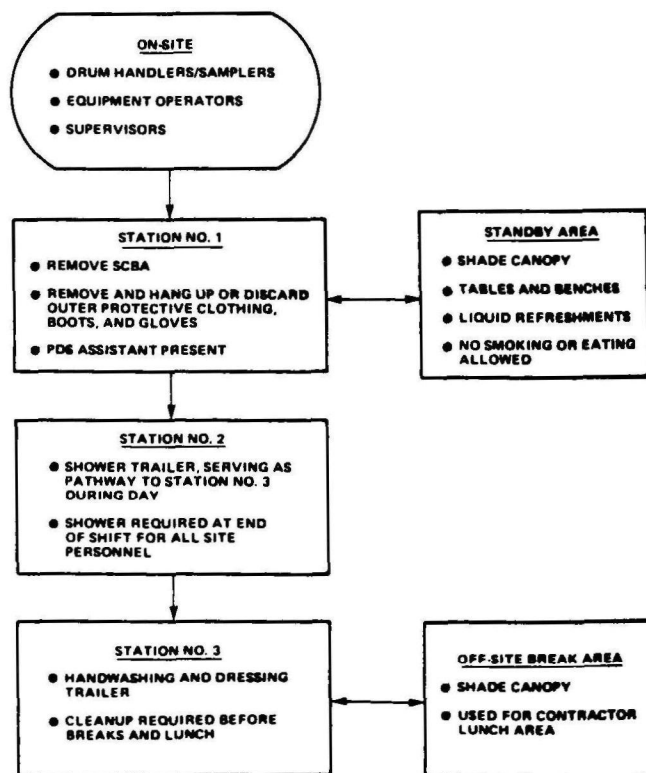


Figure 5  
Personal Decontamination Sequence

The most obvious health concern with a "dry" contamination procedure is that workers inevitably touch outer surfaces of their garments during donning and disrobing despite training on techniques to minimize contact. This procedure would not be recommended if extremely hazardous materials were suspected or if clothing became chronically and heavily contaminated.

## HEALTH SURVEILLANCE

Preparation for contingencies at a remedial cleanup depends upon a realistic evaluation of worst case scenarios and likely events based on the proposed level of effort and the environmental conditions at the site. Clearly, contingency procedures must anticipate physical and chemical injuries, as well as heat stress incidents when impermeable protective clothing is worn. Distinct emergency and injury prevention networks must be developed for each of these possibilities, including the development of emergency transportation systems, identification of medical centers, notification protocols, first aid/CPR and protocols for identifying specific chemical exposures.

The following comments are based on the experiences at General Disposal. Physical injuries in the form of sprained ankles or backs, puncture wounds, or broken bones are nearly unavoidable despite safety awareness and training. The preponderance of jagged metal, uneven terrain, construction debris, heavy lifting and encumbered movement due to protective equipment increases the likelihood of physical injuries.

Significant chemical exposures are probably less likely to occur due to the conservative precautions already taken in the form of respiratory and dermal protection. For chemical injuries, on-site first aid is largely limited to the use of eyewashes, deluge showers and oxygen inhalators. In anticipating a chemical injury, emphasis should be placed on location and maintenance of first aid equipment and developing protocols for its use. An additional network should be developed for identifying the chemical agent(s) to which the worker(s) may have been exposed.

At General Disposal real-time air monitoring was available, as was a mobile laboratory for agent-specific determinations. Safety protocols required collection of soil, liquid or air samples within the general vicinity of any exposure. This information would then be relayed to the attending physician shortly after arrival of the injured person at the hospital.

In the one incident where a chemical injury did occur at General Disposal, the chemical identification protocols were satisfactorily activated. However, the chemical results proved questionable. By the time the individual had been attended to and samples collected, several minutes had passed. Vapors had subsequently dispersed and the quality of air had changed, leading to uncertainty regarding the specific chemicals involved and their concentrations at the time and place of the exposure. At best this protocol would yield only an approximation and any results obtained should be relayed to the physician as only a possible exposure.

Heat stress incidents may not be a health concern at many remedial cleanups. However, almost anytime impermeable protective clothing is worn, significant planning into preventive measures and emergency response is essential. Practical field techniques for heat stress management can vary greatly in sophistication. Determination of pulse and sweat rates, inner body temperatures, and application of one of the many heat stress indices may be deemed appropriate in some cases, while modification of traditional work schedules may suffice in others.

At the peak of activity at General Disposal, the heat stress management program was designed around the use of work-rest cycles. The work day was also shifted toward the cooler morning hours after the possibility of nighttime work was eliminated as too hazardous due to lighting problems and disturbance to the public. Generally, teams worked for the duration of a 45 ft<sup>3</sup> air cylinder (about 25 min) and then rested for approximately the same period. Drinking water and dilute electrolyte replacement fluids were provided during rest cycles. As ambient temperatures increased, longer periods were devoted to testing and work cycles were shortened.

Despite seemingly liberal rest periods in the shaded standby area (some approaching 45 min) several mild cases of heat stress—heat cramps and exhaustion—occurred. As temperatures hovered over 100°F on some afternoons, the activity of the field crews was severely reduced, although equipment operators maintained a nearly normal pace.

Lack of adequate acclimatization played an important role in the heat stress incidents. The occurrence of at least two major shutdowns and the rotation of new unacclimatized personnel into the work force contributed significantly to the occurrence of heat stress incidents. Failure to recognize the need for reacclimatization after the lengthy shutdowns and the lack of a personnel tracking log to identify first-time workers were probably the greatest deficiencies in the heat stress management program. Unfortunately, the urgency of the cleanup effort tended to overshadow these needs. At future sites requiring impermeable protective clothing, it is felt that a program based on work-rest cycles is practical and adequate but that a required acclimatization schedule (3-5 days for fit males) be implemented.

## EVALUATION CONSIDERATIONS

The uncontrolled release of chemical vapors or a conflagration that threatens onsite personnel or the public is clearly a worst case situation that must be anticipated. At a drummed waste facility the most likely cause for evacuation is fire and/or explosion from a spark or chemical reaction, although some scenarios may also include uncontrolled releases of volatile vapors (ruptured or leaking barrels can generally be covered or contained before the incident escalates to evacuation status).

Typically, sirens and air horns have been used to warn workers of a pending disaster. However, at many sites they may have little practical merit. This is particularly true at sites where distance, noise of heavy machinery, respiratory protection equipment and protective clothing combine to muffle an emergency signal. During peak operating periods at General Disposal the noise levels were significant. To alleviate this problem a 20 ft observation tower was erected at the southern end of the site with radio-communication both to on-site and off-site personnel. From the scaffold, the observer not only functioned to warn of pending incidents, but also kept track of individual workers and noted safety infractions. At least one evacuation drill should be practiced during the first full week of operation to test the efficiency of the evacuation protocols.

Decisions need to be made on the amount of on-site disaster mitigation that should take place before an evacuation is ordered. It was felt at General Disposal that limited firefighting could be handled by on-site personnel smothering flames or chemical reactions with sand or lime. Quantities of both were readily available. Similar procedures were to be followed should volatile vapor concentrations reach certain onsite or perimeter action levels. Fire extinguishers were to be used only for personal protection or equipment fires. The Santa Fe Springs Fire Department approved of the two step emergency notification protocol and was prepared to respond to any major emergencies.

An independent community evacuation plan prepared by the local fire or law enforcement agencies is an integral part of the safety plan. On-site personnel will not have the manpower or the authority to order or carry out a community evacuation. The plan should contain: 1) a description of responsibilities and command, 2) procedures for notifying residents (drive by, air, door-to-door), restricting traffic and security protocols, 3) evacuation destination and routes, 4) communication frequencies and reporting procedures, 5) coordination with ambulance and hospital services, and 6) maps, telephone numbers, and names. Ideally the plan should be prepared and disseminated prior to any on-site activity, which requires early interaction with the respective local agencies.

## OPERATIONS SAFETY

Throughout the daily operation of a remedial action, countless decisions are made that influence the movement of men, materials

and equipment. Often, many of these are unanticipated or inadequately addressed during safety plan preparation. Operations safety is the one area where most tradeoffs are made between operational expediency and minimization of risk to the worker and public.

Each site is unique with regard to operations. Discussed below are selected operational considerations that impacted safety at General Disposal. Some of the site operations are illustrated in Fig. 6.



Figure 6

- The use of a drum opening bunker constructed with sandbags or concrete dividers was originally planned, but later discarded because of the logistical difficulties and increased handling involved in moving an estimated 8,000 barrels to and from the bunker. The bunker technique would have essentially isolated each barrel as it was opened, thereby reducing the explosion potential, but would have required more handling and contact. An alternative approach was taken where the barrels were staged in rows of two or three with 12-18 in. between each barrel. It was felt that the spacing would minimize the domino effect if one barrel exploded and/or caught fire. This alternative allowed for rapid remote opening of the drums and eliminated the need to relocate the barrels.
- All heavy equipment, including rental backhoes and bulldozers, were fitted with 0.75 in. plexiglass screens to protect the operators. Inadvertent or deliberate barrel crushing often spewed contents toward the operators. On numerous occasions the screens saved them from possible injury.
- To minimize air emissions, crushed drums were removed from the site daily and batching tanks were covered with polyethylene during shutdown periods.
- Airline respirators were used only by heavy equipment operators adapted to 220 ft<sup>3</sup> air cylinders mounted on the equipment. Attempts to use traditional airline equipment for workcrews during the second phase of the cleanup proved to be inefficient and dangerous.
- Daily meetings were held to brief workers on work assignments and discuss safety infractions observed the previous day. After each successive day of working without an accident or injury there was a tendency to become less cautious and more liberal in bending the rules. These "tailgate" meetings reinforced safe work practices and were critical to maintaining the high level of safety consciousness necessary at the site.
- A variation of the buddy system for on-site work tacitly evolved. Because many tasks occurred simultaneously (e.g., drum opening, drum sampling, drum documentation, sludging and bulking), it was not always feasible for workers to work side by side. Except for drum handlers who always worked in groups of two or more, workers with less physical drum contact (e.g., air moni-

toring, drum documentation and supervisors) were often not paired with a buddy. This procedure was justified because of the relatively small size of the site and the large number of workers. The overhead observer also acted as an onsite "buddy"

### AIR MONITORING

The scope and adequacy of a comprehensive air monitoring program is without question one of the most important and controversial elements of the overall safety and health program. Two interests must be addressed: the health and safety of on-site personnel and the health and safety of the surrounding public. Without this dual perspective a seemingly adequate on-site air monitoring program can seriously fail to address the qualitative and quantitative parameters needed to evaluate the hazard to the unprotected public. Distinct programs must be implemented for each.

At General Disposal, the task of procuring and maintaining the instruments and conducting the air monitoring was left largely to the prime cleanup contractor. The contractor judiciously focused on air monitoring for personal safety as outlined in the safety plan. As the cleanup progressed it became necessary to quantify the offsite emissions to address the concerns of the local health officials, even though on-site levels indicated a minimal hazard. Eventually, a perimeter monitoring program was implemented during active work periods.

On-site organic vapor emissions (within 2 ft of a source) were commonly around 10 ppm with rare instantaneous peaks of up to 100 ppm in the drum crushing area or sludging pit. Draeger colorimetric detector tube analysis indicated that acetone was a common and predominant species. Perimeter concentrations were generally less than 5 ppm total organic vapor with peaks (3-5 times daily) of up to 30 ppm. The final air monitoring scheme is shown in Table 3.

Two sets of arbitrary action levels were established for on-site and offsite locations. On-site concentrations of 30 ppm total organic vapor (flame ionization or catalytic combustion detectors) in the breathing zone would indicate the need to verify the source and modify operations as necessary. Public evacuation criteria and strategy were developed by the California Department of Health Services (DHS) and were based on the sustained presence (a few minutes) of selected volatile organics at the perimeter fenceline.

The action levels selected by DHS were the threshold limit values (TLVs) of four compounds alleged to be on-site (benzene, hexane, methyl butyl ketone, carbon tetrachloride). Sustained readings of 5-50 ppm total volatile organics at the perimeter on

Table 3.  
Air Monitoring Strategy  
General Disposal Co. (August 1981)  
(refer to Figure 2 for locations)

Location	Purpose/Procedure	Instrumentation
•drum opening/sludging/staging area	evacuation criteria; action level 30 ppm total organic vapor; stationary w/ audible alarm	•combustible gas monitor (Gas-Tech Model 1238 or GX3A)
•mobile monitor around site and perimeter	evacuation criteria/ air characterization; hourly spot checks adjusted to changes in operations	•combustible gas monitor (Bacharach TLV Sniffer) •organic vapor detector (Century System OVA or HNu Photoionization Detector) •colorimetric detector tubes (Draeger Detection System)
•perimeter-north and south	evacuation criteria; continuous monitoring; adjusted to wind shifts	•organic vapor detector (Century Systems OVA w/recorder or HNu Photoionization Detector w/recorder)
•drum crushing area/bulking tank	air characterization; agent-specific; time-weighted average; stationary; as requested	•sampling train with personal sampling pump, charcoal and Tenax collection media

either the flame ionization or photoionization detectors would trigger the use of colorimetric detector tubes to verify the presence of one of the criteria compounds.

Several comments are worthwhile on how the action levels were determined. The use of conservatively staggered on-site and perimeter action levels, in which there is corrective intervention if the on-site level is exceeded, greatly reduces the chance that conditions on-site will deteriorate to a point where the perimeter action level is breached. For example, when on-site levels approached 30 ppm, the ambient air concentrations at the perimeter still remained far below the 5-50 ppm action levels for the specific compounds. This scheme, however, has several drawbacks as applied at General Disposal. First, the use of the TLV as the criteria for setting an action level is not appropriate when the consequences are as serious as a residential neighborhood evacuation. In fact, they clearly represent a most conservative criteria, being based on an eight-hour time-weighted average. Furthermore, unless a major fire occurs in which there would be no question of an evacuation because of the proximity of residents, vapor emission episodes are likely to be short and controllable. Despite the presence of more susceptible elderly or young children in the downwind population, an intermediate action level approaching the short-term-exposure limits (American Conference of Governmental Industrial Hygienists) may be more realistic for fence-line evacuation criteria.

Another drawback is that perimeter action levels were based on specific substances—substances that were suspected yet not proven to be on-site in significant quantities. Considering the instrument and operator capability at the site, substance-specific determinations were difficult. Colorimetric detector tube verification of specific agents would be time-consuming, possibly futile, and subject to all interference and sensitivity variables of colorimetric detector tube methodology. An alternative approach could have been to use a total organic vapor reading instrument with a backup of a portable gas chromatograph for species-specific determination. Standards run previously could be used for baseline comparison. Within 10-15 min a chromatogram could be complete and appropriate action taken (either on-site mitigation or evacuation).

Some of the fundamental decision-making factors considered in planning an air monitoring program are summarized in Table 4.

## CONCLUSIONS

The unique evolution of cleanup efforts at the General Disposal waste storage facility in Santa Fe Springs, California, illustrates the breadth of occupational and public safety factors and decisions that apply to many site cleanups. General Disposal was a valuable lesson in the differences between textbook approaches to safety management at waste sites and the functional realities of actually implementing a comprehensive program. Critical factors which affected implementation of a safety program included the emergency nature of the cleanup, non-traditional work schedules, unexpected shutdowns of site work and discontinuity in cleanup contractors. The relationship between site monitors and cleanup personnel varied significantly over two phases of operations involving different prime contractors with different sources of funding.

General Disposal's proximity to residential neighborhoods and small businesses also created significant concerns relating to public health and safety. Effective site management therefore included a broad range of health concerns pertaining to both contractor personnel and the public at large.

There are several general axioms that grew from the General Disposal experience:

- The willingness to accept risk determines the latitude the safety-decision-makers will have in designing operating procedures. Gen-

**Table 4.**  
**Fundamental Monitoring Applications and Considerations**

Application	Consideration
Evacuation Criteria	<ul style="list-style-type: none"> <li>•Occupational and public health focus</li> <li>•real-time monitoring</li> <li>•variable action levels</li> <li>•on-site and perimeter locations</li> <li>•volatile organics and agent-specific</li> <li>•stationary, downwind</li> </ul>
Modification of Levels of Personnel Protection	<ul style="list-style-type: none"> <li>•occupational health focus</li> <li>•real-time and TWA monitoring</li> <li>•arbitrary action levels based on exposure and toxicity factors</li> <li>•on-site, worst-case locations</li> <li>•volatile organics and agent-specific</li> <li>•personnel and area monitoring</li> </ul>
Air Characterization and Documentation	<ul style="list-style-type: none"> <li>•informational or planning focus</li> <li>•real-time or TWA monitoring</li> <li>•episode related, correlate with operation</li> <li>•on-site, perimeter, and off-site (background)</li> <li>•volatile organics and agent-specific</li> <li>•area monitoring</li> </ul>
Sample Characterization	<ul style="list-style-type: none"> <li>•emergency assistance focus</li> <li>•real-time monitoring</li> <li>•quantify to extent possible</li> <li>•on-site, incident location</li> <li>•agent-specific</li> <li>•grab sample</li> </ul>

erally, the less risk the responsible parties are willing to take, the more expensive and resource intensive the cleanup becomes. It is the role of the safety professional to optimize both concerns.

- Establishment of a safety supervisor with line management authority or a safety advisor with access to supervisory personnel is essential to a strong, consistent safety program.
- Allocation of off-site/perimeter air monitoring responsibility to a qualified public agency or contractor independent of the cleanup contractor is preferred because of conflict of interest and traditional occupational focus.
- Fundamental safety procedures and air monitoring protocols should be developed prior to initiation of work, even in emergency cleanups. The urgency of a cleanup should not be allowed to supersede basic program elements. Equipment and instrumentation must be in place with qualified operators before operations begin.
- Levels of personnel protection should be established equally upon known or anticipated toxicity and exposure potential factors as well as realistic accident scenarios. However, speculative worst case accident scenarios should be avoided when translating them into operations safety.
- All agencies having interest in the design of the safety program should be solicited for their input before operations begin, although a single individual or agency will have to draft initial procedures and absorb the burden of implementing modifications.
- Formal understandings should be developed between site managers and cleanup contractors regarding the efficient and frequent transfer of essential data that could influence site or public safety. This agreement should include air monitoring results, accident/injury data, laboratory operating procedures, waste characterization protocols, sample results and performance of protective equipment.



# USES AND LIMITATIONS OF ENVIRONMENTAL MONITORING EQUIPMENT FOR ASSESSING WORKER SAFETY IN THE FIELD INVESTIGATIONS OF ABANDONED AND UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Hazardous waste site field investigations pose a risk from hazards such as potentially flammable or explosive wastes, the presence of radioactive materials, and direct or indirect exposure to chemical wastes that might necessitate special protective clothing and equipment for workers. In order to fully assess the hazard and minimize risk, a comprehensive background data search must be completed prior to any on-site work.

At some sites, information concerning the types and quantities of waste present may be obtained from Federal, State and local officials, manufacturers, and others who live or work in close proximity to the site. However, in many cases adequate data are not available concerning the waste types, toxicity, or past disposal practices, especially at abandoned or uncontrolled sites.

At the sites where background information is unavailable or inadequate, it may be necessary to characterize the hazards prior to the field investigation through the use of environmental monitoring equipment such as combustible gas indicators, oxygen meters, gas detector tubes, radiation detectors, photoionization detectors and flame ionization detectors. The initial site entry characterization with these instruments will determine the nature of the waste present and its hazard potential. Obtaining reliable data from the environmental monitoring equipment is the most important aspect of the site characterization with respect to determining the proper level of personnel protection required at that site.

In order to prescribe the proper level of protection which will maintain a balance between health, safety, and efficiency, the monitoring equipment used in site characterization must be reliable and applicable to the varied and unique conditions at each and every site. The lowest level of protective equipment and clothing necessary to ensure worker health and safety is usually the most desirable level since the efficiency and effectiveness of the workers are often greatly reduced when higher levels of personnel protection are used. Some of the monitoring equipment presently being used for site characterization was designed more specifically for other intended uses in the industrial work place and is not ideally suited for use at a typical hazardous waste site where complete background information is lacking.

Other authors have previously addressed the subject of using environmental monitoring equipment to assess worker safety, however, their discussions have been limited to the theoretical versus the practical application and effectiveness of using this equipment to characterize hazardous waste sites. The purpose of this paper is to detail the uses and limitations of the environmental monitoring equipment currently available for use by field investigation teams and to demonstrate the data gaps which result from using equipment in the field in a capacity for which it was not specifically designed.

In early 1980, contractor Field Investigation Teams (FIT) were established to provide nationwide support services to each of the ten regional offices of the USEPA. As a member of the Fred C. Hart Associates Field Investigation Team for Region VIII of the

USEPA, the author has gained valuable experience from participating in numerous field investigations of abandoned and uncontrolled hazardous waste sites. The multi-disciplinary team contributes scientific and management services to identify, investigate and remedy existing uncontrolled and/or abandoned hazardous waste sites. Over 200 investigations have been completed ranging from site inspections and sample collection to detailed studies concerning the nature and extent of surface water, groundwater, air, and soil contamination at a particular site. The experience gained in the field enables the author to address from a practical and field-oriented point of view the benefits, drawbacks, and improvements needed in the equipment currently used to characterize sites and assess worker safety.

In this paper, the author focuses on the uses and limitations of environmental monitoring equipment to assess the hazards and determine the levels of contaminants present onsite. However, the actual selection of specific clothing or equipment to protect the workers from these various levels of contaminants is beyond the scope of this paper. See references 1 through 6 for more complete information on selecting protective equipment.

Because of the limited availability of monitoring equipment designed specifically for hazardous waste field work, it is hoped that the information contained in this paper will encourage modifications to the existing instruments or development of new instruments which will provide more specific and dependable data.

## INITIAL SITE ENTRY CHARACTERIZATION

Toxic materials can enter the body in three ways: 1) gastrointestinal tract; 2) skin; and 3) lungs. Of these three modes of entry, the human respiratory system presents the quickest and most direct avenue of entry because of its intimate association with the circulatory system and the constant need to oxygenate tissue cells. Therefore, the most significant hazards posed to a field investigation team at a site, where background information is insufficient, are related to the ambient air quality. These hazards include oxygen-deficient air, combustible gas, airborne radioparticulates, and gaseous and/or particulate contaminants. Of these four hazards, the determination of the type and concentration of contaminants in the air is the most difficult due to the numerous varieties of contaminants which may be present and the limitations of the instruments used to detect their presence.

The initial site entry characterization is performed by first determining the oxygen content of the air with an oxygen indicator, then the explosive potential of the atmosphere is measured with a combustible gas indicator, and then radiation levels onsite are evaluated using one or more of the radiation detection survey instruments. If there is sufficient oxygen in the atmosphere, no explosive gases are detected, and radiation levels are concurrent with background readings, then the characterization will continue. Otherwise, work may be halted at the site due to the extreme and unsafe conditions encountered. The final step in the characterization is to determine the type and concentration of contam-

inants present in the ambient air using a combination of gas detector units and organic vapor detector instruments.

According to USEPA guidance documents, the initial site entry characterization is performed with the work party wearing SCBA's unless field conditions dictate otherwise. Problems have been encountered with this blanket rule. First of all at many sites, there may be a strong political pressure from the client to maintain a low-key profile while performing investigative field work to avoid attention, causing undue stress to area inhabitants. This is a difficult situation to be confronted with and a blanket rule is not always applicable. Therefore, it is imperative that a field investigation team be allowed to choose the proper level of personnel protection.

## ENVIRONMENTAL MONITORING EQUIPMENT

There are many instruments and procedures available for measuring concentrations of airborne substances. There is no single, universal instrument for all such measurements, and there probably never will be. In fact, the trend seems to be toward development of a greater number of specialized instruments.

Instruments and procedures can be classified as follows: 1) those that give a direct reading; 2) those that remove the substance from a measured volume of air for later analysis; and 3) those that collect and retain a measured volume of air for later analysis. The choice of the instrument and procedure to be used depends on many factors: portability, ease of operation, sensitivity, accuracy, reliability, availability, the type of information desired and personal experience.

Grab, or instantaneous direct reading tests, require only a few seconds to a few minutes to attain results. They indicate fluctuations in concentration of airborne substances and are useful in determining maximum and minimum concentration.

A continuous test or collected sample requires from several minutes to an entire day to collect. Such tests give information on the average concentration of the airborne substance.

There is a need for both grab and continuous methods, as both give useful information. However, direct reading instruments are most applicable for the initial site entry characterization because the information required is gained instantly and can be monitored for changes throughout the site. However, no matter what instrument is selected, only qualified individuals with complete familiarity with the unit and its operation should be permitted to use the instrument in order to assure accuracy of the results.

### Oxygen Indicator

The normal content of oxygen in the air is 20.9% by volume. A reading of less than 19.5% is to be considered an oxygen-deficient environment and all further work must be performed in air-supplied respirators. Oxygen concentrations below the range of 16-19.5% will not support combustion and are considered unsafe for human exposure because of harmful effects on bodily functions, mental processes, and coordination. Levels higher than 25% indicate oxygen-enriched conditions and all further work is halted due to fire hazard.

The oxygen indicator measures atmospheric concentrations of oxygen over a range of 0-25%. Oxygen diffusing through the face of the galvanic cell undergoes redox reactions which generate a current proportional to the oxygen partial pressure. The current is converted to a proportional voltage displayed on the indicator as a percent of oxygen.

The typical applications for which the instrument was designed include checking utility manholes, sewers and mines. The readings obtained with the oxygen indicator can be influenced by temperature, relative humidity, and altitude as well as high concentrations of interfering chemicals. High concentrations of strong oxidants, such as fluorine, chlorine, and ozone will lead to erroneously high oxygen readings.

The oxygen indicator is simple to use, compact and practical for most all field investigations. The model used by the FIT has the sensing cell in a separate plastic holder at the end of a 10 ft

cable. This extension facilitates the testing of hard to reach areas before entering. The only notable problem that has been encountered while using the meter in the field is inconsistency and fluctuation in the readings obtained while dangling the sensor cell from the body of the meter.

### Combustible Gas Indicator

The combustible gas indicator is used to determine the explosive potential of an atmosphere. Although there are many units available commercially, most test for the concentration of flammable gases and vapors by measuring the heat produced by the combustion of a test sample. A wide variety of materials are combustible, and a combustible gas indicator does not express their concentrations directly, but rather as a percentage of the lower explosive limit (LEL). The LEL is defined as the lowest concentration of flammable vapors or gases by volume in air which will explode, ignite, or burn when there is an ignition source.

The meter must also be capable of determining if flammable gases or vapors are present in concentrations above the upper explosive limit (UEL). The UEL is defined as the highest concentration of flammable vapors or gases by volume in air which will explode, ignite, or burn when there is an ignition source. Although mixtures of flammable gases or vapors will not explode if they are present in concentrations above the UEL, these mixtures can easily be diluted into their explosive range.

While the operation of the combustible gas indicator is relatively straightforward, it is important that the operator be skilled in interpreting the meter reading correctly. Many physical and chemical properties of the sample and other factors affect instrument responses. These include oxygen level, relative humidity, the physical nature of the sample (solid, liquid, or gas/vapor), the presence of interfering substances, and temperature. Most combustible gas indicators will not detect an atmosphere which is explosive due to dusts or mists. They will not record accurately in oxygen-deficient atmospheres and can generate explosions in oxygen-enriched atmospheres that contain combustible vapors.

In order for the combustible gas indicator to properly function, the atmosphere must be normal and not one that is oxygen deficient or oxygen-enriched. Therefore, the oxygen indicator must be used in conjunction with the combustible gas indicator to ensure valid results. Any reading on the meter above 10% of the LEL requires evacuation to reevaluate the work plan. A reading above 20% of the LEL is immediately dangerous to life and health, and all investigative work must stop until the hazard is reduced.

Leaded gasoline, silanes, silicones, silicates and other compounds containing silicon in the tested atmosphere may seriously impair the response of the meter. Even minute traces of these materials can rapidly poison the filament and destroy the sensitivity of the instrument. This may prove to be a problem at a site where an explosive gas such as methane is present in conjunction with possible petroleum product vapors. Two alternative approaches to testing in the presence of leaded gasoline vapors are to use an inhibitor filter or to use a specialized model which was designed for service where leaded gasoline vapors are present. Another limitation is that petroleum vapors and combustible gases cannot be differentiated unless a charcoal filter is employed.

The combustible gas indicator is simple to operate, easily portable and generally reliable. No major problems have been encountered while using it in the field to determine the explosive potential of the atmosphere.

### Radiation Survey Meters

It is imperative to be able to confirm the presence or absence of radiation levels above background level near the site. If radiation is detected above background readings, then the investigation is not completed until the advice of a health physicist is obtained.

The radiation survey instrument used by the FIT during an initial site entry characterization is a personnel radiation monitor, a large

area detector probe used with a portable pulse count ratemeter and a sensitive, wide range survey meter. The latter two instruments should be used only by persons who have been trained in the proper interpretation of its readings. These instruments are intended solely for the detection of ionizing radiation.

In addition to the two survey instruments, a personnel radiation monitor is worn by field personnel during on-site work. The pocket-sized radiation monitor gives an audible warning when a gamma radiation field is encountered. It can be easily worn in the chest pocket of a coverall. This is an effective device for limiting personnel exposure to radiation both during an initial site entry and during field activities when onsite conditions can change.

These instruments are used by the FIT to detect radiation levels during an initial site entry characterization. This enables the safety officer or radiation specialist to discriminate between proceedings or halting planned field work to ensure worker safety. A trained radiation specialist is valuable for interpreting the readings, assessing the unique conditions at each site which contribute to those readings, and deciding if the readings indicate a safe level for work party exposure.

### Gas Detector Tubes

There are many commercially available gas detector tubes and associated pumps. In general, the tubes operate on the specific reaction of a chemical compound with a colorimetric reagent. The detector tube and pump are the two major components of the system. Detector tubes are normally species specific. Some manufacturers produce tubes for groups of gases such as for hydrocarbons in general. Pumps used for drawing air through the tubes come in two basic forms: bellows pump and piston-type (syringe). The pumps are manufactured under strict specifications so as to draw only a specified volume of gas.

Each detector tube has specific detector chemicals which react with the specifically designated gas being sampled. Each tube requires a set volume of gas to be drawn through by the pump. Once the proper volume of gas has been drawn, the tube can be examined. A chemical reaction between the sample gas and the detector chemical is represented by a color change. The length of the color is proportioned to the concentration.

Gas detector tubes are a prime example of an instrument designed specifically for use in the industrial workplace which is being used for hazardous waste site field investigations with limited success. The problems encountered stem from the sharp contrasts between the overall conditions found at a hazardous waste site and the industrial workplace. In the industrial workplace, there is usually a thorough knowledge of the process, related equipment, raw materials, end-products and by-products which can possibly create an exposure hazard. As a result the air monitoring performed at the industrial workplace can be site-specific at a known location for a known chemical species. The situation at an abandoned or uncontrolled hazardous waste site will often be close to the opposite due to a combination of inappropriate waste management/disposal practices and inadequate background information. In addition, there are many substances that interfere with the color reaction and give false-positive readings. Although these interferences are usually well documented, the unknown nature of hazardous waste sites usually precludes absolute knowledge of potentially interfering substances. While the tubes are accurate under controlled laboratory conditions, the variable and inconsistent conditions in the field contribute to unreliable and limited applicability.

The FIT has been fortunate to have access to additional pieces of air characterization equipment besides the gas detector tubes. The effectiveness of an initial site entry characterization would be markedly diminished if the gas detector tubes were used alone. Their ability to detect ambient air contamination is weak, even at sites where specific chemicals are suspected or known to be present. Their applicability for characterizing drummed material is also weak and limited by the hundreds of tubes which have to be used if the contents are unknown. Therefore, it is obvious that in many

cases the gas detector tubes cannot provide substantive data to assess worker safety.

### Organic Vapor Detectors

The two types of instruments used by the FIT to monitor for organic vapors are a portable vapor analyzer with a photoionization detector and a portable organic vapor analyzer with flame ionization detector. Each of these instruments employs a different technique to detect and measure the concentrations of trace gases in the atmosphere.

The photoionization analyzer employs the principal of photoionization for detection. A wide variety of organic compounds and some inorganic compounds can be measured with this technique.

The flame ionization detector is designed to detect and measure trace quantities of organic materials in air by utilizing the principal of hydrogen flame ionization. The instrument measures organic vapor concentration by producing a response to an unknown sample, which can be related to a gas of known composition to which the instrument has previously been calibrated. During normal survey mode operation a continuous sample is drawn into the probe and transmitted to the detector chamber by an internal pumping system.

In areas where mixtures of organic vapors are present, it often becomes necessary to determine the relative concentration of the components and/or to make quantitative analysis of specific compounds. The flame ionization detector has an available gas chromatographic (GC) column attachment useful for separating mixtures of gaseous compounds. When the instrument is adapted for GC the instrument takes a preset volume of ambient air and passes it through a column containing a material with which the organic components in the air interact in a non-destructive manner. As the sample passes through the column the components of the sample are separated (in time) by their respective different interactions with the column material. By recording the detector response versus time on a strip chart recorder a complex mixture can be analyzed.

The instrument was designed for use as a portable survey instrument for determining organic air pollutants and for monitoring potentially contaminated areas. In hazardous waste site investigations, its ability to detect contaminants has varied from site to site. At an inactive municipal/industrial landfill it was very effective for detecting compounds in concentrations varying from 1 to 1,000/ppm in the survey mode. In addition, some of these compounds were identified with the instrument in the GC mode. The instrument was ineffective at an investigation at a petroleum waste disposal site, where it was unable to pick up the lower molecular weight compounds associated with petroleum products. This could have been related to the weather conditions during the survey. Ambient temperature was about 40°F, which is not conducive to volatilization.

The complementary nature of the organic vapor detector and the photoionization detector used together in the field, increases the confidence of the data gathered. However, their effectiveness for ambient air characterization has been found to be inconsistent and unpredictable at different sites depending upon the nature of contamination present.

### CASE STUDIES

In the following section two hazardous waste site investigations where the environmental monitoring equipment was used in the initial site entry characterization with polarized results are discussed.

The first site is located in a suburb of Denver, Colorado in a moderately industrialized area. Between the late 1950s and 1965 a chemical company operated a pesticide formulation facility on this site. In 1965, the facility was destroyed by fire and the demolition debris from the building was disposed of on a vacant lot directly adjacent to the original site.



Concern was expressed in 1979, when a worker installing a buried sewer line at the boundary of the vacant lot complained to the State health department of noxious odors. Subsequent sampling by Federal, State and local agencies identified the presence of a number of pesticides in the soil (Table 1). In Mar. 1982, the Region VIII office of the USEPA directed the Fred C. Hart Associates, Inc. FIT to assess the nature, magnitude, and extent of contamination to the soil, groundwater and surface water on and originating from the site.

Table 1.

Results from Soil Samples Collected at a Former Pesticide Facility in 1979.

Pesticides (mg/l)	Sample Number									
	1	2	3	4	5	6	7	8	9	10
Aldrin	0.15	0.5	1.3	ND	ND	35	11	0.1	ND	ND
L-BHC	420	240	700	35	375	700	ND	ND	ND	ND
DDT	0.8	8	60	0.13	0.4	294	152	0.4	ND	ND
Dieldrin	3	5	3	0.4	0.4	88	45	0.5	ND	0.2
Endrin	0.4	0.7	4	ND	0.05	447	224	0.1	ND	0.1
Heptachlor	0.45	2.2	1.3	ND	ND	103	85	ND	ND	0.1
Lindane	ND	ND	ND	ND	ND	38	45	ND	ND	ND
Methoxychlor	1.6	6.7	23.5	0.3	0.4	116	87	0.4	ND	0.1

ND - Not detected

Prior to commencing field activities, an exhaustive background information search was performed. Valuable information was obtained and a study plan was developed, including a sampling plan. An initial site entry characterization was performed to assess existing hazards. It was necessary to re-evaluate the existing hazards because over a year had passed since previous fieldwork was completed and conditions at the site could have changed.

The characterization was not performed in SCBAs because the highest levels of contaminants previously detected were low enough to be able to safely wear an air purifying respirator with an organic vapor/particulate cartridge. Two members of the FIT dressed in steel toed rubber boots, Tyvek disposal coveralls, surgical gloves, full face respirators and hard hats. They carried an oxygen indicator, a combustible gas indicator, the radiation survey meters and the organic vapor detectors. Gas detector tubes were not utilized because there are no detector tubes manufactured which will identify the suspected pesticides.

From the beginning of the site characterization it was understood by the FIT that detection of any pesticides with either of the organic vapor detectors was highly unlikely due to their low volatility and ionization potential. A manufacturer's representative was consulted for each instrument, concerning its applicability for detecting the suspected pesticides. The consultation confirmed the FIT's idea concerning the instrument's limitations. However, the site characterization with the organic vapor detectors was carried out to monitor for any other contaminants which might be detected with the instruments.

A perimeter survey was performed initially to assess the site hazards and to indicate localized hot spots for more detailed sampling. The oxygen content was 20.5%, no explosive gases were detected, the radiation levels were consistent with area background levels and no organic vapors were detected above background levels.

The characterization continued and moved onto the site. The work party began walking with the monitoring equipment in a grid pattern equally spaced approximately every 15 ft to maximize areal coverage of the site. Similar readings were obtained throughout the entire site; none were above the background levels recorded earlier. The next step was to focus the monitoring equipment directly around the obvious rubble disposal areas. The piles of rubble visible above ground were scrutinized with both of the organic vapor detectors. No vapors above background levels were detected. The rubble piles were then stirred with a long handled stainless steel spoon to allow volatilization of any compounds present which might elicit a response on the instruments, but again there were no responses above background readings.

Although the hazards associated with the volatilization of the pesticides were low, there was concern about the exposure risk associated with inhalation of pesticide contaminated soil particles in the air, especially during soil sample collection. This is a case where the results of the initial site entry characterization could have misled the FIT to believe no exposure potential existed if the background information was not available. However in this case, because of the extensive background data, the results of the site characterization reflected the instruments limitations in detecting pesticides versus the site being free of contaminants.

The second site is located approximately 15 mi southeast of downtown Denver in a predominantly rural area that is within 3 mi of a rapidly growing and populated residential area. The site is 1,600 acres in area and contains both an active and inactive landfill. From 1966 to 1980 the owner/operator of the landfill accepted municipal refuse and chemical waste. The solid wastes were dumped and periodically compacted and covered with earth. The liquid wastes were poured into unlined trenches and eventually were filled with trash and covered with earth. In 1980, a new operator assumed management responsibilities of the landfill as a waste storer, treater and disposer. The facilities were expanded and improved, three solar evaporation ponds and a drum burial cell were constructed and segregation of municipal refuse from industrial waste began.

Odors, arising from the improper management of the landfill in its earlier years, became a major issue of concern for residents and health officials alike. Residents of the area, even as far away as 5 mi, complained strongly and repeatedly to local officials of the obnoxious odors associated with the landfill. The number and magnitude of complaints prompted the USEPA to direct the Fred C. Hart Associates, Inc. FIT to assess the extent to which vapors were migrating and to determine what effects these vapors were having on the air quality both on and off site.

A study plan was developed to satisfy the following objectives: (1) to identify the origin of organic vapors at the landfill, (2) determine the extent to which these vapors were migrating from the landfill and then, based on the survey results, (3) develop an ambient air monitoring program for qualitative and quantitative analysis.

The use of the organic vapor detector was integral to the success of the investigation from the initial site entry characterization to the development of a more intensive air monitoring program. The survey was conducted in three stages. The first investigation consisted of an organic vapor detector perimeter survey of the landfill to determine the background levels and ambient air levels of total organic hydrocarbons possibly traversing the landfill boundary. A second survey consisted of monitoring the ambient air on the landfill in the vicinity of the active landfill waste disposal operations such as brine ponds, solar evaporation ponds, sludge landfarming operations and potential clay liner breaches.

Additionally groundwater monitoring wells on the landfill were uncapped and subject to organic vapor scans. The instrument was operated in the GC mode for a number of the monitoring wells. The instrument was also employed for night surveillance one mile north of the landfill. Finally, the organic vapor detector was employed to produce a gas chromatograph strip chart of trade organic vapors after two puncture holes were induced in the clay cap at the southwest section of the landfill. The gas chromatograph verified the presence of vinyl chloride, trichloroethane and trichloroethylene.

Under the prevailing meteorological wind regime during the survey period, no significant values of total hydrocarbons were detected outside the landfill boundary. Background levels of total organic hydrocarbons were on the order of 5 ppm with a maximum reading of 7 ppm. Elevated instrument readings of 200-300 ppm were detected in one of the wells during the survey operation, and a 350 ppm reading was obtained from the clay cap puncture holes.

Because of the successful organic vapor detector survey results, the FIT proposed an intense program of ambient air sampling for the disposal facility.

## CONCLUSIONS

In the new and rapidly-growing field of waste management, specialized monitoring equipment for effective field investigations is developing slowly. The best available technology for assessing hazards at hazardous waste sites continues to be the equipment developed for use in the industrial workplace.

Of the major pieces of equipment discussed, three of them: gas detector tubes, the photoionization detector and the organic vapor detector should be re-evaluated for their adequacy in assessing the contaminants which may exist at a hazardous waste site. All three do not detect certain substances. There are not enough cross checks between the instruments to confirm or substantiate the results of each individual piece of equipment. However, the importance of this equipment cannot be overemphasized since it is used to detect what contaminants are present in order to employ the proper protective clothing and equipment which will ensure health and safety of the work party.

The author has not suggested the development of a universal instrument for performance of a full hazard assessment, but has rather discussed problems encountered in the field of the existing equipment. A greater understanding of the problems encountered with this equipment may encourage modifications which will improve the reliability of the results.

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# WORKER SAFETY AND DEGREE-OF-HAZARD CONSIDERATIONS ON REMEDIAL ACTION COSTS

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## INTRODUCTION

The passage of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in Dec. 1980 established the legal and economic basis for a concerted effort by the federal government to address the environmental and health problems associated with uncontrolled hazardous waste sites. Among the requirements of this "Superfund" legislation is a provision in Item 2 of Section 105 to develop methods for evaluating the relative costs of remedial actions.

Responsibility for developing the procedures to evaluate remedial action costs was placed with the USEPA in the Office of Emergency and Remedial Response (OERR) and the Office of Enforcement (OE). The Office of Research and Development (ORD) was, in turn, requested to provide support in developing these procedures. SCS Engineers was then contacted to review, update, compile, and integrate existing data on remedial action costs at hazardous waste sites.

In this paper, the authors review two SCS projects undertaken to determine remedial action costs. The basic approach to developing costs was to identify the remedial action unit operations which may be combined to provide a remedial action plan. Component cost items were identified which contribute to each unit operation. By determining the cost associated with the component cost items, the total unit operation cost can be developed. A completed remedial action plan for a site can be evaluated by summing the costs of each of the remedial action unit operations involved.

The first project, "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites", compiled existing data in terms of scope, location, and time-frame and provided a methodology for computing the costs of remedial action unit operations. The sources of available cost information did not incorporate the increased costs associated with health and safety considerations. Therefore, a methodology was needed to identify and compute the increased costs encountered on hazardous waste sites due to health and safety concerns.

The second project, "Impact of Health and Safety Considerations on Remedial Action Costs", was designed to incorporate the incremental costs associated with the degree-of-hazard conditions at uncontrolled hazardous waste sites. Incremental cost factors, representing a percentage increase in base construction costs at four different degree-of-hazard levels, would be computed for each unit operation. The increased cost for a remedial action unit operation would be determined by multiplying the base costs (computed using procedures outlined in the first project) by the incremental cost factor associated with the degree-of-hazard conditions at the site during remedial actions.

A related project, "Selecting Among Alternative Remedial Actions for Uncontrolled Hazardous Waste Sites", was also undertaken by SCS Engineers to expand on the use of procedures outlined on the first project. However, information concerning this third project is not included in this paper.

## DETERMINING COSTS OF REMEDIAL ACTIONS

### Remedial Action Unit Operations

Twenty-five remedial action unit operations have been identified in the course of the two projects. These were derived primarily from previous USEPA reports.<sup>1,2,3,4</sup> These remedial action unit operations are identified in Table 1 and grouped into four general categories: (1) surface water controls, (2) ground water controls, (3) migration controls, and (4) waste controls

### Cost Variations

Three major factors impacting costs were evaluated in the first project. These factors were: (1) geographic location, (2) facility type, and (3) facility size. The 1980 costs for each unit operation were computed at three separate cost levels reflecting geographic locations of: (1) upper U.S. average, (2) lower U.S. average, and (3) specific costs encountered at Newark, N.J. Facility types investigated included each of landfills and surface impoundments. Remedial action unit operation costs were then examined at each of five separate scales of operation for landfills and surface impoundments. Unit costs appropriate to various remedial actions (e.g., dollars/square meter of wall face for a grout curtain) are given in Table 2. Costs per hectare for direct comparisons among "competing technologies" are shown in Table 3. These costs reflect the variations due to regional location.

The impact of geographic location, facility type, and facility size varies for different unit operations. An example of unit operation costs of a bentonite slurry trench at five hypothetical landfills and demonstrates the marked impacts of geographic location are shown in Fig. 1. In contrast, the effect of facility size with unit operation costs for a well point system at five different sizes of surface impoundments is illustrated in Fig. 2.

Table 1.  
Remedial Action Unit Operations

#### Surface Water Controls:

1. Surface Sealing with Synthetic Membranes
2. Surface Sealing with Clay
3. Surface Sealing with Asphalt
4. Surface Sealing with Fly Ash
5. Revegetation
6. Contour Grading
7. Surface Water Diversion Structures
8. Basins and Ponds
9. Dikes

#### Ground Water Controls:

10. Well Point System
11. Deep Well System
12. Drain System
13. Injection System
14. Bentonite Slurry Trench
15. Grout Curtain
16. Sheet Piling Cutoff
17. Grout Bottom Sealing

#### Gas Migration Controls:

18. Passive Trench Vents
19. Passive Trench Barriers
20. Active Gas Extraction Wells

#### Waste Controls:

21. Chemical Fixation
22. Chemical Injection
23. Excavation and Reburial
24. Leachate Recirculation
25. Treatment of Contaminated Water

**Table 2.**  
**Remedial Action Costs—Appropriate Units\***

REMEDIAL ACTION	UNIT	Overhead Allowance (Percent)	Contingency Allowance (Percent)	Life Cycle (10 Year) Cost/Unit		
				U.S. Low	U.S. High	Newark, NJ
Surface Sealing with Synthetic Membrane	\$/m <sup>2</sup> A	25	35	18.59	27.00	22.10
Surface Sealing with Clay	\$/m <sup>2</sup> A	25	35	9.63	16.33	13.50
Surface Sealing with Asphalt	\$/m <sup>2</sup> A	25	35	6.73	9.27	8.36
Surface Sealing with Fly Ash	\$/m <sup>2</sup> A	25	35	9.59	16.57	13.66
Revegetation	\$/m <sup>2</sup> A	25	10	1.43	1.81	1.70
Contour Grading	\$/m <sup>2</sup> A	25	15	1.63	1.99	1.90
Surface Water Diversion Structures	\$/m <sup>3</sup>	25	15	1.75	3.63	3.13
Basins and Ponds	\$/ha	25	20	N/A	N/A	N/A
Dikes	\$/m <sup>3</sup> B	25	20	N/A	N/A	N/A
Well Point System	\$/m	25	25	107.29	152.70	139.40
Deep Well System	\$/m <sup>2</sup> B	25	30	28.60	37.17	34.48
Drain System	\$/m <sup>2</sup> B	25	25	59.50	69.41	66.53
Injection System	\$/m <sup>2</sup> B	25	30	1,760.00	1,785.00	1,777.00
Bentonite Slurry Trench	\$/m <sup>2</sup> B	25	30	61.41	106.05	95.53
Grout Curtain	\$/m <sup>2</sup> B	25	30	937.00	1,881.00	1,643.00
Sheet Piling Cutoff	\$/m <sup>2</sup> B	25	25	73.00	108.00	95.00
Grout Bottom Sealing	\$/m <sup>2</sup> A	25	40	52.96	102.24	89.23
Passive Trench Vents	\$/m <sup>2</sup> B	25	20	16.70	24.34	21.79
Passive Trench Barrier	\$/m <sup>2</sup> B	25	20	47.96	73.03	64.75
Gas Extraction Wells	\$/m <sup>2</sup> B	25	30	13.9	23.3	20.4
Chemical Fixation	\$/m <sup>2</sup> A	25	35	8.25	14.51	12.95
Chemical Injection	\$/m <sup>3</sup> C	25	30	2.16	3.81	3.38
Excavation and Reburial	\$/m <sup>3</sup> C	25	40	116.00	120.00	119.00
Leachate Recirculation	\$/Ha A	25	20	19,675.00	24,030.00	22,662.00
Treatment of Contaminated Water	\$/liter/day	25	40	2.52	4.38	3.86

\* Assumes a medium-size (5.41 ha) landfill.  
 m<sup>2</sup> = 1.2 yd<sup>2</sup>  
 m<sup>3</sup> = 35 ft<sup>3</sup>  
 A Surface Area

B Intercept Face  
 C Landfill Volume  
 N/A Not Applicable

### Derivation of Component Costs

In computing specific remedial action unit operation costs, each unit operation first had to be broken down into its specific component requirements. In addition, each component cost item could be further defined in terms of subcomponents, with specific costs assigned to labor, materials, and equipment/supplies. For this project, component cost items for each unit operation for both the landfill and surface impoundment were divided into capital and operation and maintenance (O&M) cost subcomponents.

Price lists were developed to itemize material, labor, and equipment costs for each of the components used within a unit operation. For the most part, the 1980 Means and Dodge Guides were used to obtain the costs needed. These price lists were adjusted to obtain revised material and labor costs for upper U.S. average, lower U.S. average, and Newark, N.J. estimates.

### Hypothetical Problem

This section has been included to demonstrate the combination of remedial action unit operations into a total cleanup scenario appropriate for a given pollution situation. In this example, an abandoned hazardous waste site has been investigated and found to have contaminated surface and groundwater. It is decided that the site must be isolated by: (1) preventing surface runoff from entering the stored hazardous waste, (2) preventing groundwater migration to the site, and (3) implementing a monitoring program to confirm the effectiveness of the steps taken. Specific unit operations required are as follows:

- Contour grading and surface diversion
- Surface sealing
- Bentonite slurry trench cutoff wall (monitoring is included in this unit operation)

For purposes of this example, it was assumed that the hypothetical site has the following dimensions:

- Surface area = 4 hectare
- Site is square, at 200 m each side
- Average depth of bentonite slurry trench cutoff wall must be 10 m to impervious material
- Hydrogeologic investigation indicates that the bentonite slurry trench cutoff wall must extend around three sides of the site to cutoff ground water migration through the site.

The procedure for estimating the cost of this hypothetical remedial action scenario is as follows:

- Refer to the pertinent tables in the project report and list the appropriate capital and O&M components of the unit operations selected. This step is shown in the first column of Table 4.
- Refer to the price list in the Appendix of the project report and determine what units will be required to make sure the cost of each component (e.g., hectare, m<sup>2</sup>, etc.). This step is shown in the second column of Table 4.
- Calculate the number of units of each cost component required for the site. This step is shown in the third column of Table 4 for the hypothetical site used in this example.

**Table 3.**  
**Remedial Action Unit Operation Costs—Constant Units\***

Remedial Action	U.S. Low			U.S. High			Newark, NJ		
	Initial Capital \$	First Year O&M \$	Life Cycle Cost \$	Initial Capital \$	First Year O&M \$	Life Cycle Cost \$	Initial Capital \$	First Year O&M \$	Life Cycle Cost \$
Surface Sealing with Synthetic Membrane	185,900	-0-	185,900	270,000	-0-	270,000	221,000	-0-	221,000
• Surface Sealing with Clay	96,300	-0-	96,300	163,300	-0-	163,300	135,000	-0-	135,000
Surface Sealing with Asphalt	67,300	-0-	67,300	92,700	-0-	92,700	83,600	-0-	83,600
Surface Sealing with Fly Ash	95,900	-0-	95,900	165,700	-0-	165,700	136,600	-0-	136,600
Revegetation	13,400	105	14,300	16,500	185	18,100	15,700	157	17,000
Contour Grading	15,300	114	16,300	17,900	240	19,900	17,260	207	19,000
Surface Water Diversion Structures	Included in Contour Grading								
Sedimentation Basins and Ponds	647	-0-	647	1,028	-0-	1,028	909	-0-	909
• Dikes									
Well Point System	23,120	1,930	39,660	36,650	2,083	56,450	34,050	2,046	51,540
Deep Well System	9,900	1,820	25,375	16,240	1,970	32,980	14,160	1,930	30,600
Drain System	3,490	1,620	17,150	5,090	1,770	20,010	4,570	1,730	19,200
Injection System	7,830	20,250	178,900	9,140	20,400	181,475	8,650	20,360	180,680
• Bentonite Slurry Trench	109,100	1,600	122,600	197,900	1,750	212,600	176,300	1,713	190,700
Grout Curtain	1,858,000	1,600	1,871,000	3,741,000	1,750	3,755,800	3,264,700	1,713	3,279,150
Sheet Piling Cutoff	146,100	-0-	146,100	215,350	-0-	215,350	190,300	-0-	190,300
Grout Bottom Sealing	5,282,470	1,600	5,295,970	10,209,110	1,750	10,223,867	8,908,930	1,713	8,923,375
• Passive Vents	17,150	20	17,300	24,850	44	25,220	22,280	36	22,590
• Passive Trench Barriers	27,830	140	29,015	41,690	295	44,180	37,040	253	39,170
• Active Gas Extraction Wells	19,560	1,100	28,900	29,900	2,160	48,200	26,620	1,890	42,640
Chemical Fixation	69,100	1,600	82,500	130,000	1,750	145,000	115,050	1,713	129,500
Chemical Injection	46,425	6,400	59,920	90,830	7,000	105,590	79,180	6,850	93,630
• Excavation and Reburial	12,751,100	1,600	12,764,600	13,176,000	1,750	13,190,000	13,059,300	1,713	13,073,760
Leachate Recirculation	5,270	1,700	19,700	8,360	1,850	24,000	7,300	1,813	22,660
Treatment of Contaminated Water	123,800	9,600	204,900	209,600	17,440	356,850	183,970	15,470	314,620

\* All units in dollars per hectare of site surface area.  
ha = 0.41 acres

• Refer to the price list in the Appendix of the project report and list the unit cost of each cost component required. A decision will have to be made on whether to use upper U.S. average, lower U.S. average, or Newark, N.J. costs. For this example scenario, upper U.S. costs were used and are shown in the fourth column of Table 4.

• The final cost calculation required for multiplication of the number of units (Step 3 above) by the unit cost (Step 4 above) as appropriate, and summation of the cost components to arrive at a total cost. For this example, see the fifth and sixth columns of Table 4.

For the hypothetical remedial action scenario used here as an example, the estimated costs were calculated as follows:

Total Capital Costs = \$1,006,300  
Total O&M Costs During 10 Years = \$ 177,200  
Total 10 Year Life Cycle Cost: = \$1,183,500

## HEALTH AND SAFETY COST CONSIDERATIONS

### Identification of Cost Components

Ten basic health and safety cost components were identified (Table 5) through a combination of previous experience and observation on hazardous waste sites, contractor discussions, and literature reviews.<sup>5,6,7</sup>

### Degree-of-Hazard Impacts on Health and Safety Costs

The primary factor in determining the cost of health and safety for a unit operation on an abandoned hazardous waste site is the degree-of-hazard associated with the site. As the degree-of-hazard increases, concern for providing protection of health and safety also increases. Personnel protective equipment, medical surveillance/services, decontamination, site security, and environmental/personnel monitoring must be sufficient to prevent excessive exposure. Personnel training, emergency preparedness, and insurance must be suitable for addressing potential releases of hazardous materials. Manpower inefficiencies increase with the use of personnel protective equipment and clothing due to the physically limiting characteristics of their use. Finally, recordkeeping must provide documentation necessary to increase information available for planning appropriate remedial actions, complying with regulations, limiting liabilities, and addressing legal considerations.

The degree-of-hazard associated with an uncontrolled hazardous waste site is a function of the toxicology of the waste and its physical and chemical properties in combination with the physical and environmental characteristics of a site and remedial action activities on site (Fig. 3). The materials released at an uncontrolled site are a function of the physical properties of the materials, the environmental and physical characteristics of the site, and the site management and control activities. The physical properties and environmental and physical characteristics of the site will determine the pathways of dispersion. Site management activities will determine

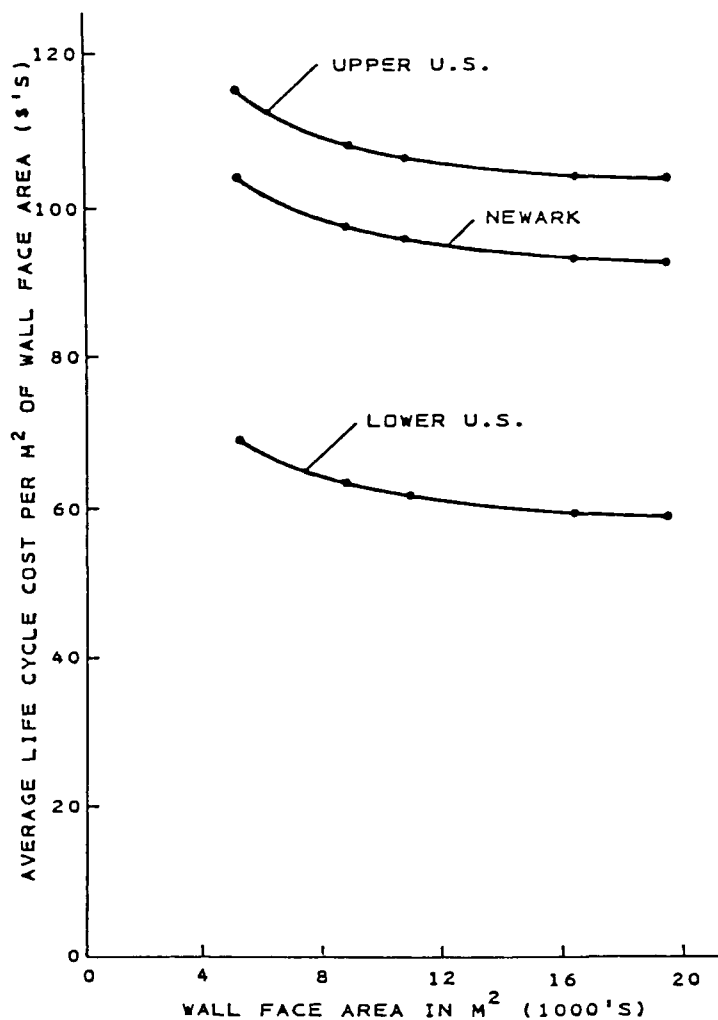


Figure 1.

Unit Costs of Bentonite Slurry Trench at Five Hypothetical Landfills

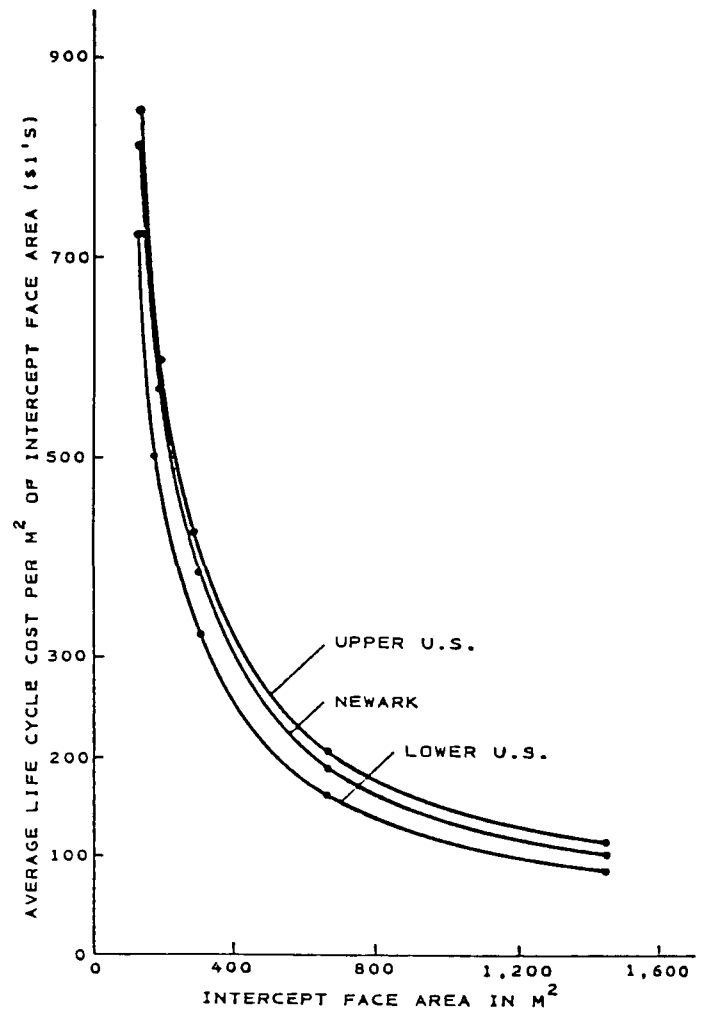


Figure 2.

Unit Costs of Well Point System at Five Hypothetical Impoundments

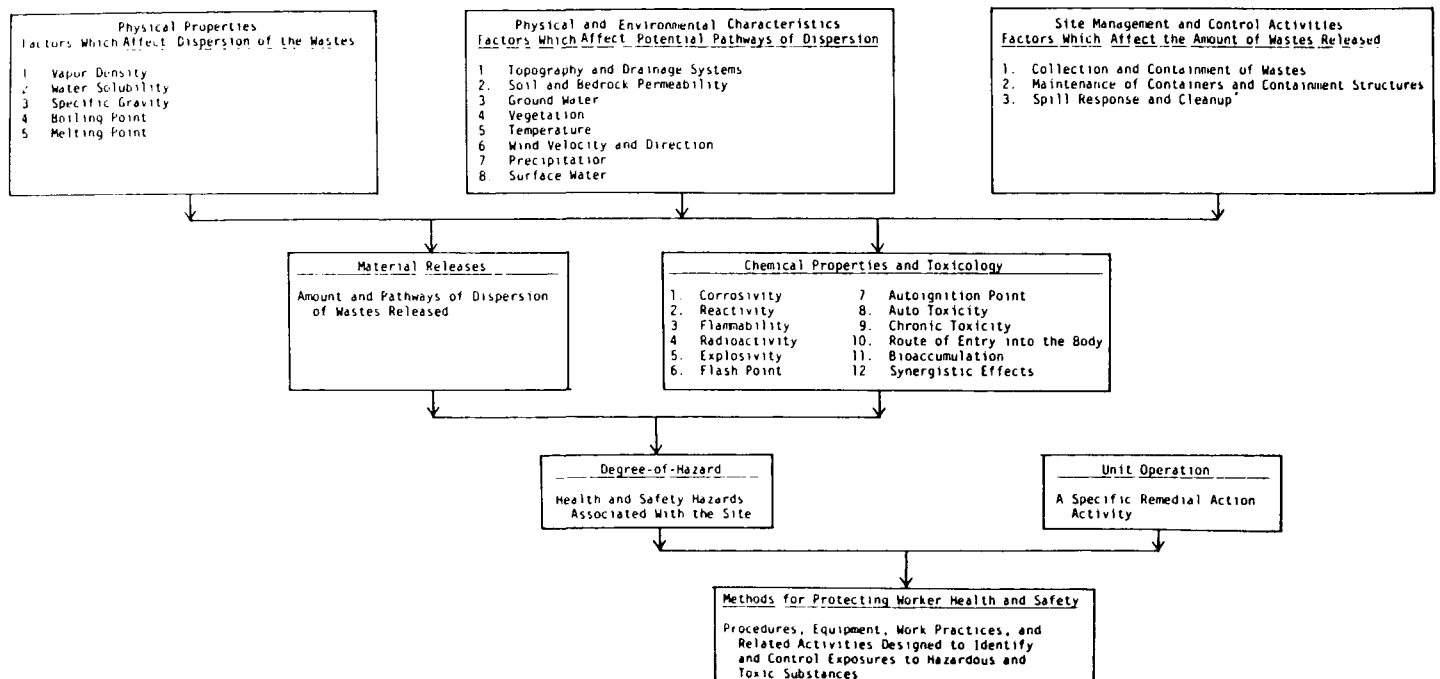


Figure 3.

Factors Impacting Health and Safety Costs

**Table 4.**  
**Sample Calculation of Remedial Action Costs for Hypothetical Landfill**

Unit Operations and Components	Unit of Measurement	No. of Units This Scenario	Upper U.S. Component Cost Per Unit (\$)	Total Cost Component (\$)	Unit Operation Total (\$)
<b>Unit Operation 1. Contour grading and surface water diversion.</b>					
1. Excavation, and recontouring of site, labor plus equipment	m <sup>3</sup>	0.5 m x 40,000 m <sup>2</sup> 20,000 m <sup>3</sup>	1.83	36,600	
2. Excavation and grading soil, labor plus equipment	m <sup>3</sup>	0.3 m x 40,000 m <sup>2</sup> 12,000 m <sup>3</sup>	1.05	12,600	
3. Diversion ditch	m <sup>3</sup>	4 m x 2 m x 200 m 16,000 m <sup>3</sup>	3.63	5,800	
4. Capital cost (subtotal)				55,000	
5. Overhead allowance (25 percent)				13,750	
6. Contingency allowance (15 percent)				8,250	
7. Total capital cost					77,000
8. Maintenance and repair cost, diversion ditch two times per year	m <sup>3</sup>	1,600 m <sup>3</sup> x 2 = 3,200 m <sup>3</sup>	3.60	11,520	
9. Total O&M cost (present value of outlays for 10 years)					97,000
10. Total life cycle cost					174,000
<b>Unit Operation 2. Surface sealing.</b>					
1. Excavation and grading waste (Included in unit operation No. 1; thus not duplicated here)					
2. Excavation and grading soil (Included in unit operation No. 1; thus not duplicated here)					
3. Surface seal, bituminous concrete cap (0.08 m thick) installation and materials	m <sup>2</sup>	40,000 m <sup>2</sup>	4.55	182,000	
4. Capital cost (subtotal)				182,000	
5. Overhead allowance (25 percent)				45,500	
6. Contingency allowance (35 percent)				63,700	
7. Total capital cost					291,200
8. Maintenance and operation cost (none)					
9. Total life cycle cost					291,200
<b>Unit Operation 3. Bentonite slurry trench.</b>					
1. Geotechnical investigation	lump sum	1	6,500	6,500	
2. Slurry trench excavation and installation of bentonite slurry	m <sup>3</sup>	220 m x 3 x 10 m x 1 = 6,600 m <sup>3</sup>	54.5	359,700	
3. Bentonite, delivered	tonnes	6,600 m <sup>3</sup> x 0.039 tonnes/ m <sup>3</sup> = 257 tonnes	177	45,500	
4. Capital cost (subtotal)				411,700	
5. Overhead allowance (25 percent)				102,900	
6. Contingency allowance (30 percent)				123,500	
7. Total capital cost					638,100
8. Maintenance and operation, sample collection	hour	96 hrs/yr	16.60	1,600	
9. Maintenance and operation, sample analysis	sample	24 samples/yr	330	7,900	
10. Total O&M cost (present value outlays for 10 years)					80,200
11. Total life cycle cost					718,300



**Table 5.**  
**Worker Safety and Degree-of-Hazard Cost Components**

1. PERSONNEL PROTECTION
  - a. Levels of protection
  - b. Individual protection
    - boots
    - gloves
    - eye goggles
    - overgarments
    - head gear
    - safety line
    - two-way communications
    - cartridge masks
    - full face mask
    - air-supplied helmets
    - SCBA
  - c. Mobile and stationary equipment storage and operation stations
2. MEDICAL SERVICES/SURVEILLANCE
  - a. Medical examinations
    - prior to site work
    - periodic
    - follow-up to site work
    - unscheduled due to illness, accident, or exposure
  - b. On-site
    - first aid (explosions, animal/insect bites, falls, exposure, etc.)
    - emergency communication
    - medical personnel
    - rescue equipment
    - emergency showers/eye washes
    - emergency medical facilities/equipment
    - periodic or continuous monitoring while working
  - c. Off-site
    - transportation (ambulance)
    - medical facilities
    - fire department
    - life squad
    - coordination with health/medical services and authorities
3. PERSONNEL TRAINING
  - a. Waste handling
  - b. Emergency procedures
  - c. Medical
  - d. Protective gear/equipment
  - e. Monitoring equipment
  - f. Communication equipment
  - g. Special/seasonal equipment
  - h. Rehearsals
  - i. In-house training
  - j. Outside programs
  - k. Safety and health practices
4. MANPOWER INEFFICIENCIES
  - a. Restricted mobility
  - b. Waste handling procedures
  - c. Monitoring requirements
  - d. Buddy system
  - e. Pre- and post- work activities
  - f. Heat stress
5. RECORD KEEPING
  - a. Management requirements
  - b. Labor union requirements
  - c. Governmental
  - d. Medical
  - e. Training
  - f. Work history
  - g. Site safety/maps
6. DECONTAMINATION
  - a. Personnel
  - b. Protective gear
  - c. Cleanup equipment
  - d. Monitoring equipment
  - e. Required facilities, equipment, structures, etc.
  - f. Change rooms/facilities
7. SITE SECURITY
  - a. Restriction out of access by personnel or vehicles
  - b. Signs and tags
  - c. Security personnel
  - d. Security systems/equipment
  - e. Coordination with law enforcement agencies
8. INSURANCE
  - a. Medical
  - b. Liability
  - c. Workman's compensation
  - d. Unemployment
9. EMERGENCY PREPAREDNESS
  - a. Fire fighting
    - extinguishers
    - turnout gear
  - b. Spill containment/control
    - absorbents
    - oil booms/containment devices
10. HAZARD ASSESSMENT
  - a. Sample packaging and shipping requirements
    - special containers
    - special packing materials
    - labels, markings, and placards
    - authorized transporters
  - b. Monitoring equipment
    - oxygen detectors
    - combustion gas
    - organic vapor analyzers
    - radiation detectors
    - field test kits
    - specialized laboratory equipment
  - c. Sampling equipment
    - disposable sampling equipment
    - special material construction
    - specialized equipment
  - d. Analytical costs (field and contract laboratories)
    - qualitative
    - quantitative
  - e. Review and interpretation of data
    - establishment of levels of protection
    - assessment of contaminant migration
    - source identification

the amount of materials released. The materials released in combination with the chemical properties and toxicology of the materials will determine the degree-of-hazard associated with the site.

Actions taken at an uncontrolled hazardous waste site during the course of remedial action unit operations will require a level of worker protection appropriate for the degree-of-hazard conditions existing on the site. The cost of worker protection and related component cost items (e.g., medical surveillance, personnel training, etc.) will increase as the degree-of-hazard is not a static condition and may change with environmental conditions (e.g., air inversions, temperature variations, and precipitation), site activities which generate increased releases (e.g., spills, dusting, and vapor releases), and combinations of both environmental changes and site activities (e.g., reducing pressure within a container by venting off vapors during an air inversion).

Other factors which can impact health and safety related costs include: (1) social and political awareness and concern, and (2) protected environments (e.g., nature preserves, national parks, state parks, and historical sites). For the purposes of this project, only the costs of worker health and safety protection are being examined. By examining the costs at the point of greatest contamination (i.e., on-site) most, if not all, of the cost increases should be incorporated into the cost calculations.

## DEVELOPING INFORMATION FOR HEALTH AND SAFETY COSTS

### Availability of Health and Safety Cost Information

Contacts were made with hazardous waste site cleanup contractors, regulatory officials, and other consulting firms involved in related USEPA projects. The information obtained was primarily general cost information on equipment and materials. Specific prices with reference to suppliers and manufacturers were provided for equipment and clothing costs. Costs associated with

equipping an individual worker for four levels of personal protection as defined by the Interim Standard Operation Safety Procedures developed by the USEPA Emergency Response Team is found in Table 6.<sup>8,9</sup> Some preliminary estimates for health and

**Table 6.**  
**Costs for Equipping a Worker at Four Levels of Protection[8]**

#### Level A—\$1,854

##### Includes:

Fully-encapsulating chemical resistant suit  
Pressure demand, self-contained breathing apparatus  
Gloves, inner, chemical resistant  
Gloves, outer, chemical resistant  
Boots, chemical resistant, steel toe and shank  
Hard hat  
Boots, outer, chemical resistant, disposable

#### Level B—\$1,136

##### Includes:

Chemical resistant clothing—jacket, bib overalls  
Pressure demand, self-contained breathing apparatus  
Gloves, inner, chemical resistant  
Gloves, outer, chemical resistant  
Boots, chemical resistant, legging  
Boots, chemical resistant, steel toe and shank  
Boots, outer, chemical resistant, disposable  
Hard hat

#### Level C—\$736

##### Includes:

Saran-coated disposable suit  
Full face air purifying cannister respirator:  
-front belt mounted  
-back belt mounted  
Gloves, inner, chemical resistant  
Gloves, outer, chemical resistant  
Boots, chemical resistant, legging  
Boots, chemical resistant, steel toe and shank  
Boots, outer, chemical resistant, disposable  
Escape mask  
Hard hat

#### Level D—\$260

##### Includes:

Disposable coveralls  
Gloves, outer, chemical resistant  
Boots, chemical resistant, steel toe and shank  
Escape mask  
Hard hat and face shield

safety costs for individual cost components are shown in table 7.<sup>10</sup>

Determining the health and safety costs for actual site cleanups was difficult. The number of variables that enter into the degree-of-hazard and required health and safety considerations (Fig. 3) make comparisons of costs difficult. Additionally, information on costs has traditionally not been collected in a way that enables health and safety costs to be distinguished from other costs. Similarly, more recent cost information available from documents does

not provide sufficient detail to identify specific health and safety cost items. As indicated by the variations in bids submitted for a site cleanup under Superfund, various components appear to be included under different categories by different contractors. Bid quotations submitted for the site in question are given in Table 8. As a result, the approach used on this project was developed to obtain the necessary cost information in a consistent format which would allow for comparisons between different sites by controlling as many variables as possible.

**Table 7.**

**Preliminary Estimates of Health and Safety Components Costs [10]**

Health and Safety Cost Components	Preliminary Estimate of Costs
•Baseline Physical	\$150/person
•Medical Coverage	3 to 10% of base pay
•Personnel Protection (includes clothing and monitoring equipment)	\$4,100 to \$5,000/person
•Decontamination (capital)	\$12,000 to \$15,000/site
•Decontamination (operational and disposal)	\$100/day
•Site Security (general)	1 to 5% of bid price
•Site Security (guard service)	\$10/hour
•Training—new employee	5 to 10% of activity
•Training—after 6 months	1 to 5% of activity
•Recordkeeping	1 to 5% of working hours
•Manpower Efficiencies—losses (primarily affected by temperature extremes and level of protection)	25 to 40%
•Insurance—Liability	\$1 to \$2/\$100 of sales
•Insurance—Workman's Compensation	\$1 to \$25/\$100 of wages
•Insurance—Bonding	20 to 100% of bid price

**Development of Uncontrolled Hazardous Waste Site Scenarios**

Hazardous waste site scenarios were developed to be representative of three basic types of sites: (1) subsurface burial, (2) surface impoundments, and (3) above grade storage. Whenever possible these scenarios were developed by reference to actual cleanup operations either completed, in progress, or planned for the near future. This approach was adopted partially to ensure that the scenarios would reflect realistic conditions, and partially to assist in identifying organizations and individuals experienced in particular types of cleanup operations.

Each scenario was composed of a number of distinct unit operations. For each scenario, site characteristics (e.g., topography, size, weather conditions, hydrogeology, etc.) were defined to provide a detailed profile of the site. Similarly, the characteristics of the waste at the site were defined so that the levels of protection could be determined for each unit operation. The levels of personnel protection used for the project were those defined by USEPA in their Interim Standard Operating Safety Procedures. A brief description of the conditions associated with the levels of per-

**Table 8.**  
**Bid Quotes for Cleanup of a Superfund Site**

Bids	1 Insurance Bonds, Permits	2 Other Project Start- Up and Site Services	3 Site Preparation	4 Liquid Material Disposal	5 Solid Material Disposal	6 Salvage of Motors	7 Salvage of Scrap Steel	8 Disposal of Drummed Material Cur- rently on Site	Total
A	\$18,143	\$ 193,762	\$161,680	\$135,927	\$ 534,640	\$ 2,327*	\$ 9,400	\$ 1,080	\$1,052,305
B	\$13,625	\$ 236,628	\$ 80,310	\$493,072	\$ 423,392	\$ 4,310*	\$ 4,000*	\$ 1,045	\$1,239,762
C	\$21,500	\$1,048,679	\$ 34,958	\$165,590	\$ 536,683	\$ 3,590*	\$ 5,000*	\$ 1,179	\$1,799,999
D	\$16,000	\$ 600,000	\$345,835	\$199,312	\$ 522,760	\$ 431*	\$ 200*	\$ 1,440	\$1,684,716
E	\$19,000	\$ 552,000	\$290,000	\$266,812	\$ 532,000	\$ 4,310*	\$ 2,000*	\$ 4,200	\$1,657,702
F	\$ 1,500	\$ 446,300	\$ 60,000	\$154,677	\$ 659,334	\$ 8,620*	\$ 4,000	\$ 720	\$1,309,911
G	\$26,470	\$ 190,000	\$130,000	\$173,250	\$1,280,200	\$ 4,310*	\$ 3,000*	\$ 1,680	\$1,794,420
H	\$20,000	\$ 992,248	\$296,500	\$ 33,025	\$ 161,950	\$ 1,077	\$ 2,000	\$ 4,200	\$1,511,000
I	\$11,250	\$ 475,581	\$187,431	\$203,960	\$ 297,522	\$ 8,620*	\$ 2,000*	\$ 1,308	\$1,166,432
J	\$10,000	\$ 101,600	\$112,100	\$211,272	\$ 442,340	\$ 2,004	\$ 2,000	\$ 900	\$ 882,216
K	\$60,000	\$ 185,000	\$207,753	\$336,247	\$ 241,000	\$43,100*	\$ 4,000*	\$ 4,500	\$ 987,400
Average	\$19,767	\$ 456,527	\$173,324	\$215,740	\$ 511,984	\$76,537*	\$21,600*	\$22,252	\$1,371,442

\* Credit

**Table 9.**

**Conditions Associated with Levels of Personnel Protection [9]**

1. Level A—require full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).
2. Level B—requires self-contained breathing apparatus (SCBA), and cutaneous or percutaneous exposure to unprotected areas of the body (i.e., neck and back of head) is within acceptable exposure standards (i.e., below harmful concentrations).
3. Level C—hazardous constituents known; protection required for low level concentrations in air; exposure of unprotected body areas (i.e., head, face, and neck) is not harmful.
4. Level D—no identified hazard present, but conditions are monitored and minimal safety equipment is available.
5. No hazard—standard base construction costs.

sonnel protection is given in Table 9.

Contractors were identified with particular experience in each type of scenario. Cost information was then solicited from selected contractors based on their particular experience, availability of qualified personnel, and their willingness to provide the necessary information. The information initially requested was a breakdown of health and safety costs (using the cost components shown in Table 5) for each unit operation in a scenario, along with the baseline construction costs excluding any such health and safety costs. This approach was intended to obtain incremental health and safety costs for specified levels of personnel protection associated with the unit operation and the waste being handled.

To extend the usefulness of the data from each scenario, further information was sought on health and safety costs for each unit operation at different levels of protection. For example, if the scenario under consideration included the unit operation of ex-

cavation and reburial for dioxin wastes at a level of protection designated "A", then the additional costs developed would be for the same operation involving less hazardous wastes at levels designated "B", "C", and "D".

A further important refinement was to consider the effects of variations in site conditions, particularly weather conditions. Where the impacts of varying site conditions were identified as significant for extremes of heat and cold, these incremental costs were also investigated as an extension of the scenarios.

The data collected using these scenarios will be used to establish a health and safety incremental cost factor for each unit operation identified at each of the four degree-of-hazard levels associated with the four levels of personnel protection. The incremental cost factors can then be used to adjust the remedial action construction costs determined in the first project to properly reflect health and safety cost considerations.

## CONCLUSIONS

In current decision making processes, concern for cost-effective use of funds is a major issue in political, economic, and budgetary considerations. The limitation of available Superfund monies to address the problems associated with uncontrolled hazardous waste sites necessitates cost-effective evaluation and selection of remedial actions. This need has been reflected in the requirements of the Superfund Act to provide methods for an analysis of the relative costs of alternative remedial actions. The studies discussed in this paper were designed to assist in fulfilling these requirements.

The primary result of these studies will be a costing methodology which can be consistently applied to the various unit operations and reflect variations due to geographic location, facility size, and health and safety concerns. The resulting cost estimates would enable regulatory officials, consultants, and contractors to: (1) compare costs for alternative unit operations performing the same function, and (2) compute cost estimates for combinations of unit operations comprising complete remedial action plans. Other useful applications might include:

- Design of a specific unit operation. For example, cost data generated by this project could help determine the location of a bentonite slurry wall. Should it be placed on-site where excavation could require installation at Level C personnel protection? Or would it be more cost-effective to move further down-grad-

ient where a longer wall would be required to contain a dispersed plume, but personnel protection is not required?

- More study versus start of cleanup actions. For example, should remedial action proceed immediately without the benefit of detailed waste analyses, assuming that worst-case Level A protection is required? Or should further sampling and analysis be performed if there is a possibility that results will allow a lessening of personnel protection to Level B or C?

## ACKNOWLEDGEMENTS

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# HAZARDOUS WASTE SITE INVESTIGATIONS: SAFETY TRAINING, HOW MUCH IS ENOUGH?

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## INTRODUCTION

With the exception of some state and Federal employees, specialty consultants and spill cleanup contractors, many individuals associated with inspection, evaluation, and remedial actions at uncontrolled hazardous waste sites lack adequate safety training. The investigation and possible subsequent cleanup of a site containing known or suspected hazardous material, whether funded privately or with governmental monies, is a complex task involving a diverse group of engineers, scientists, technicians, and contractors. Safety training and other operational considerations, including medical monitoring, are often perfunctory or non-existent for those involved in sample collection, geophysical surveys, or subsurface investigations.

With greater emphasis being placed on remedial action by private industry, local government or through the "Superfund" program, more and more of the construction trades will be found on hazardous sites. The employers have both a legal and moral obligation to ensure that their employees are prepared to undertake work at uncontrolled sites. In particular, employers or their representatives should satisfy themselves that those they have employed have been thoroughly screened and trained for on-site work. In order to maximize the needs of the individual and minimize budget and time restrictions a tiered training approach is usually the most efficient.

## TRAINING APPROACH

Many individuals employed by the government or specialty consultants and contractors have been given some degree of training in accordance with their level of responsibility. Others receive only on-the-job training (OJT).

The USEPA, for example, now requires that all of their employees engaged in field activities undergo a training program and be certified to a level commensurate with the degree of anticipated hazards. Their training program is divided into three categories.

The Basic Level requires a minimum of 24 hours of health and safety training which includes emergency help and self-rescue, and the safe use of field and personnel protective equipment. The Intermediate Level adds an additional 8 hours or more training in such areas as safety plan development and decontamination. The Advanced Level includes an additional 8 or more hours with emphasis placed upon management of restricted and safe zones, procedures for dealing with the public and the media, and the safe use of specialized sampling equipment. The training is further enhanced by a required OJT period and supplemented by additional training as deemed necessary.

For others who work with hazardous materials, however, these training programs, as well as other more intensive training programs, are either unavailable or unobtainable. Also, although numerous volumes are available to outline textbook approaches to safety during field investigations, oftentimes the procedures outlined for optimum personnel protection may not be workable in actual field situation. This is especially true from the standpoint of minimizing the potential conflict between the safety of the investigators and any undue anxiety among individuals of neighboring residential or industrial areas. Organizations with limited training budgets and/or resources must approach the training requirement from a pragmatic standpoint.

All individuals working at hazardous waste sites have different roles and levels of responsibilities. Organizations perform different functions at sites; and site hazards and conditions vary greatly both

between sites or portions of the same site. Training must therefore be organized for the specific needs and levels of comprehension of the individual, their organizations, the work assignment of that organization, and the specific requirements of a particular site.

## BASELINE CONSIDERATIONS

All individuals required to have access to a site containing known or suspected hazardous materials must undergo baseline medical profiling. The specific elements of the medical program are a function of the individual's duties and the need to maintain a balance between site, safety and an individual's right to privacy. However, it is not unusual for a worker to feel that his job may be in jeopardy by the disclosure of medical test information.

Medical profiling normally includes the following tests: pulmonary function, blood chemistry, urine analysis and liver and kidney functions. These tests, in conjunction with a thorough medical history, can serve as indicators of possible preexisting abnormal conditions or unusual sensitivities to certain types of toxic compounds. Other tests which might be appropriate include chest X-ray, electrocardiogram and specific tests for exposure to certain chemicals or physical agents. Medical profiling should be repeated yearly (as a minimum). Exit physicals should be given to any worker terminating his employment.

## OVERVIEW TRAINING

The first level of a recommended training program is overview training. Overview training serves as an introduction of the worker to the nature and types of hazards he or she might encounter in the field. A number of generalized hazardous material short courses are given by government agencies, educational institutions, professional societies and consulting organizations.

Although normally well received, these courses, in many instances, fall short of satisfying the basic needs of individual workers outside of the sponsoring agency. For example, a hazardous material emergency response course given by FEMA's National Fire Academy is excellent for firefighters; however, it is not appropriate for those engaged in field investigations or remedial measures.

The overview training then, even though basic in nature, must be designed for a specific audience, its needs and its level of comprehension, in order to be successful. Course length is a function of the needs of the organization. The workers of a geophysical firm may need less training than those employed by a well drilling contractor, due to the nature of anticipated hazards and exposure risk. Of course, budgetary constraints are an unfortunate consideration.

Course length for overview training normally runs from 2 to 5 days, with little or no time for hands-on training. Overview training programs for emergency response and military personnel, however, run two weeks or longer in order to familiarize the student with protective equipment before intensive training commences.

Class size is limited by the organization's needs or available resources. It is best to try to limit class size to a maximum of 25 students.

Large organizations in industry or government who oversee or participate in investigations or remedial actions should have all personnel involved in the program attend the training. In addition

to field workers and supervisors, administrative, legal, and technical support personnel should be involved in order to better appreciate problems encountered in the field.

The contents of a typical four day overview course for an organization with responsibility in overseeing remedial actions at abandoned uncontrolled hazardous waste facilities is given in Table 1. Most of the topics can only be touched upon within the time frame allowed. Since only one day has been allocated for personnel protection, no more than a preliminary treatment of equipment selection, fitting, use and maintenance can be given.

The course is designed so that a variety of the organization's employees from field personnel to specification writers can profit from the course. Although the topics are geared to the organization's responsibility and protective equipment already available, much of the topics covered will be found in existing courses. For many, overview training or overview training with a little OJT with a more experienced worker is all that is needed. For others, discipline intensive training followed by detailed site specific training may be required.

### DISCIPLINE INTENSIVE TRAINING

Certain supervisory, technical support, or field personnel may require intensive training in specific areas such as incident management, respiratory protection, radioactive material handling, safe sampling and decontamination techniques, etc. It is normally beyond the capabilities of most organizations to develop their own courses but fortunately, just as there are numerous basic courses, there are also many excellent intensive training programs given by many of the same groups. On the other hand, many of these courses are restricted to the sponsoring organization employees or to only government employees.

As an aid in determining what courses are available, many organizations are preparing directories and catalogues. The USEPA, FEMA, Corps of Engineers, and the National Environmental Training Association are presently preparing listings of available hazardous material courses. Although for use primarily by the respective organizations, the information, particularly the USEPA's, which is the most comprehensive, should be made available to interested parties.

### SITE-SPECIFIC TRAINING

The final required training, and probably the most important, is site-specific training. During this phase the individual receives detailed training in the actual conditions and hazards which may be encountered. Depending on the amount of information regarding on-site material, the worker may only be instructed in the hazards and appropriate responses to a limited set of conditions. For example, a site may be known to contain only PCB contaminated soil. The workers' site specific training would stress the hazards of PCBs and the degree of protection required for anticipated concentrations to be found in water, soil and surrounding air. It is, however, assumed that all employees have received some degree of overview training prior to being tasked with a field assignment.

Site-specific training may last just a few hours for a simple site or several days for a complex site preparing field workers to properly utilize and maintain site measuring devices and protective clothing. Actual respiratory protection devices to be worn are fit-tested and the individual given sufficient training in their use under both normal and emergency working conditions during this phase. It is important that site-specific training be given well in advance of actual site work for a complex or high hazard site. Not everyone can wear or tolerate wearing protective equipment, particularly the fully encapsulated suit. Adequate time must be budgeted between training and actual on-site work to secure and train replacement workers if necessary.

Some site-specific safety training must be accomplished at the site, such as review of emergency escape routes, emergency communications, and location of emergency equipment. During this

phase the worker should also become familiar with the site's Personnel Decontamination Station, with rehearsals conducted using non-toxic materials.

### ADDITIONAL CONSIDERATIONS

Two other critical elements in safety training are first aid and physical fitness. All on-site workers, including support personnel, should complete a basic first aid program prior to on-site work. As a minimum, each worker should pass the American Red Cross or equivalent 8 hour standard First Aid course and the Cardiopulmonary Resuscitation Course. These courses are readily available and inexpensive. They can be incorporated into an overview training program or taken separately. First aid procedures for anticipated site specific materials are given during the site specific training phase.

Finally, even though a person has passed medical profiling and all prerequisite training, he or she may still be unsuitable for on-site work. Field investigation and remedial action work is in itself both physically and mentally demanding. Work in cumbersome protective clothing can be performed safely only by those in top physical condition. It is critical that individuals engaged in on-site work be encouraged to maintain a program of physical fitness.

### CONCLUSIONS

How much training is enough? Obviously one cannot be over-trained when dealing with hazardous materials. One might argue that a worker can never be fully trained when dealing with mixed hazardous wastes on a complex site. Training must progress through a tiered approach, evaluating the needs of the individual, his job function and level of comprehension; the organization he works for and their project responsibility; and the degree of known or anticipated hazards for a specific site. Personnel training needs are satisfied through a program of overview, discipline intensive and site specific training, designed to accommodate time and budgetary restrictions.

Prior planning and proper training can generally prepare personnel for unexpected conditions while mitigating the potential for serious accidents. Training in the proper and appropriate use of specialized protective equipment and site entrance and egress controls can also ameliorate the possible conflict between the safety of the site worker and any undue anxiety among individuals of neighboring residential or industrial areas.

**Table I.**  
**Remedial Measures Training Overview Course**

#### **Day 1 Introduction—Defining the Problem**

Introductory Remarks and Course Overview  
CERCLA and the Organization's Role  
Superfund Sites, What Are They? How Were They Determined?  
Physical-Chemical Properties of Hazardous Materials  
Toxic Properties of Hazardous Wastes  
Hazardous Chemical References and Their Use  
Base Line and Personnel Considerations

#### **Day 2 Personnel Protection**

Measuring Devices  
Respiratory Protection  
Protective Clothing  
Practical Exercises

#### **Day 3 Operational Considerations**

Site Entrance and Decontamination  
Sampling Techniques  
Dealing with the Public and the Media  
Practical Exercises

#### **Day 4 Remedial Measures**

Hazardous Waste and Hydrology  
Remedial Techniques  
Defining the Scope and Extent of Remedial Actions  
Specifications  
Contingency Planning

# ADDRESSING CITIZEN HEALTH CONCERNS DURING UNCONTROLLED HAZARDOUS WASTE SITE CLEANUP

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## INTRODUCTION

The Midwest Industrial Waste Disposal Company, Inc., (Midco I) uncontrolled hazardous waste site is located in Gary, Lake County, Indiana. The surrounding area consists mostly of wetlands with some usage by light industry. Across a limited access highway approximately one-half mile to the west, is the Hessville neighborhood in the City of Hammond, Indiana (Fig. 1). Approximately 20,000 people live within a one-mile radius of the site, mostly within the corporate boundaries of Gary and Hammond, Indiana.

Operations that began in 1975 consisted mainly of temporary bulk liquid and drum storage of various industrial wastes that came primarily from industries located in the greater Chicago and Northern Indiana area. Some solvent reclamation activities were undertaken at times. Other operations included neutralization of acids and caustics.

Waste handling activities began in the mid-1970s at two Midco facilities. Midco II, a sister site to Midco I is also located in Gary and began operations after Midco I was destroyed by fire.

Midco I was incorporated on July 21, 1975. The primary director and registered agent was Mr. Ernest DeHart, a Crown Point, Indiana resident. The site is on land owned by Mr. DeHart and several others. The operation of Midco I utilized DeHart's land and with or without permission land owned by others adjacent to his property.

Actual activities at the site started Apr. 21, 1975. DeHart continued operation until Dec. 21, 1976, when a fire destroyed 14,000 55 gal drums of waste material on site. The Gary, Indiana fire marshal determined the fire was the result of a chemical reaction that occurred when acids and solvents from leaking barrels comingled. Evidence of the fire remained on the site prior to USEPA's cleanup actions; the drums that were damaged or destroyed had never been removed.

Mr. DeHart reportedly sold the business logo, telephone number and customer list of Industrial Technonics. Operations at the facility were begun again by this firm in 1977. At that time, the site contained 14,000 burned out 55 gal drums. Industrial Technonics (Intec) leased approximately 0.5 acres of the Midco I site from Mr. DeHart. During the course of their activities, an additional 2,000 drums accumulated at the site.

As mentioned above, this site is located near a highly populated area in northwest Indiana. During periods of unusually intense rainfall, runoff from this entire Gary, Indiana area often flooded the adjacent Hessville neighborhood of Hammond, Indiana (Fig. 2). The entire area has a history of past industrial use and midnight dumping activities. The main concern of the Hessville residents was the possibility that, during future heavy rains, chemically-contaminated runoff would flow from the Midco I site and general area into their streets and sewers, flood their basements and threaten their health.

The residents were also worried about the hazards of children playing in the vicinity of the site. In fact, concern was so great that after a storm event in June, 1981, a sand and concrete barrier

was placed across a connecting street between Gary and Hammond to stop the flow of runoff from the large open area, under Cline Avenue into the Hessville area. The dike that blocks the main thoroughfare between predominantly black Gary and predominantly white Hammond, for the stated purpose of diverting floodwater, has been a matter of disagreement between the two communities (Fig. 3).

## Need for Agency Action

On Dec. 21, 1976, a fire destroyed drums and bulk tanks stored at Midco I. This fire, however, did not create a lasting concern among citizens; the site was not recognized as a continuing hazard. On Mar. 14, 1981, a 14 year old Hessville boy suffered leg burns while playing near the site; his parents attributed the burns to

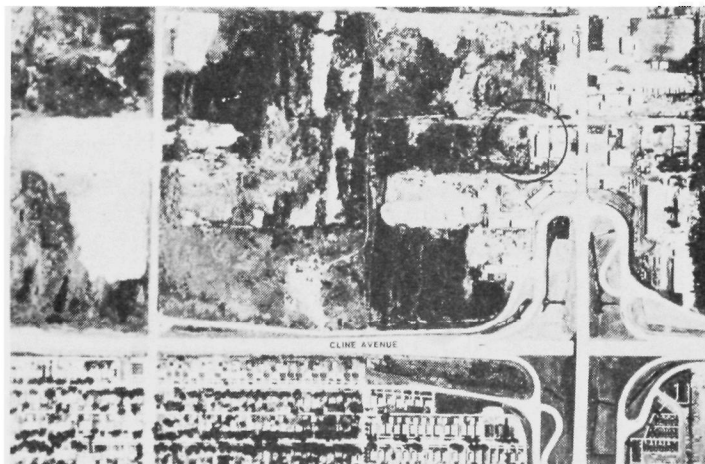


Figure 1.  
This aerial photograph depicts the general location of Midco I (encircled) in relation to the Hessville area of Hammond located below Cline Avenue.



Figure 2.  
View looking northwest from the site toward the 9th Avenue bridge underpass at Cline Avenue.





Figure 3.

Close-up of the sand dike built by Hammond authorities to keep run-off waters from entering Hessville.

chemicals from the Midco I site. Shortly afterward, on June 14, 1981, exceptionally heavy rains sent floodwaters through the Hessville neighborhood. Many residents complained of rashes and burns, blaming chemical runoff from the Midco I site.

After the alleged chemical burn incident, an On-Scene Coordinator from Region V inspected the site and obtained samples. Based on the location of the site (a wetland area with a predominant drainage pattern toward the Grand Calumet River), Section 311(k) funds were obtained from the USCG to construct a security fence around the site.

#### Responsible Parties and Enforcement

Three companies successively operated at the site between 1975 and 1979. Each provided temporary bulk liquid and drum storage for various wastes and reclaimable material. In 1979, all operations ceased.

In 1980, a preliminary injunction was granted, ordering various owners and operators to abate the imminent and substantial danger posed by the site. The parties subject to the order failed to abate the hazard.

Transporters and generators of the waste were then requested to undertake response actions. Upon failure of these parties to undertake the necessary action, initial response actions were taken under authority of the Comprehensive Environmental Response Compensation and Liability Act of 1980.

Most of the owners and operators of the site, and the owners and operators of the reclamation businesses which used the site, have been in contact with the USEPA since 1979, when the government filed suit to enjoin operations there. Mr. Ernest DeHart, the principal figure in the Midco I company, was not located until July 1981. Criminal charges are pending against DeHart in Lake County, Indiana, in connection with his Midco operations. The state also brought a civil action in Lake County and an injunction concerning limited work at another site. Civil and criminal proceedings were brought against DeHart in Grant County in connection with a third site in Upland Indiana.

The responsible parties identified were asked to undertake the cleanup. Owners and operators indicated they could not afford to clean up the site. Transporters and generators responded with varying degrees of cooperation. One company removed approximately 800 drums. Several companies indicated an interest in monetary settlement; many reserved judgment concerning responsibility. A few companies have refused to seriously consider settlement.

#### The Agency's First Planned Removal

After the Hessville boy suffered the burns, allegedly attributed to chemicals at the site, and the storm that sent runoff and floodwaters into the Hessville neighborhood, individual Hessville citi-

zens and Hammond officials began to press for cleanup of Midco I. Considerable program uncertainties existed at this time, since it had been merely six months since passage of Superfund.

Region V's assessment of the site indicated that the greatest immediate threat to public health and environment was associated with waste material contact. Once the security fence had been constructed, USEPA's concerns involved the potential for indirect contact via runoff and floodwaters, and the longer term environmental problems associated with groundwater and subsurface contamination. After the fence had been completed, USEPA felt confident there would be time to obtain some level of competition for the procurement of contractor services to initially perform a surface cleanup.

Although the National Contingency Plan had not yet been published, planned removal program guidance had been developed sufficiently enough to provide a mechanism for funding approval and contract procurement. Much of this guidance was based on Region V's novel approach for waste material removal involving use of limited solicitation to obtain contractor services for bulk waste removal at the Seymour Recycling Center, Seymour, Indiana.<sup>3</sup>

Cost estimates on an immediate removal basis for a surface cleanup from reputable contractors ran as high as \$2.5 million. The range of costs among those contractors who submitted proposals was from \$450,000 to approximately \$1.7 million. After the evaluations had been made, the low cost contractor was selected from among those considered equal technically. Ultimately, the total cost for the entire cleanup effort was approximately \$900,000. Additional costs were incurred due to an emergency runoff control project and an expansion of the project scope to address drums brought onto the site by Intec (Table 1).

Table 1.  
Cleanup Costs at Midco I

Task	Costs
Removal and disposal of drums destroyed by fire	\$192,696.72
Sampling and disposal of Midco drums	151,381.47
Sampling and disposal of Intec drums	250,735.71
Soil removal	278,577.47
Emergency runoff containment and treatment	29,267.43
	<hr/> \$902,658.80

In order to fully evaluate the accuracy of the original scope of work and cost estimates, it is necessary to debate the costs associated with the Intec materials. When USEPA formulated the scope of work, the Agency assumed successful negotiations with the company and, therefore, did not include this aspect of cleanup in the overall cost estimate. Comparing the cost of cleanup without Intec materials with original contractor estimates reflects a 45% cost overrun (Table 2).

Table 2.  
Comparison of Cleanup Costs

Task	Costs
Cost of cleanup less Intec material	\$651,923.09
Contractor estimate based on Agency scope of work	450,000.00
Apparent overrun	201,923.00

Specific reasons for the cost increase involved underestimates of quantities (volumes) of fire-destroyed drums and contaminated soils. This underscores the importance of primary site investigations and of obtaining the basis on which to provide the best volume of material and cost estimates possible. Obviously, the need for action and the time frames with which it is to be taken must be considered before committing to a long term investigative effort.



## The Community Relations Plan

USEPA's community relations plan for this planned removal action was prepared in Jan. 1982. The community relations officer was remarkably accurate and perceptive in identifying the issues and potential problem areas before, during and after the cleanup activities. The plan provided an accurate history and pinpointed the time period and specific incident which stimulated the local push for a cleanup. The plan was extremely helpful in identifying the following key issues and concerns:

- Gary-Hammond relations
- Health concerns
- Additional hazardous waste dumps
- Confusion over legal actions
- Possible delays

Prior to cleanup activities, the community relations plan pointed out three primary health concerns among the Hessville residents: (1) chemically-contaminated runoff, flooding their basements, (2) hazards to children playing in the vicinity, and (3) contaminated groundwater spreading from the site and seeping into their basements. This last concern seemed to be of secondary importance to the residents during the time prior to commencement of our planned removal. People in the area who were interviewed were aware that groundwater contamination might remain after USEPA's planned removal was completed but did not appear alarmed by this possibility. This ostensible public understatement for a potential serious health effect proved to be one of several major difficulties we encountered as we proceeded toward completion of our planned removal.

## PROBLEMS ENCOUNTERED

Four specific public health incidents occurred prior to and during our site cleanup operations (Table 3). Two of these events, which have been discussed briefly above, served to focus Agency resources on the site and developed need for the planned removal.

**Table 3.**  
**Problems Occurring at Site**

Event	Time of Occurrence
Children allegedly burned by chemical waste while playing near the site	Mar. 1981
Runoff waters from the site entering Hessville neighborhood	June 1981
Recurring Fontanyi family illnesses allegedly attributed to the site	Mar. 1981-Apr. 1982
Indiana highway department employee complaints of eye and skin irritation, nausea and dizziness allegedly due to planned removal cleanup activities at the site	Mar. 1982

Prior to cleanup, the attitude of involved citizens and local officials was that, if they had not attracted media attention to the burn and flood incidents, and had not exerted political pressure for a cleanup, the government would not have planned a response for the Midco I site. While it is difficult to identify the fine line that distinguishes program actions from political actions, the arousal of local officials as a result of these things and the subsequent media coverage required the USEPA to look at the site in closer detail.

## Storm of June 1981

A dike constructed by City of Hammond employees during the storm that resulted in substantial flooding of the Hessville area of Hammond is shown in Fig. 3. During the flooding at least 11 residents were treated for chemical burns and skin irritations after coming into contact with flood water believed to be contaminated by hazardous substances from the Midco I site. Also, ten Hammond employees who helped construct the dike were treated for suspected chemical burns and skin irritations.

Later that week, the Hammond Air Pollution Control Department requested USEPA's assistance in investigating numerous residential complaints of organic vapors emanating from basement sumps. These people believed that wastes from Midco I were carried by flood waters into the Tennessee Street area of Hessville.

USEPA's Technical Assistance Team (TAT) provided Hammond with this assistance and inspected basements in ten houses whose owners had lodged complaints with the Hammond Air Pollution Control Department. No organic vapors were detected olfactorily in any of the basements. At only one house was a reading above background registered on the H-Nu meter. This reading was taken in a sump where there were numerous tar globules. Here, the owner had stated that he had tarred his foundation about five days earlier and that the rains had probably carried the material into his sump before the tar had dried. Throughout the home to home survey, residents repeatedly complained of illness and injury due to chemical contact or smell, including reference to the city workers mentioned above. At the time of the TAT survey, these complaints comprised the primary motivation for response activities because sample analyses indicated that the huge volume of stormwater that inundated the area most likely diluted any water quality problems.

## Fontanyi Family Health Problems

Mr. Frank Fontanyi, his wife, daughter and son were residents of Hessville living on Tennessee Avenue during the flooding which occurred in June 1981. Mr. Fontanyi led a verbal assault on a variety of governmental agencies after the floodwaters entered the area. Mr. Fontanyi claimed his seven year old son, Frank Jr., was burned from contact with the water. When Regional field personnel arrived in Hessville to investigate the situation, Fontanyi waved home grown vegetables from his garden under their noses. He dared the inspectors to eat them; they politely declined.

In Aug. 1981, Fontanyi claimed a series of strange afflictions affected his family and continued for a period of six months, ultimately forcing him to abandon his home and neighborhood. The afflictions, affecting himself, his son and his daughter, included nausea, fatigue, eye irritation, headaches, muscle spasms, vomiting and inflammation of the throat and tonsils. Fontanyi had also been diagnosed by doctors as having had a slight stroke in the fall subsequent to the flooding. He believes it was due to exposure to the hazardous substances in the floodwaters. Fontanyi's children were also apparently being affected. His daughter was hospitalized three times with kidney infections over a period from Jan. to Mar. 1982. Fontanyi's son periodically needed to have his ears drained on an out patient basis and suffered a 20% hearing loss.

Conventional medical doctors could not find the cause of the Fontanyi family ailments. Fontanyi turned to a doctor who pioneered a field called clinical ecology and beginning in Mar. 1982, he and his daughter underwent six weeks of testing in a procedure called chemical detoxification. Both father and daughter were admitted to an "ecology center", in Chicago, one of half a dozen such oases in the United States where such detoxification is carried on. The center is a special world of aluminum wall paper, ceramic tile and filtered air where floors are scrubbed with baking soda. Plastics, synthetic fibers, cigarets, cosmetic and cleaning fluids are banned. Books are isolated in glass boxes and patients reach in with gloves to turn the pages.

Fontanyi and his daughter only drank spring water. They were re-tested for allergic reactions to water, food and respirable particulates such as pollen to double check previous tests. Where tests proved negative, further tests were administered for possible residual chemical contamination of the body. The clinical ecologist attending Fontanyi told him prior to testing that if anything was found Fontanyi and his family should not return to their house.

Clinical ecologists believe the body's internal defense system cannot tolerate the world technology has created. They are not worried about the major assaults, or the chemicals that everyone knows will poison, mutate genes or cause cancer. It is, in their estimation, the small, almost imperceptible insults they believe that come

from polyester clothing, sipping disodium guanylate in soup or soft drinks, those barely noticeable fumes from no-wax floors, office copiers, and perfumes or even common foods eaten in excessive quantities. The founder of clinical ecology attributes a vast array of ills to "allergies" caused by these silent insults: nausea, diarrhea, headaches, blurred vision, dizziness, fatigue, confusion, cramps, wobbly knees, asthma, fevers, "brain fog", anxiety, schizophrenia, arthritis, alcoholism.

Individuals who had experienced years of tests, drugs, and psychiatric treatment found relief through clinical ecology. Some researchers in allergy and immunology are not convinced that chemicals are the source of these problems. Clinical ecologists provoke from these researchers the same response laetrile elicits from oncologists. The head of the immunology and allergy division at San Diego's Scripps Clinic and Research Foundation describes clinical ecology as being "more a religious cult than science." He and other researchers see the ecologists patients as gullible people seeking external causes for their inability to cope with the world. The American Academy of Allergy considers ineffective or unproven the methods used by some clinical ecologists—urine injections and dropping diluted chemicals under the tongue.

#### Highway Department Employee Health Complaints

Immediately west and adjacent to the site is the State of Indiana Highway Department Gary subdistrict garage facility (Fig. 4). During the latter half of Mar. 1982, with the cleanup operation six weeks old, the area experienced a typical midwestern early spring warming trend. As expected, volatilization rates of the compounds on site increased significantly. Almost immediately, workers at the highway department facility began to complain of adverse health effects. On Mar. 18, seven employees went home sick, complaining of nausea, dizziness, coughing and a burning sensation on their skin. These individuals had been working inside the garage with the doors open less than a block from major staging and sampling activities on the site (USEPA's site safety plan required level C protection and all staging and sampling activities were in full view by highway department employees).

The On-Scene Coordinator (OSC) was concerned, but rather puzzled, that ambient air concentrations affected by the cleanup activities were causing these kinds of acute responses among the highway department employees. The OSC's twice daily total organic compounds measurements showed no levels greater than 3 ppm. However, one Mar. 19, 1982, an additional 25 employees were sent to a local hospital for tests. All of the workers were complaining of burning sensations in the eyes, nose and throat. None of the workers required hospitalization.

Again on Mar. 24, 1982, 20 more workers were forced from their workplace apparently due to ambient air concentrations of volatile organic compounds emanating from the site. At that point state highway department officials temporarily moved all of the state employees to another facility until the magnitude and seriousness of the problem was better defined. Still, daily on-site air quality readings did not seem to reflect the symptoms and complaints being displayed and voiced by the highway department workers.

#### APPROACH FOR PROBLEM RESOLUTION

Community wide public health issues associated with direct contact to hazardous materials on the site and contaminated floodwaters entering the Hessville neighborhood were addressed by obtaining funding in Oct. 1981, for a planned removal surface cleanup. While it was impossible to determine the proportionate impact the site may have had on the quality of the floodwaters that entered the Hessville area, it represented without question a source of highly contaminated runoff and groundwater contamination (Figs. 5 and 6).

It was clear to USEPA that no one in the Agency would be able to credibly address the health issues raised by Mr. Fontanyi and the highway department employees. Fortunately, the Agency had already established a dialogue and worked with on a site specific basis representatives from the Centers for Disease Control (CDC)

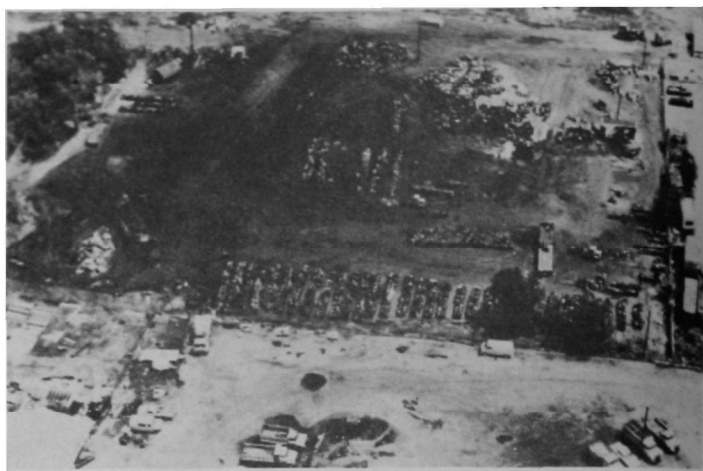


Figure 4.  
View of the Midco I site showing a portion of the adjacent highway department facility in the foreground.

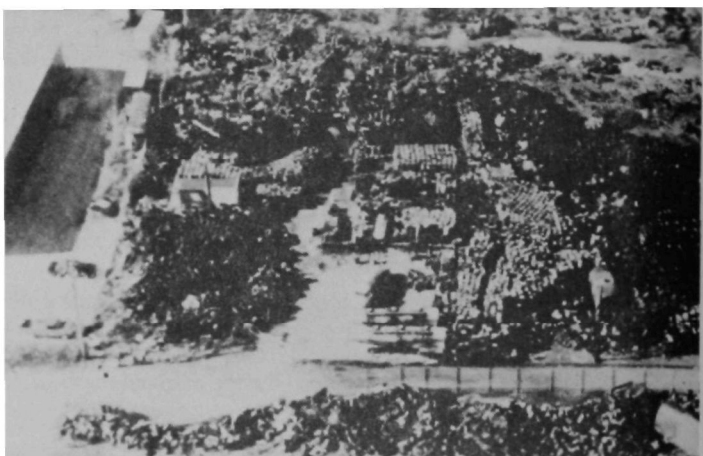


Figure 5.  
Conditions at the site prior to our cleanup activities.

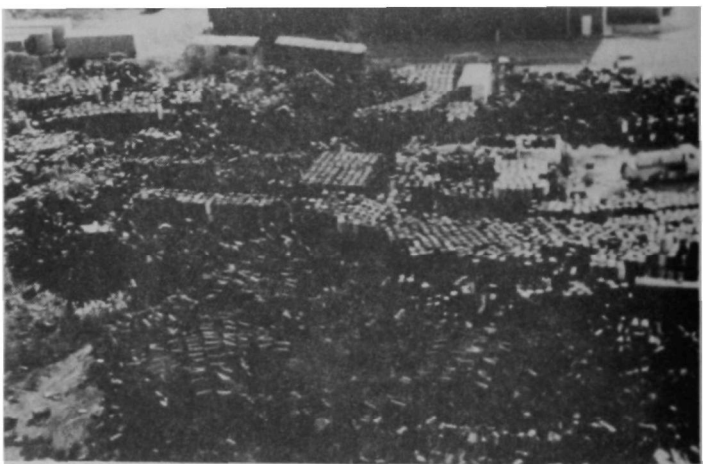


Figure 6.  
Conditions at the site prior to our cleanup activities.

Superfund Implementation Group. After USEPA forwarded basic information on the site to CDC, a medical toxicologist was assigned to provide support and direction in attempting to resolve these problems.

Shortly after the Indiana State Highway Department relocated the Gary subdistrict employees to Crown Point, USEPA designed



Figure 7.

Agency field representative setting the meteorological station, initiating the ambient air monitoring program.

and implemented a compound specific ambient air monitoring program (Fig. 7). Because total organic vapor measuring devices were being used, one could not say with certainty that the high reading of three ppm did not contain one ppm of benzene and, therefore, did not exceed the threshold limit value (TLV) for that substance.

Data from the compound specific ambient air monitoring program confirmed the OSC's professional intuition. Concentrations of organic pollutants were 10 to 100 times below the TLV's set for the work place. It was still puzzling how such minute concentrations could cause such wide spread ill effects.

When the highway department workers were still reluctant to return to Gary, a meeting with them was organized by the Agency, the State of Indiana Highway Department and CDC. The assigned physician attended this meeting; his presence and comments were pivotal in getting the employees back to their original workplace. The main point of logic he used to convince the workers to return was rooted in benzene exposure. The CDC physician calculated that additional gas consumption necessary to travel a greater distance to work increased their exposure to benzene via greater gasoline consumption. They realized they were breathing greater levels of benzene because of an increase in the number of gasoline tank fillups necessary for them to drive greater distances to work. Most of them returned to the Gary subdistrict garage.

The Agency's ability to address the Fontanyi family health issues was constrained considerably by the inaccessibility of Mr. Fontanyi and what appeared to be uncooperativeness by Mr. Fontanyi and his clinical ecologist physician. The CDC doctor was able to discuss with Fontanyi's physician his general procedures and the basis of his therapy. He refused at that time to discuss Mr. Fontanyi's case until the government had been given a release for access to his medical records. Unfortunately, after Mr. Fontanyi and his daughter were released from detoxification, they became inaccessible.

Repeated attempts were made by the Agency and CDC to contact Mr. Fontanyi so it could discuss and better understand his problems and determine the potential for others in the area to be

affected. Apparently, after Mr. Fontanyi had completed the detoxification process his doctor advised him not to return to his home or the Hessville neighborhood because the contamination in the soils and air was causing his medical problems. Finally, after many weeks, the Agency contacted Mr. Fontanyi and received his permission to review his medical records. They were just recently turned over to CDC for review.

Later, in a newspaper interview, Mr. Fontanyi's physician made the disturbing comment that part of the Hessville area is "unfit for human habitation" and that homes there should be evacuated. "The whole area is saturated with chemicals and wash-off from the dumps. This is a highly toxic area and if you continue to live there you are going to get very sick." The Agency would have hoped that this physician would have shared his data and findings with CDC and local health authorities prior to these kinds of public statements.

### Recommendations

The community relations plan cannot consider all possibilities while undertaking cleanup. Because of that, standard bylines for community relations plan development and implementation are that: (1) it must maintain flexibility, and (2) it must be updated whenever necessary.

While the community relations plan for this cleanup was one of the better ones, the OSC and program office must, whenever necessary, utilize all resources available to them. Most Regions now have assigned to them a CDC health representative responsible for interpreting and implementing health guidance and resources regarding possible adverse health effects associated with a site. If necessary, the health representative can seek a CDC physician in cases similar to Midco I. However, there will be instances when a doctor will be necessary. The problem with the highway department workers is a good example. Any person with a technical background could have used the benzene in gasoline example but it obviously meant much more to those affected individuals hearing it from a medical doctor.

Finally, at sites near areas of residential or commercial development, compound specific ambient air monitoring should be performed prior to cleanup activities and for a one to two week period during cleanup efforts. This will provide substantive data or air quality impacts and can be used to defend total organic compound measurements taken on a daily basis.

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# ESTIMATING VAPOR AND ODOR EMISSION RATES FROM HAZARDOUS WASTE SITES

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## INTRODUCTION

Odorous emissions from hazardous waste sites are often a major factor influencing community reaction. While in most cases odors are not in themselves a serious threat to health, they are directly sensed by the affected population and serve as a reminder (and a warning) that the site is emitting volatile compounds.

In this paper, the authors present a review of some of the factors influencing volatile organic emissions and present a methodology that can be used to determine the local impact of odors from a waste disposal site. Five areas of activity are addressed: emissions factors, odor emission measurement, community surveys, atmospheric transport and dispersion and community response services.

## EMISSION FACTORS

Odor problems at hazardous waste disposal sites can generally be equated to the emission of volatile organic chemicals. For contaminated soil systems, the most important mechanisms are direct volatilization (evaporation) and diffusion of vapors through the soil. The emission rate is a function of a number of factors: the area of contamination and concentration of the waste, the vapor pressures and gaseous diffusion coefficients of the various waste components, the depth and porosity of any overburden, mass flow of air and other gases, temperature, and the ambient concentration of waste components in the air above the site.

In cases where the waste material is at the surface of the soil, such as in a seep or a freshly uncovered contaminated soil layer, the dominant mechanism will be evaporation. The source strength can be approximated by:

$$Q = Km (P - P_a) / RT \quad (1)$$

where:

- $Q$  = mass flux
- $P$  = vapor pressure of the material
- $P_a$  = partial pressure of the material in the air over the surface
- $Km$  = transport coefficient of the atmosphere directly above the material
- $T$  = temperature of the liquid
- $R$  = gas constant

The transport coefficient can be estimated from:

$$Km = CU^{0.78} X^{-0.11} \quad (2)$$

where:

- $C$  = an empirical constant
- $X$  = liquid pool diameter
- $U$  = wind speed

However, care must be exercised when attempting to employ this approach for multicomponent, viscous mixtures like those found at

most waste disposal sites. The composition of the exposed liquid surface will not necessarily be replenished by mixing with the bulk of the material and emission of volatile components may be quite different than expected. Formation of films of relatively non-volatile materials that greatly reduce evaporation is commonly seen.

In sites where there is significant production of gases within the landfill, the emission of volatile compounds can be significantly affected by the mass flow out of the soil. The emissions for systems with significant outgassing can be estimated from:

$$Q = \left( \frac{-K \cdot A}{U \cdot L} \Delta p \right) C \quad (3)$$

where:

- $Q$  = mass flux
- $K$  = soil permeability
- $U$  = viscosity coefficient
- $A$  = effective area
- $L$  = effective thickness of soil cover
- $\Delta p$  = pressure differential between landfill gas and the atmosphere
- $C$  = concentration of material in the gas phase

However, the toxicity of most wastes disposed of in hazardous waste sites effectively prevents the microbial action most often responsible for landfill gas production and this mechanism is rarely dominant.

The most common situation at waste disposal sites is one where the volatile waste is buried under a semi-permeable layer of soil. In such cases, diffusion through the capping soil is the dominant mechanism of emission. The emission rate for this process can be estimated by:

$$Q = -D_a \left( C_a - C_s \right) \left( P_a^{10/3} / P_t^2 \right) / L \quad (4)$$

where:

- $Q$  = mass flux from the soil surface
- $D_a$  = effective diffusion coefficient in air
- $C_a$  = concentration of vapor in air above the surface
- $C_s$  = concentration of vapor in air of soil pores below the surface
- $L$  = soil depth
- $P_a$  = air filled porosity of the soil
- $P_t$  = total porosity of the soil

The major drawback to estimating emissions by this technique is the requirement for data on the diffusion coefficients and vapor pressures of all the materials of interest, as well as subsurface porosity and temperature. The method also assumes that the soil porosity itself is fairly uniform and that macro defects, such as cracks, root channels and animal burrows are not present in significant numbers. Finally, the estimates of vapor concentration in the



soil pores ( $C_s$ ) are subject to the same sources of error for multicomponent, viscous mixtures that evaporation calculations are.

This is not to say that models of emission rate are not useful. They can provide a reasonable starting point for estimating potential impacts. Moreover, they can be used to extrapolate how the existing rate would change as a function of site modification or change in sampling conditions.

However, for odor problems, where a whole ensemble of chemical compounds, each with its own unique set of physical and chemical properties must be considered, modeling alone, is of limited usefulness. It is much more practical to combine the models of vapor behavior with a limited set of on-site measurements.

## ODOR EMISSION MEASUREMENTS

Odor is not something that can be measured without reference to subjective response. That is, no instrument can tell you how bad something smells. This is especially true for complex odors related to mixtures of chemical compounds such as those found at hazardous waste sites. The most effective method of detecting and quantifying odorous emissions is to smell them.

Panels of odor judges, generally composed of a cross-section of the population in order to obtain a reasonable estimate of the intensity and objectionable nature of any particular odor as perceived by the community exposed, are used to quantify odors. The use of this technique is surprisingly reproducible and accurate in making quantitative measurements of a subjective phenomenon.

Samples for sensory odor evaluation are taken using the bag-in-a-drum method shown schematically in Fig. 1. A Tedlar sample bag is installed inside an aluminum sample drum. A vacuum is pulled on the drum, drawing the sample through Teflon tubing into the sample bag. When the bag is partially filled, the drum is pressurized, emptying the bag. The vacuum is then reapplied and the bag is completely filled. The partial filling and subsequent emptying of the bag serve to "precondition" the bag walls by equilibrating the inner surface with the sample gas, thereby minimizing losses caused by adsorption.

Measurements of odor source strength can be taken with the aid of a portable wind tunnel, as shown in Fig. 2. The wind tunnel provides a constant flow of odor-free air at a known velocity and isolates the area being measured from emissions from other areas. The tunnel consists of a variable flow blower with an activated carbon filter on the inlet and a three-sided tunnel on the outlet. The support feet of the tunnel are lined with acid-resistant foam to seal over uneven spots in the surface. The blower is set to deliver the desired tunnel velocity and a sample is drawn from the tunnel at various distances "downwind" using the bag-in-a-drum technique.

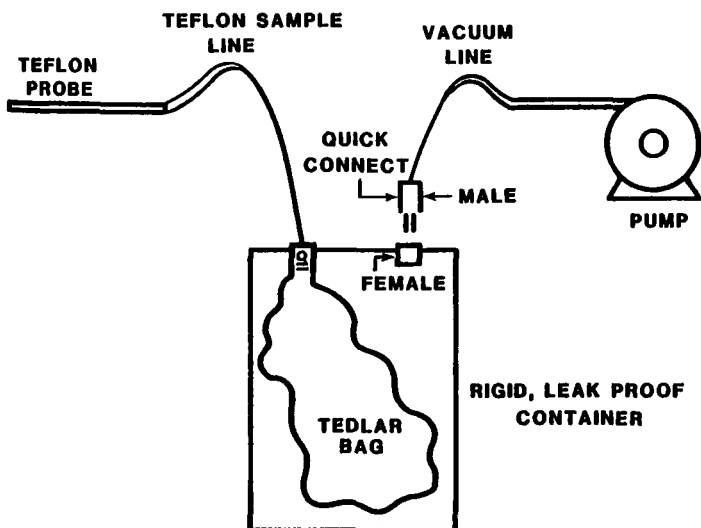


Figure 1.  
Integrated Bag Sampling Train

Odorant or volatile organic samples can also be collected by adsorption on Tenax or other sampling media, depending on the nature of the waste. Samples can be adsorbed directly from the wind tunnel or they can be transferred during sensory evaluation using a system such as that shown in Fig. 3.

Odor samples are evaluated for detectability (dilution-to-threshold level) and intensity using a panel of judges who have been screened for their ability to detect odor qualities typical of the odors to be measured. There are many techniques available for measuring both detectability and intensity. TRC uses the forced-choice triangle olfactometer<sup>5</sup> for measuring detectability and the eight-point butanol reference scale<sup>6</sup> for evaluating intensity. The measurements are done in a mobile laboratory equipped with a carbon filtration system which maintains an odor-free environment. Measurement of both properties is necessary because, although odor annoyance is more closely related to intensity, dispersion modeling is best done in terms of detectability.

The forced-choice triangle olfactometer uses carbon-filtered air to make six simultaneous dilutions of the odor sample. Each dilution level is presented by means of a cup containing three glass-sniff ports. Two ports have only odor free air while the third has the diluted odor. Panelists begin with the most dilute sample and at each stage must choose one of the three ports whether they can detect an odor or not. The median threshold for the panel, that is the point at which 50% of the panel correctly and reproducibly, selects the diluted odor, is thus determined.

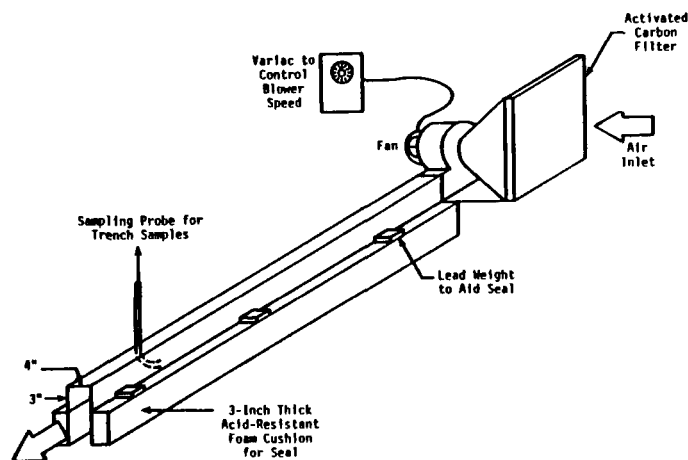


Figure 2.  
Schematic of Portable Wind Tunnel

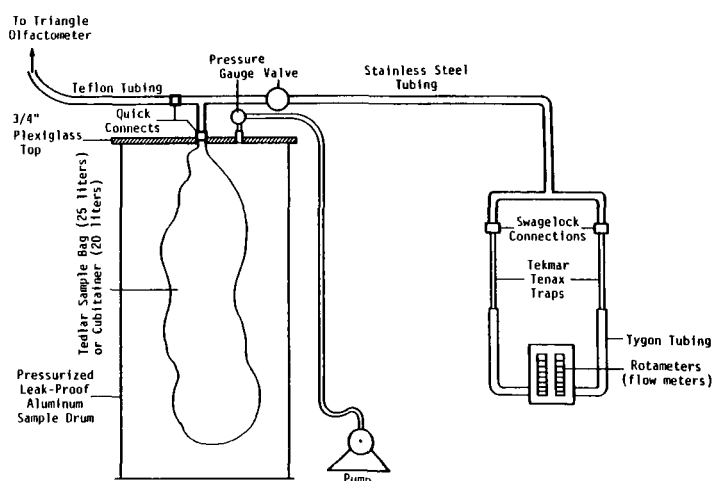


Figure 3.  
Schematic of System for Transfer of Odor Samples to Tenax Traps

The butanol intensity olfactometer provides eight simultaneous dilutions of a standard reference odorant, 1-butanol. Each level doubles in butanol concentration from the preceding level. The scale provides objective reference points for comparison of odor intensities. Each panelist compares an odor level from the triangle olfactometer to the butanol scale and select the butanol port which is perceived to have the same intensity. The choices are averaged to derive a mean value for the panel.

The detectability and intensity measurements can be used to estimate the objectionability threshold for the odors emanating from the site. A log-log plot of detectability vs. intensity of each sample, similar to a Steven's Law function, is used to determine the detectability level corresponding to an intensity of 50 ppm of butanol vapor equivalent to 2.5 on the 8-point scale. This value has been shown in previous work to be in most cases a reasonable estimate for the upper limit for an acceptable odor level.<sup>8</sup> This level provides the target for evaluating control requirements and the potential for creating an odor nuisance during mitigation activities.

In addition to direct olfactory measurements, samples can be characterized by a gas chromatography odorogram. In this procedure, the materials adsorbed on the Tenax tubes are desorbed into a gas chromatograph (GC). The column is equipped with an effluent splitter which sends a portion of the elution from the column to a flame ionization detector (FID) and the remaining portion to a sniff port. As peaks emerge, odor judges describe the odors in the sniff ports and their observations are recorded on the chromatogram. This technique helps identify which of the peaks are odorous, and a skilled judge can even provide a fairly accurate estimate of the relative contribution of each component to the overall odor.

However, this procedure does not identify the components chemically. To accomplish this, a second sample is analyzed by GC/mass spectrometry and the odorous chemicals are identified by mass number. The chromatographic system used for the GC/MS is identical to that used for the GC/odorogram so peaks can be matched directly by retention time. Of course, any of the peaks, whether odorous or not, can be identified by GC/MS, if desired.

Once the odorants or volatile organics of concern are identified chemically, they can be quantified on the GC using external standards. The resulting concentration data can be used to calculate an emissions rate for any particular chemical.

## COMMUNITY SURVEYS

Community odor surveys should be done simultaneously with on-site sampling, and at various other times of the day. The primary purpose of these surveys is to provide data which can be used to calibrate an odor dispersion model for the specific site in question. The surveys also help document the geographical extent of the odor problem and the odor levels that occur under various meteorological conditions.

Community surveys are done by experienced odor judges driving or walking in the neighborhood around the site and noting the location, time, quality, intensity and detectability of any odors detected. Wind speed and direction, ambient temperature, and other meteorological conditions are also noted. Intensity measurements are made by butanol referencing. Detectability is measured using the Scentometer, a simple field instrument shown schematically in Fig. 4.

## ODOR DISPERSION MODELING

Although the sensory measurements, chemical analyses, and community surveys all document the impact and characterize the emissions from a hazardous waste site, it is the use of an atmospheric transport and dispersion model which ties all the data together and allows predictions of the community impact of an odor source under any given set of conditions.

TRC uses a proprietary model designed specifically for use in odor situations. Odor is not a steady state or time averaged

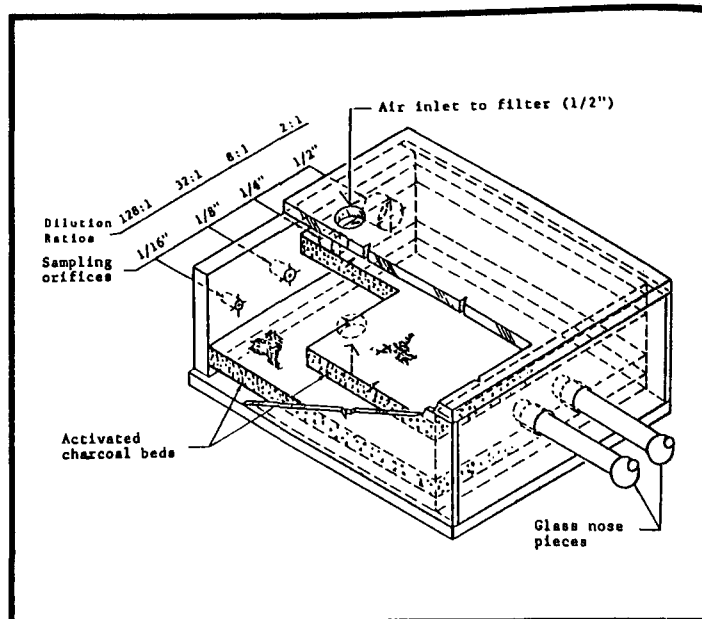


Figure 4.  
Scentometer

response. Accordingly, the model is a "fluctuating puff" model that determines dilution rates of odor emission puffs and distributions of plume centroids, from which it predicts instantaneous odor levels. Calculated results are presented as a frequency distribution of predicted odor levels at specified receptor locations. It can be used to determine peak odor level during a one-hour period and percentage of occurrence at detectable odor during a one-hour period.

The model is first calibrated using simultaneous on-site emission and community response data. The source parameters are input along with the meteorological conditions existing at the time of the survey. Odor levels are predicted for the locations at which odors were actually detected. If the predicted and observed values are in good agreement, the model is considered appropriate for that site. If there is a significant deviation, the input parameters are adjusted until agreement is attained.

Once calibrated, the model can be used to predict the odor impact under any given set of meteorological or site conditions. For instance, if an open site is to be partially covered, the source dimensions are changed in the model input. If parts of the site are to be excavated, the emission terms are modified accordingly.

## COMMUNITY RESPONSE SERVICE

Establishment of a community response service can be helpful in assessing the odor impact of a hazardous waste site, but is not essential. In most cases, a response service functions as a clearing house for odor complaints by community residents. When a complaint is received, a response team is sent to the location as quickly as possible. On-site observations of the meteorological conditions and nature and intensity of the odor by a trained odor judge are coupled with sampling of the odor for later analysis where appropriate.

The complaining resident is then asked to complete a questionnaire designed to evaluate the intensity and odor quality at the time of the complaint. If possible, matching information is solicited in the area immediately up and downwind of the affected area. The information obtained not only helps define the conditions that the community considers objectionable, but the act of setting up such an operation often has a beneficial public relations effect.

## EXAMPLE OF AN APPLICATION OF THE METHODOLOGY

Results from a study in which the methodology described above was applied to a hazardous waste site used for petroleum wastes are shown in Tables 1 and 2 and Fig. 5. Since the time the site was active, the neighborhood around it has been developed so that now there are houses within 150 ft of major emission points.

**Table 1.**  
**Sample Results of Sensory Odor Measurements**  
**a. Surface Samples**

Location	Soil Condition	Soil Temp. (°F)	Length of Wind Tunnel (meters)	Tunnel Velocity (m/sec)	Detectability (ED <sub>50</sub> )	Intensity At ED <sub>50</sub>
Sump 1	Dry	60	4.9	1.0	11	1.9
Sump 2	Dry	69	8.6	1.0	38	4.2
Sump 3	Dry		8.6	1.0	20	2.9
Sump 4	Dry		8.6	1.0	70	3.1
Sump 5	Dry	69	4.9	1.0	33	2.1
Sump 6	Dry	88	4.9	1.0	39	3.1
Sump 2	Dry	79	8.6	2.5	17	1.9
Sump 4	Dry	76	8.6	2.5	17	2.5
Sump 1	Wet	64	4.9	1.0	13	1.5
Sump 2	Wet	63	8.6	1.0	12	1.6
Sump 3	Wet	67	8.6	1.0	30	2.0
Sump 4	Wet	63	8.6	1.0	<10	0.6
Sump 5	Wet	73	4.9	1.0	<10	0.9
Sump 6	Wet	75	4.9	1.0	15	2.4
Sump 4	Drying	66	8.6	1.0	<10	0.8
Sump 3	Drying	78	8.6	1.0	74	2.5
Sump 2	Drying	80	8.6	1.0	19	1.6
Sump 1	Drying	76	4.9	1.0	53	2.7
Sump 5	Drying	80	4.9	1.0	19	1.7
Sump 6	Drying	84	4.9	1.0	39	2.6

**b. Subsurface Samples**

Sample		ED <sub>50</sub>	Odor Level in Cup 6 ED <sub>50</sub> 250	Intensity at ED <sub>50</sub> 250
Core Hole A	4½ ft. BWS*	4,782	19.1	4.9
Core Hole A	9½ ft. BWS	4,427	17.7	4.2
Core Hole A	20 ft. BWS	16,293	65.2	5.3
Core Hole A	30 ft. BWS	18,334	73.3	5.4
Core Hole B	7 ft. BWS	12,661	50.6	4.5
Core Hole B	10½ ft. BWS	14,099	56.4	4.5
Core Hole B	20 ft. BWS	18,597	74.4	4.9
Core Hole B	27 ft. BWS	19,077	76.3	4.9

\*BWS = Below waste surface

Results of sensory odor measurements made on both surface samples taken from the wind tunnel and subsurface samples taken from a flux chamber lowered into core holes are shown in Table 1. Surface sampling showed that the odor levels varied with soil moisture conditions and soil temperature, but not with wind tunnel length, after a relatively short run. This implied that the concentration of odorants in the air above the soil did not need to be very high for a diffusion equilibrium to be established. In this particular case, the odor levels at the surface were fairly low, but because of the size of the source, the overall emission rates were high enough to cause objectionable odors in the community under stable meteorological conditions. Subsurface samples showed very high odor level potential if excavation was attempted.

The relationship between detectability and intensity for the surface and subsurface samples are shown in Fig. 5. For the surface samples, an odor would begin to be considered objectionable at about 8 times its threshold level. This estimate was confirmed by the results of the community response questionnaire, which indicated that at an odor level 8 times higher than the threshold concentration complaints began.

However, the results of the subsurface sampling indicated that the nature of the odor beneath the surface was quite different. Such an odor would be considered objectionable as soon as it was detectable. Therefore, if the site was to be excavated, it would have to be done in such a way as to maintain community odors at less than their detectability threshold.

The odorogram indicated that the mixture of wastes was highly complex, with as many as 70 peaks, of which over 30 were strongly odorous (Table 2). Considering this complexity, the semi-empirical source measurement program clearly represents the easiest way to quantify the problem.

**Table 2.**  
**Chemical Compounds Found in a Typical Surface Sample**

1,1-Dibromo-2-chloro-2-fluorocyclopentane	1,4-Dimethylcyclohexane
Oxirane	Tetrahydrothiophene
Methyloxirane	2,3,5-Trimethylhexane
Methylene chloride	2-Methyloctane
2-Methylpropanal	Ethylcyclohexane
Hexane	1,1,3-Trimethylcyclohexane
Trichloroethene	1,2,4-Trimethylcyclohexane
Methylcyclopentane	2,3-Dimethylheptane
1,1,1-Trichloroethane	Ethylbenzene
Benzene	2-Methyloctane
2-Methylhexane	m,p-Xylene
2,3-Dimethylpentane	o-Xylene
3-Methylhexane	Nonane
1,3-Dimethylcyclopentane	1-Ethyl-4-methylcyclohexane
2-Ethyl-1-hexanol	Octahydroindene
1,2-Dimethylcyclopentane	Propylcyclohexane
Heptane	1,1'-Oxibisocane
Methylcyclohexane	2,2,5,5-Tetramethyl-3-hexane
2,5-Dimethylhexane	2-Methylnonane
Ethylcyclopentane	1-Ethyl-1-methylcyclohexane
1,2,4-Trimethylcyclopentane	octanol
2,3,4-Trimethylcyclopentane	Decane
2,3,3-Trimethylpentane	1-Ethyl-1-hexanol
2,3-Dimethylhexane	1-Ethyl-3-methylcyclopentane
Toluene	1-Decanol
3-Methylheptane	2,2,5-Trimethylhexane
1,3-Dimethylcyclohexane	Decahydronaphthalene
2,2,5-Trimethylhexane	2,2,3,4-Tetramethylpentane
1,2-Dimethylcyclohexane	Undecane
Octane	

**Table 3.**  
**Comparison of Predicted and Observed Odor Levels for Daytime Conditions**

Receptor Location	Observed Odor Level (D/T)	Predicted Peak Odor Level (D/T)	Predicted % Time Detectable Odor Levels
A	Threshold to 8	8	88
B	Threshold to 32	12	99.5
C	None	0.1 (undetectable)	0
D	Threshold to 8	8	96.5
E	Threshold to 32	8	74
F	Threshold to 2	1	0

The documentation of odor impact that can result from community surveys is shown in Fig. 6. These data are very helpful in assessing the geographic extent and severity of the odor impact, as well as in evaluating the effects of local topography and meteorology on odor dispersion patterns for scheduling mitigation activities.

The calibration of a site-specific odor dispersion model is shown in Table 3. The odor emission data shown in this table were put into



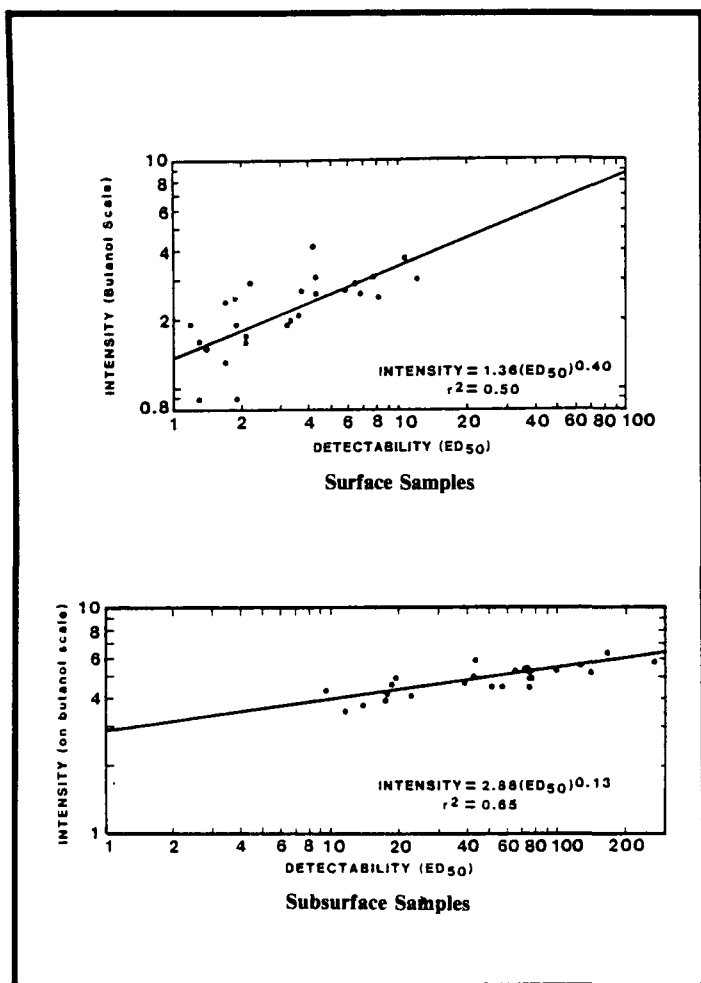
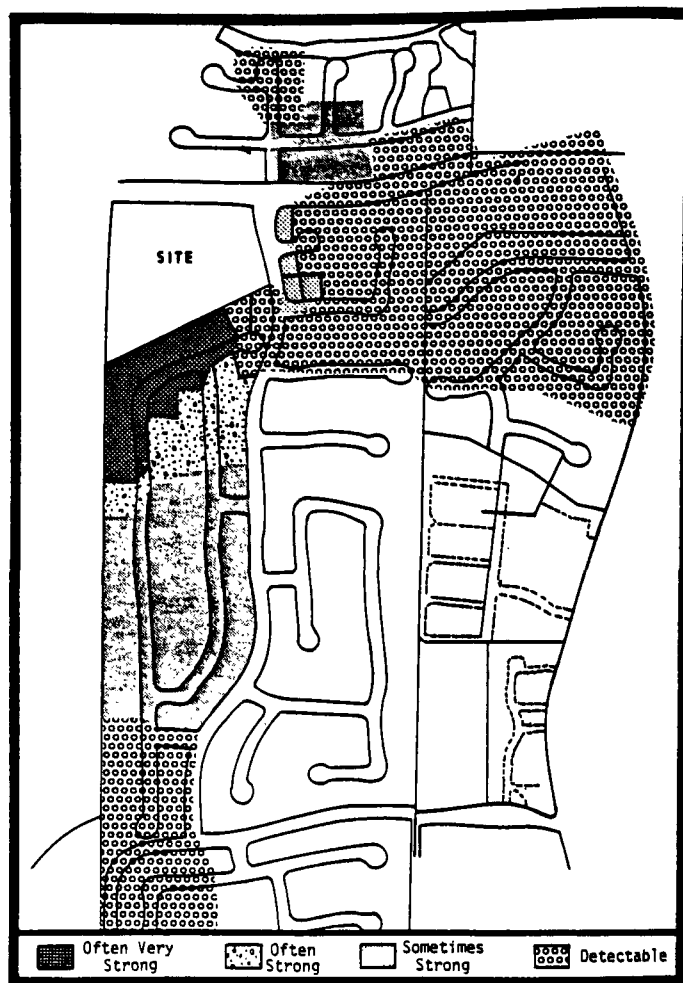


Figure 5.  
Relation of Detectability and Intensity



Patterns are based upon both location of complaints residences and TRC surveillance.

Patterns are highly influenced by local topographical as well as meteorological conditions.

Figure 6.  
Odor Impact in Vicinity of Site Under Existing Conditions

the model along with meteorological data recorded during a survey. The predicted odor impact agreed very well with that observed, and the model was considered calibrated for this particular site.

## CONCLUSIONS

Despite the complexity of the mechanisms involved, there is a practical methodology available which will provide the data necessary to evaluate odor impacts of hazardous waste sites, as well as the potential impact of mitigation activities. The method involves odor and volatile organics sampling, sensory odor measurements, speciation and quantification of volatile organics, community surveys, and dispersion modeling. Establishment of a service to respond to community complaints can be helpful, but is not essential for the successful application of the method.

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# AIR MODELING AND MONITORING FOR SITE EXCAVATION

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## INTRODUCTION

Usually at an abandoned hazardous waste site, groundwater contamination or surface runoff are the major concerns. During site excavation, however, air impacts due to contaminated fugitive dusts and liberated volatile compounds may be the major source of risk. In general there are three steps in a risk minimization program for air impacts:

- Planning site activities (principally modeling)
- Monitoring (principally during remedial action)
- Dealing with community and agency concerns (integration and interpretation of monitoring and modeling results)

In addition to allaying concerns at the time, proper documentation of actual exposure levels can prevent future liabilities.

Generally both monitoring and modeling activities are concerned with the determination of ambient concentrations at the point of worker exposure, at the property line and in populated nearby areas. The parameters on which concentration and exposure depend are shown in Table 1. Predicted or monitored concentration levels can then be compared with threshold limiting values (TLVs), OSHA standards (adjusted for the fact that they pertain to an 8-hour day) or other appropriate requirements. If concentrations or exposure are deemed unacceptable a number of avenues of recourse are available.

Fugitive dusts can be controlled by a number of practices at the site including fogging or misting. Wetting the ground can also reduce volatile emissions. In addition, pre-planning site activities as to season, area of disturbance, and duration can influence acceptability.

Table 1.  
Parameters of the Air Pollution Problem at Hazardous Waste Sites

Concentration depends on:

- Chemical compound
- Wind speed
- Ambient temperature
- Overburden (volatiles)
- Soil moisture
- Soil porosity
- Dust control measures

Exposure depends on:

- Concentration
- Population movement in space and time
- Area and duration of excavation
- Indoor/outdoor air relationships

## MODELING

The models of interest in this paper estimate emissions. Having an estimate of the mass rate of emissions, conventional urban and industrial source complex dispersion models can be used to calculate downwind concentrations for compounds which are not rapidly reactive in the atmosphere.

Both fugitive dust and hazardous vapor emissions will be influenced by geometry as shown in Fig. 1. Material at the bottom of a pit deeper than it is wide (in the windward direction) is shielded from atmospheric turbulence, volatiles can only escape via molecular diffusion, a slow process and hence a low emission rate. For a shallow pit (wider than it is deep) the excavation acts as an additional roughness element as shown in Fig. 1 b. Enhanced turbulence due to a stationary vortex will increase emissions. A similar phenomenon occurs at piles (Fig 1 c). In the lee of the pile near the peak a vortex system is responsible for fugitive dust emissions.

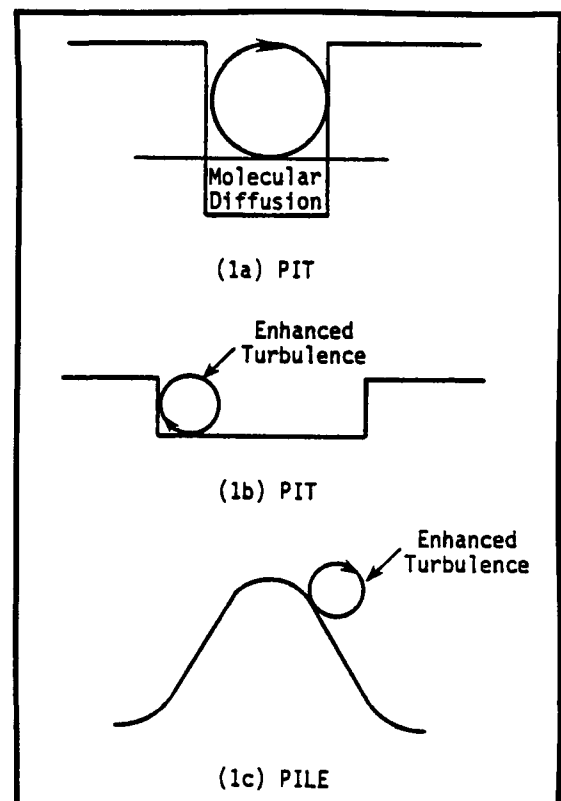


Figure 1.  
Influence of site geometry

The fact that fugitive dust emission rates in particular depend on such local factors is important from a measurement standpoint. It means that single monitor measurements are likely to be misleading since a small shift in wind direction will shift the monitor reading off centerline or perhaps cause the plume to be missed entirely.

## VOLATILES

First volatile compound emissions will be considered. The geometry is shown in Fig. 2. Note that geometrical effects discussed

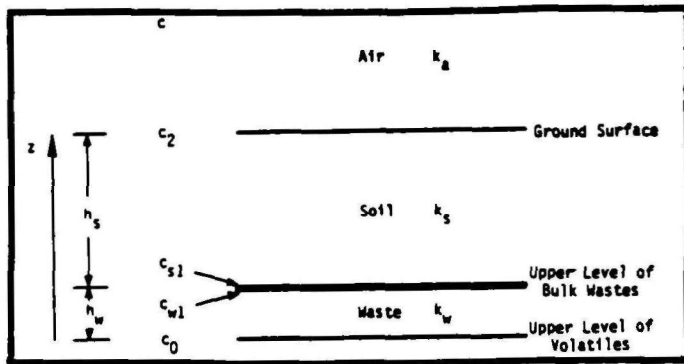


Figure 2.  
Volatile compound emissions from buried waste

earlier are neglected. Volatiles must diffuse through the bulk waste then through the soil then into the lower atmospheric boundary layer. Conservation of flux  $F$  gives:

$$F = k_w (C_0 - C_{w1}) = k_s (C_{s1} - C_2) = k_a (C_2 - C), \quad (1)$$

where the  $k$ 's are mass transfer coefficients in each regime and the  $C$ 's are concentrations at the locations shown. Any significant wind will rapidly remove material once it enters the windstream, hence  $C \ll C_2$ . Further, the liquid and gaseous phase concentrations are related by:

$$C_{s1} = C_{w1} \frac{H}{RT} \quad (2)$$

where  $H$  is a Henry's Law constant,  $R$  is the gas constant and  $T$  is the temperature.

From Equations 1 and 2, one can obtain the series conductance relationships:

$$F = k C_0 \quad (3)$$

$$\frac{1}{k} = \frac{1}{k_w} + \frac{RT}{H} \left( \frac{1}{k_a} + \frac{1}{k_s} \right) \quad (4)$$

The various  $k$ 's are given by:

$$k_w = \frac{D_w}{h_w} \quad (5)$$

$$k_s = \frac{D_a}{h_s} \frac{(P_a)^{10/3}}{P^2} \quad (6)$$

$$k_a = .0292 V^{.78} L^{-.11} S_c^{-.67}, \quad (7)$$

where  $D_w$  and  $D_a$  are molecular diffusion coefficients ( $m^2/s^2$ ) in the waste and in air,  $P$  is the soil porosity,  $P_a$  is the air filled porosity,  $V$  is the wind speed ( $m/s$ ) at 10 m,  $L$  is the dimension of the waste in the windward direction and  $S_c$  is the gas phase Schmidt number.

Equation 6 for the soil mass transfer coefficient has been derived from the theoretical work by Millington and Quirk<sup>1</sup> and experiments by Farmer *et al.*<sup>2</sup> The theoretical basis for this result is suspect since it is based on hydraulic rather than diffusion theory. However, Equation 6 is an adequate representation of the limited experimental results.

Equation 6 applies to substances whose transport through soil is by vapor rather than liquid phase. Only a few substances with  $D_{H_2O} D_a \left( \frac{H}{RT} \right)^{-1}$  would not behave in this manner. Equation 7 is due to Sutton<sup>3</sup> and reflects the vertical turbulence structure of the earth's boundary layer.

The problem is time dependent inasmuch as the flux into the atmosphere decreases the amount of volatile in the waste and increases the gradient scale  $h_w$ :

$$F = - \frac{d}{dt} (C_0 h_w), \quad (8)$$

which can be combined with Equations 3 through 5 to give:

$$D_w = \frac{RT}{H} \left( \frac{1}{k_a} + \frac{1}{k_s} \right) \left( \sqrt{1 + \frac{2 \tau H^2}{D_w (RT)^2 \left( \frac{1}{k_a} + \frac{1}{k_s} \right)^2}} - 1 \right) \quad (9)$$

which together with Equations 3 through 5 now provides a complete description for the emissions. Several comments are in order concerning these equations:

- As overburden is removed  $h_s$  decreases,  $k_s$  and becomes unimportant in Equation 3. The formula then becomes the same as for evaporation from bulk waste at the surface.
- When there is significant overburden soil moisture makes a large difference through the factor  $(P_a)^{10/3}$  in Equation 6. The flux can decrease by an order of magnitude between wet and dry soil.
- The dependence of concentration on wind speed will range from  $V^{-1}$  to  $V^{-.22}$  depending on whether or not  $k_a$  is controlling rather than  $k_w$  or  $k_s$ . Thus low wind speeds will produce peak concentrations although emissions are greatest under high wind speeds.

### FUGITIVE DUST

Equation 7 for  $k_a$  also applies to fugitive dust. Its usefulness however is negated by two factors. First, the amount of suspendable dust is *a priori* not known. Second, dust particles are bound to each other and to the substrate by a variety of forces. Because of these difficulties one falls back on a few rules of thumb, although these have not been developed specifically for excavation sites. Two such rules are:<sup>4,5</sup>

- Fugitive emissions are negligible if soil moisture content is more than 4% by weight.
- Emission rates range from 0.1 to 0.3 lb/ton of material handled at 1% moisture content based on experience with crushed gravel and sand.

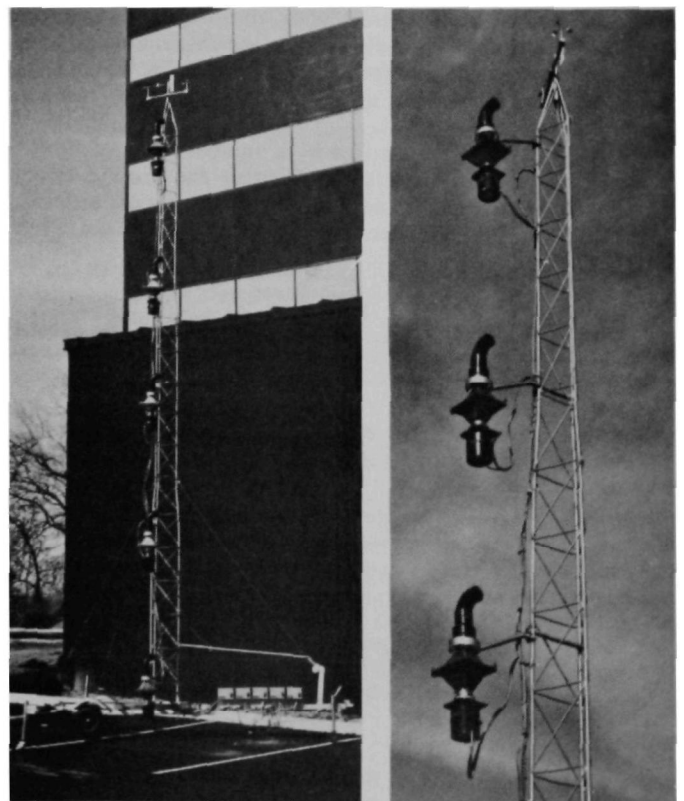


Figure 3.  
TRC MEDUSA fugitive dust monitoring system

Clearly there are opportunities for substantial improvements in modeling fugitive dust emissions due to remedial activities at hazardous waste sites. Activity specific measurements are badly needed particularly with controls such as misting and fogging in use.

## MONITORING

Some of the presently available methods for monitoring are shown in Table 2. The large scale (9.4 m horizontally or vertically) "medusa" hi-vol array developed at TRC for fugitive measurements is shown in Fig. 3. With this array it is possible to tell whether the plume centerline has been captured or not unlike the use of a single monitor. The advantage of a hi-vol system as compared to a nephelometer is that concentrations are available for subsequent laboratory analysis. This is important since a variety of emission sources are likely to be present, e.g., background or equipment emissions.

The TRC portable wind tunnel used for volatile emissions measurements is shown in Fig. 4. It can be assembled where terrain permits in sections up to 8.8 m, a long fetch being desirable to achieve an equilibrium solution. The wind tunnel method for estimating volatile emissions is only valid when  $k_d > k_s$ ,  $k_w$ , i.e., appreciable wind speeds.

## COMMUNITY CONCERNS

Dispersion modeling may be desirable in conjunction with ambient monitoring to extrapolate to between monitor values, to larger distances or to different meteorological values. Particular emphasis may be placed on densely populated regions or potentially sensitive receptors as schools or hospitals.

Table 2.  
Monitoring Methods

Method	Comment
Fugitives	
Multiple Hi-Vols	Area monitoring needed to capture source
Nephelometer	May be confounded by diesel equipment emissions or fogging/misting operations
Volatiles	
Sorbent Filters	Ambient measurement
Portable Wind Tunnel	Direct emissions measurement

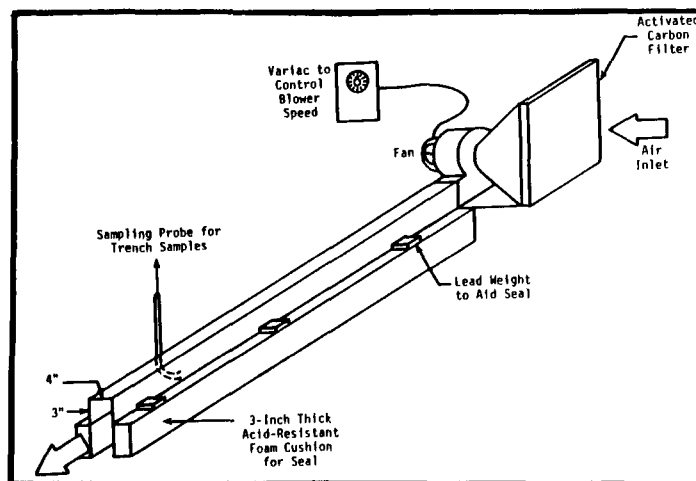


Figure 4.  
Schematic of portable wind tunnel

Odors and toxicity are not synonymous. Public information programs which distinguish odor and health impacts may be useful. Separate odor modeling and analyses as described in the paper by Duffee and Stankunas<sup>6</sup> at these proceedings may be necessary.

## ACKNOWLEDGEMENT

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# SAMPLING TECHNIQUES FOR EMISSIONS MEASUREMENT AT HAZARDOUS WASTE SITES

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## INTRODUCTION

Emission measurements at hazardous waste sites provide a mechanism by which existing and potentially hazardous conditions can be assessed and evaluated. Emission measurements are used to estimate the amount of a specie(s) emitted from a given surface area to waste exposed to the atmosphere over time. These data are necessary to estimate the population exposure through modeling efforts. The exposure level can be subsequently used to quantitate risk and assess potentially hazardous conditions at or near waste facilities. Involvement in hazardous waste facility assessment, evaluation and remedial action has necessitated improved sampling techniques for emissions measurements.

A number of sampling approaches,<sup>1</sup> both direct and indirect, are reported in the literature that could be used to obtain emissions data at hazardous waste sites. An example of an indirect method is the concentration-profile technique described by Thibodeaux.<sup>2,3</sup> Emission measurements are obtained by measuring the concentration of specie(s) at various heights above the waste surface. The concentration data, along with meteorological data are used to estimate the emissions from the waste based upon a micrometeorological model. An example of a direct emission measurement is the isolation flux chamber technique.<sup>4,5,6,7</sup> Here, an enclosure is placed on a waste surface and emission measurements are made directly by measuring the concentration of specie(s) from a known sweep air flow rate for a given surface area of waste.

Both of these sampling approaches provide quantitative emissions data needed for hazardous risk assessment. In this paper, the authors present examples of both indirect and direct emission measurement sampling techniques that have been used successfully by Radian to measure emissions from waste facilities. Sampling methodology design, materials and equipment used, advantages and disadvantages encountered, as well as example results are discussed.

## INDIRECT EMISSION MEASUREMENTS— CONCENTRATION-PROFILE TECHNIQUE

Organic emissions from waste lagoons have been measured indirectly using the concentration-profile technique.<sup>2,3</sup> As originally conceived, this technique involved collecting organic vapor samples in liquid oxygen cooled glass bead traps at 6 logarithmically spaced heights above the water surface. Wind speed and temperature profiles were simultaneously obtained and then were used for calculation emission rates using a micrometeorological model. The concentration profile technique has been used by Radian to measure organic emissions at two wastewater treatment facilities for the organic chemical manufacturing industries.<sup>8</sup>

### Methods and Materials

A 6m pontoon boat was outfitted to perform sampling on lagoon surfaces. The boat contained a 3m sampling mast, on-board computer, power supply and breathing air (Fig. 1). The sampling mast

consisted of six wind speed and temperature sensors, six air sampling probes and transfer lines, all at logarithmically spaced intervals above the water surface, and one wind direction sensor.

Since cryogenic traps are somewhat impractical for field use, evacuated stainless steel canisters were used to collect integrated air samples over a 20 min period. After collection, the samples were pressurized with ultra high purity nitrogen to approximately 15 psi. The air collection system did not require power, and alleviated problems due to contamination and moisture condensation, which are commonly encountered with pumping systems.

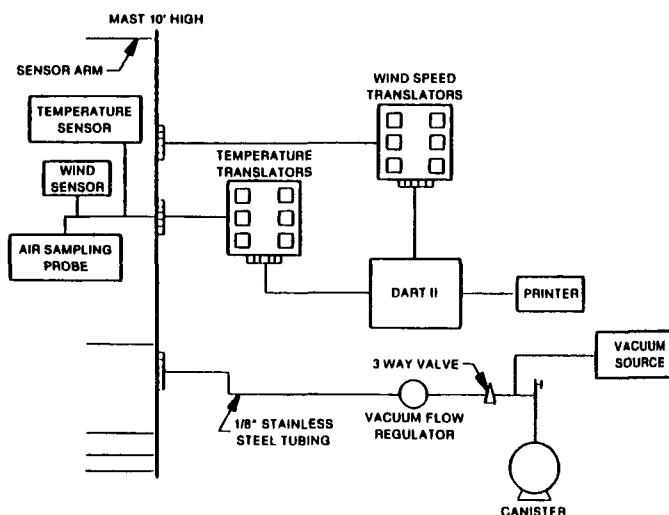


Figure 1.  
System Block Diagram for the Concentration-Profile Technique

### Field Sampling

Meteorological data and air samples were collected continuously over 20 min periods. In addition, water samples, water temperature, and relative humidity were obtained during each sampling period. To properly fit the concentration-profile micrometeorological model, the boat was positioned at least 50 (and preferable 200) times the distance of the height of the dike or other significant wind obstruction, away from the edge of the pond (along the direction of average wind). Profile measurements taken closer than this cannot reflect the logarithmic profile and consequently emission data may not be valid. Also, data were only collected during stable atmospheric conditions (Richardson numbers greater than  $-0.1$ ).

### Results

Results of three concentration-profile tests performed at each of two sites are presented in Table 1, while a typical species profile is shown in Fig. 2. The logarithmic wind speed profiles, chemical con-

centration profiles, and resulting flux rates are presented. Standard errors, correlation coefficients and T-values are also reported for estimates of slopes.

Flux rates (indirect emissions) for benzene, diethyl-ether, indene, styrene, and total aromatics were measured at the first site which was an aerated treatment basin. Flux rates for benzene, acetone and cyclohexane were measured at the second site, which was a

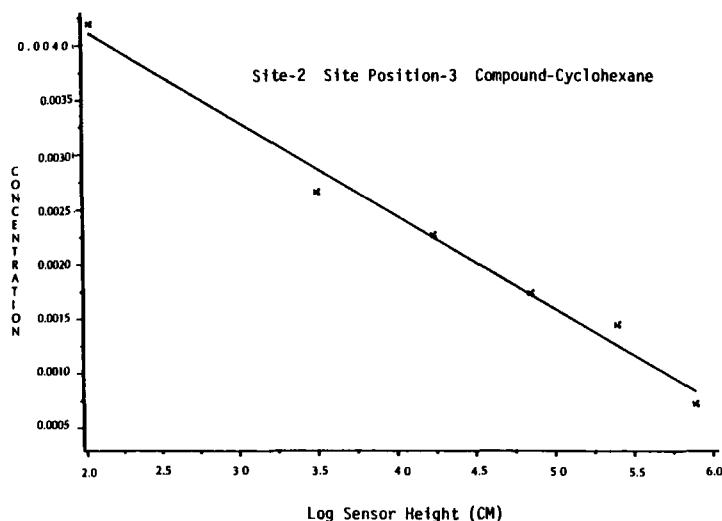


Figure 2.  
Specie Profile, Plot of Concentration-vs-Height Above  
Emission Surface  
Site 2—Site Position 3 (Compound-Cyclohexane)

nonaerated basin. In general, standard errors for measured flux rates were significant, due to the low levels of organic species which were measured in the air.

### Discussion

The concentration-profile technique has provided emissions measurement data over a range of natural conditions, with minimal disruption of natural processes. There are, however, disadvantages of this technique.

The sampling apparatus is bulky and expensive. It is difficult to accurately determine temperature profiles within 3m of a surface at ambient temperature. Also, since organic species concentrations decrease logarithmically above the sampling surface, accurate measurements at upper heights can be difficult due to analytical sensitivity limitations. Finally, restrictions of the Concentration-Profile model do not allow sampling on small lagoons which potentially could produce serious emissions. Meteorological restrictions of the model also limit its utility. Despite these limitations, indirect emissions measurements using the concentration profile technique and emissions estimate provide reliable emissions data for risk assessment for applications such as these which are difficult or impossible to sample by other conventional techniques.

### DIRECT EMISSION MEASUREMENTS— ISOLATION FLUX CHAMBER TECHNIQUE

Isolation flux chambers of various size and shape have been used by Radian. Each of the chambers described below was designed for a specific measurement application at a waste site. However, all types can be discussed in general terms (Fig. 3).

An isolation flux chamber isolates a given soil/waste surface area. Clean, dry sweep air is added to the chamber at a fixed, con-

Table 1.  
Calculated Chemical Flux Rates and Statistical Regression Parameters Using Indirect Emission Measurements

Site/Sample	n	Windspeed (cm/sec) vs Ln Sensor Ht (cm)				Species	n	Chemical Conc (ng C/cm <sup>3</sup> ) vs Ln Sensor Ht (cm)				Flux Rate (ng C/cm <sup>2</sup> sec)	
		Slope Estimate	Std. Error	r	T-value			Slope Estimate	Std. Error	r	T-value	Estimate	Std. Error
FB-1	5	73.0	7.7	0.98	9.5	Benzene	5	-0.0054	0.0030	0.73	-1.8	0.0679	0.0544
						Diethyl Ether	5	-0.0048	0.0034	0.63	-1.4	0.0604	0.0543
						Indene	4	-0.0039	0.0010	0.95	-4.1	0.0357	0.0163
						Styrene	5	-0.0010	0.0002	0.94	-4.8	0.0104	0.0044
						Total Aromatics	5	-0.0104	0.0045	0.80	-2.3	0.1169	0.0643
FB-2	5	73.0	7.7	0.98	9.5	Benzene	5	-0.0066	0.0024	0.84	-2.7	0.0761	0.0500
						Diethyl Ether	5	-0.0103	0.0017	0.96	-6.0	0.1207	0.0582
						Indene	3	-0.0048	0.0008	0.99	-6.4	0.0410	0.0230
						Styrene	3	-0.0026	0.0035	0.59	-0.73	0.0250	0.0440
						Total Aromatics	5	-0.0192	0.0031	0.96	-6.3	0.2001	0.0914
FB-3	5	56.2	17.4	0.88	3.2	Benzene	6	-0.0030	0.0023	0.55	-1.3	0.0336	0.0426
						Diethyl Ether	6	-0.0039	0.0014	0.82	-2.8	0.0442	0.0558
						Indene	6	0.0007	0.0005	0.57	1.4	-0.0054	0.0045
						Styrene	6	-0.0003	0.0008	0.16	-0.33	0.0025	0.0090
						Total Aromatics	6	-0.0042	0.0057	0.35	-0.74	0.0425	0.0902
TB-1	6	99.5	12.6	0.97	7.9	Benzene	4	-0.0007	0.0004	0.77	-1.7	0.0077	0.0049
						Acetone	5	-0.0008	0.0010	0.44	-0.85	0.0121	0.0152
						Cyclohexane	4	-0.0005	0.0001	0.95	-4.5	0.0051	0.0015
TB-2	6	123.7	7.2	0.99	17	Benzene	2	-0.0003	**	1.0	—	0.0032	0.0227
						Acetone	5	-0.0026	0.0009	0.84	-2.7	0.0397	0.0138
						Cyclohexane	2	-0.0006	**	1.0	—	0.0058	0.0215
TB-3	6	114.3	16.3	0.96	7.0	Benzene	6	-0.00004	0.0004	0.04	-0.08	0.0004	0.0053
						Acetone	5	-0.0027	0.0010	0.84	-2.7	0.0422	0.0207
						Cyclohexane	5	-0.0008	0.00005	0.99	-17	0.0087	0.0019

\*\*A standard error of 0.002 ng C/cm<sup>3</sup> was used in computing the standard error of the flux rate estimate.

Notations: n number of observations

r correlation coefficient

T-value is the t-statistic for testing the null hypothesis that the slope equals zero.

trolled rate. The volumetric flow rate through the chamber is recorded and the concentration of the species of interest is measured at the exit of the chamber.

The emission is calculated using the following equation:

$$E_x = \frac{(C_x)(Q)}{A}$$

where:

$E_x$  = emission rate of species  $x$ ,  $\mu\text{g}/\text{m}^2 \text{ min}^{-1}$

$C_x$  = measured concentration of species  $x$ , ppmv converted to  $\mu\text{g}/\text{m}^3$

$Q$  = sweep air flow rate,  $\text{m}^3/\text{min}$

$A$  = exposed surface area,  $\text{m}^2$

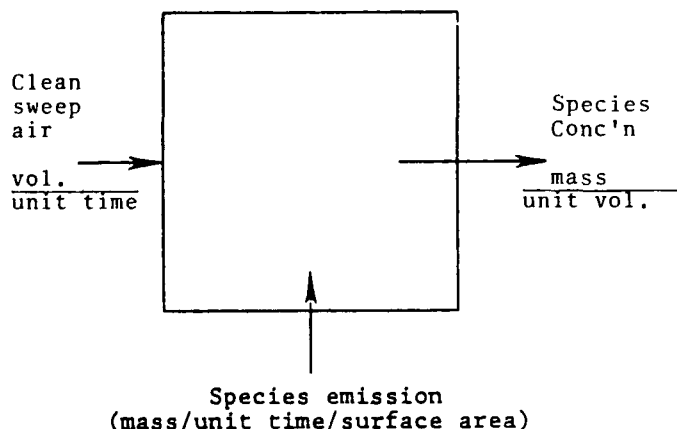


Figure 3.  
Concept of an Isolation Flux Chamber

The chamber shape or geometry determines the chamber volume and source exposed surface area. The chamber volume must be small enough and/or the sweep air flow rate high enough that the response time of the chamber is short. The response time is typically characterized by residence time. The chamber resident time ( $\tau$ ) is a function of chamber volume ( $V$ ) and sweep air flow rate ( $Q$ ). The quotient of volume and flow rate ( $V/Q = \tau$ ) is the theoretical residence time. Three to five residence times are needed to establish steady-state conditions in the chamber at which time representative sampling can occur.

The compromise between chamber design and operating parameters is also influenced by the expected species concentration and the lower limit of the analytical method of detection. The source surface area permitted along with the sweep air flow rate and emission source strength determines the concentrations of emissions species of interest. Thus, low source emission can be compensated somewhat by chamber design and operating conditions.

#### Methods and Materials

Undisturbed and disturbed surface isolation flux chamber measurements were made using the surface flux chamber shown in Fig. 4. A clear, acrylic, commercially available sky light was used as the chamber body. The chamber had a volume and surface area exposure (once placed on the soil/waste surface) of 26.0 liters and  $0.319\text{m}^2$ , respectively. The chamber was stirred with an 8 bladed, 8.9 cm diameter impellor driven by a 12-volt DC motor. The sweep air was introduced from a bottle supply, regulator and rotometer through 0.64 cm Teflon® tubing, 0.64 cm stainless swage bulkhead fitting, and a .15 cm Teflon® inlet line extending to a corner of the chamber in close proximity (but not venting on) the undisturbed soil/waste surface. The chamber output manifold consisted of a 0.64 cm stainless swage bulkhead fitting on 0.64 cm Teflon® tubing leading to the instrument manifold. The entire internal surface

area of the chamber and associated components were Teflon® coated. The chamber material, prior to coating, had a transmittance rating of 92% for visible light and 85% for solar energy (manufacturer published values). The range of sweep air flow rates used was 3.1 to 23 l/min. resulting in a residence time of 1.4 to 1.1 minutes).

The surface flux chamber had a narrow (0.64 cm) lip as a footer on the bottom edge of the chamber. No attempt was made to force seal the chamber on the soil/waste surface. Any attempt to do so would either introduce an unwanted effect (i.e., contaminant source or sink) or constitute a surface disturbance. Therefore, the output manifold was operated on negative pressure relying on the combined instrument sampling pump motive. The total consumption of output gas was less than 1 l/min with a larger input flow. The excess chamber gas was vented at the chamber/surface interface without effect on emission rate measurements, since the chamber is a well-mixed system.

Downhole emission measurements were performed at various depths inside a hollow-stem auger. A schematic of the downhole chamber is shown in Fig. 5. The chamber was fabricated from 6.4 cm I.D., 7.6 cm O.D. Plexiglass pipe with a 0.64 cm thick, 7.6 cm diameter Plexiglass flat cemented on the tube top constructing the chamber. The exposed surface, once the chamber was placed on the soil/waste surface, was  $0.00318\text{m}^2$ . The sweep air was introduced from a bottle supply, regulator and rotameter through 0.64 cm Teflon® tubing, 0.64 cm stainless swage bulkhead fitting, and a 18 cm Teflon® inlet line ending in a 90° glass bend. Thus, the clean sweep air was introduced at near bottom of the chamber in close proximity (but not venting on) the core hole surface.

The chamber output manifold consisted of a 0.64 cm stainless swage bulkhead fitting and a 0.64 cm Teflon® tubing leading to the instrument manifold. The chamber input and output lines were 13 m in length facilitating flux measurements to a 9m (Below Land Surface) depth. Both Teflon® coated and noncoated chambers were used in the study with no detectable difference observed (shown by quality control simulations).

The range of sweep air flow rates used was 1.5 to 12 l/min monitored by a calibrated rotameter. The top of the chamber was weighted which reduced raising and lowering difficulties in the hollow auger. The chamber was attended by a 0.64 cm steel support cable.

Although the chamber was weighted, no attempt was made to force seal the chamber on the core hole exposed surface. Rather, the output manifold was operated on negative pressure relying on the combined instrument sampling pump motive. The total consumption of output gas was less than 1 l/min with a larger input flow. Thus, the excess chamber gas was vented at the chamber/surface interface.

Subsurface emission measurements were made at shallow depths (0.6 m and 1.6m BLS) using a slightly different technique. Subsurface emission rates were obtained by driving specially designed ground probes into the soil/waste fill and passing clean sweep air

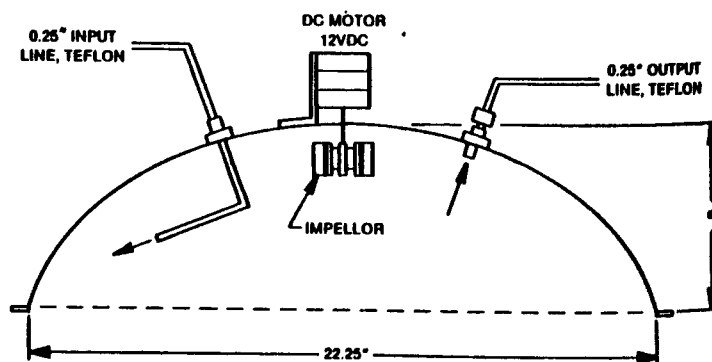


Figure 4.  
Schematic Diagram of the Surface Isolation Flux Chamber



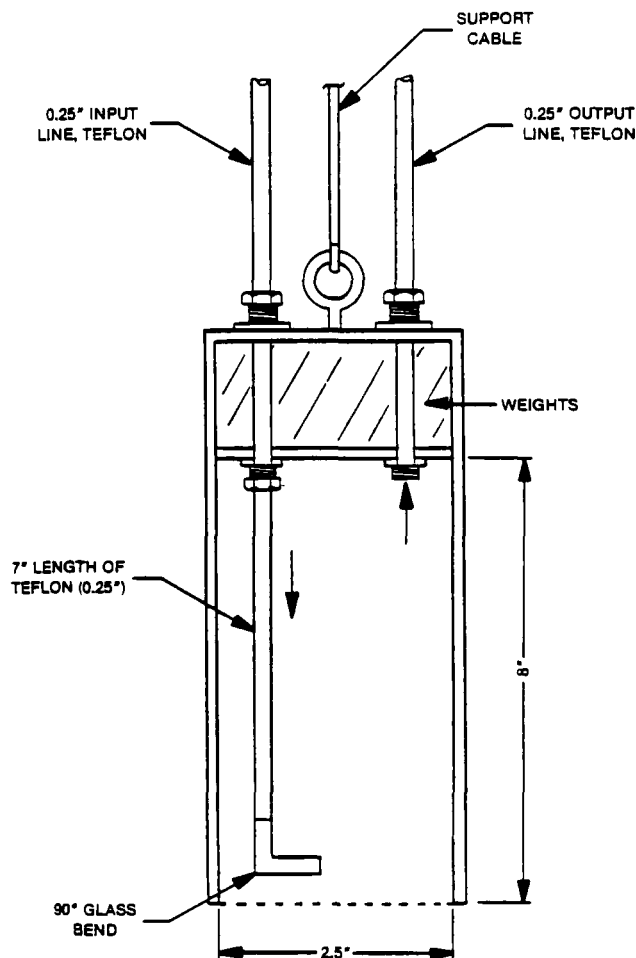


Figure 5.

Schematic Diagram of the Downhole Isolation Flux Chamber

through the probes. The concept behind the shallow mapping investigation is identical to that of the isolation flux chambers described earlier.

The ground probes were fabricated out of 2m lengths of Teflon® -coated schedule 40 galvanized steel pipe. The probe and associated equipment is shown in Fig. 6. Teflon® -coated iron drive heads with support cables were fabricated to afford probe installation and monitoring at 0.6 m and 1.6 m BLS depths. The probes were fit with drive heads, capped, and driven into the soil/waste manually. Once in place (i.e., 0.6m) the probes were pulled 5 cm off the drive heads, exposing a small surface of material at said depth. A Teflon® input line, 1.6 m long so that sweep air was added close to and exposed surface. The bottled sweep air flow rate was controlled by a regulator and monitored with a rotometer. The output line consisted of a 0.64 cm Teflon® tube which extended 2.5 to 5.1 cm into the probe and delivered the output to the output manifold and instruments.

SO<sub>2</sub> and THC were monitored using the analyzers described in Table 2. The range of instrument(s) response (SO<sub>2</sub>: 0.005-10 ppm, 1.0-5,000 ppm and THC: 1-100,000 ppm) provided for emissions monitoring over a wide range of waste types and emission levels. Ambient and waste surface temperature were also monitored continuously using K-type thermocouples with direct digital temperature readout. The SO<sub>2</sub> and THC instrument response was recorded using portable Soltec strip chart recorders while the temperature was manually recorded.

Grab samples were collected for hydrocarbon and sulfur speciation by GC, GC/MS analytical speciation and quantitation. The hydrocarbon/sulfur speciation sampling and analytical methods used are described in detail in the accompanying manuscript in

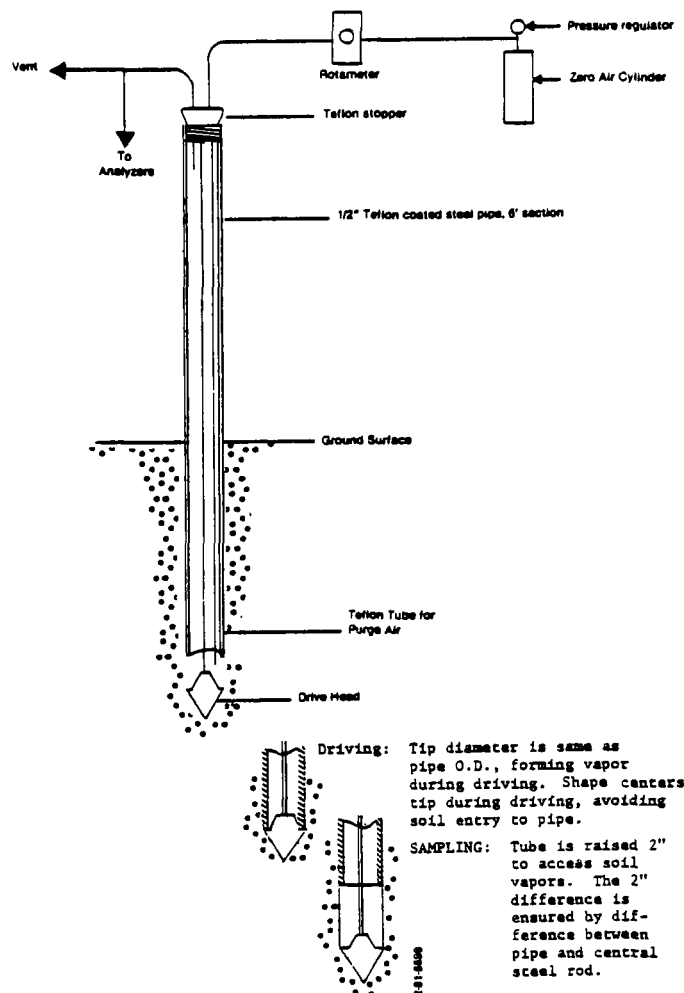


Figure 6.

Schematic Diagram of the Ground Probe

Table 2.  
Description of Analyzers

	SO <sub>2</sub>	THC	
Manufacturer	Theta Sensor, Inc.	CSI <sup>a</sup>	Century System
Model	1041	SA 165-3	OVA-1
Technique	Electrochemical <sup>b</sup>	Flame Photo-metric	GC/FID
Precision	1% F.S.	1% F.S.	10% for Standard Analyses
Sensitivity	1% F.S.	10 ppb	1 ppm (methane)
Response Time	60 seconds	15 seconds	1 second
Range	0-500 ppmv 0-1,500 ppmv 0-5,000 ppmv	0-1.0 ppm 0-.5 ppm	1-10,000 ppm 1-100,000 ppm logarithmic
Power Supply	AC	DC	DC
Service Life (continuous use/charge)	---	4 hours	8 hours
Weight	6.8 kg	9.1 kg	6.4 kg

a. Sensitive to all "single atom sulfur species" noted as SO<sub>2</sub><sup>\*</sup>, response as ppm 20<sub>2</sub>.

b. Interferences from hydrocarbons are avoided using a proprietary scrubber/prefilter.

these proceedings entitled: "Screening and Analysis Techniques for Organic Vapor Emissions for Hazardous Waste Disposal," by R.D. Cox, K.J. Baughman, Radian Corporation, Austin, Texas.

### Field Sampling

The generic sampling procedure for emission measurements using the enclosure technique is summarized below:

- Locate equipment instruments at the sampling location and document location time, conditions, air and surface temperatures
- Begin sweep air flow and address instruments and recorders
- Interface enclosure to waste, record time
- Monitor emissions documenting steady-state concentrations after 3-5 residence times
- Record temperatures
- Collect grab samples if desired
- Remove enclosure, end determination
- Relocate to next sampling location

Appropriate quality control both for analytical instrumentation and chamber operation was included to document the accuracy and precision of results.

### Results

A theoretical range of measureable emission rates for the three sampling techniques described are presented in Table 3. The reported theoretical emission rates are based on practical sweep air flow rates for field measurements (with consideration given to enclosure residence time). The design of enclosure greatly affects the emissions range of the technique. The analytical sensitivity used for these estimates are those of the instruments used during field monitoring. Design of the enclosure, field operation of the device and the range of analytical response can be attenuated to specific sampling needs to specialize the sampling technique for certain applications.

Table 3.  
Theoretical Range of Emission Per Enclosure

Isolation Chamber	SO <sub>2</sub> (mg/m <sup>3</sup> min <sup>-1</sup> )		THC (mg/m <sup>3</sup> min <sup>-1</sup> )	
	Min	Max	Min	Max
Surface	$2.2 \times 10^{-1}$	$1.1 \times 10^6$	5.4	$5.4 \times 10^5$
Downhole	$5.3 \times 10^{-1}$	$5.0 \times 10^7$	$1.3 \times 10^1$	$2.5 \times 10^7$
Ground probe	$2.6 \times 10^2$	$4.6 \times 10^9$	$6.5 \times 10^3$	$2.3 \times 10^9$

An example emissions profile for a gas species over a solid waste site using the surface isolation flux chamber is given in Fig. 7. The rise in species concentration up to about time  $3\tau$  is a characteristic build-up of species concentration approaching steady-state conditions in the enclosure. After approximately  $3\tau$ , the fluctuations observed represent variations in emission due to several factors including: natural emission processes, temperature, sky cover (ultra-violet radiation), surface disturbances, etc. An average emission value and uncertainty can be used to represent the emission for the isolated waste.

Downhole emissions data using the downhole isolation chamber can be correlated to drilling data in solid waste disposal facilities generating vertical survey information. Core hole data plotted with emissions data can provide subsurface information that can be useful in remedial action activities. Data from two drilling explorations are shown in Fig. 8a and 8b for two different waste sites. Data for organic and inorganic species are shown in both plots. The variability in emission levels and relative emissions between species of interest, as shown here, are often quite large depending on the waste type investigated.



Figure 7.

Emissions Profile of Gas Species from a Waste Disposal Facility  
Measured using the Isolation Flux Chamber Technique

Ground probes can be used to obtain cost effective shallow subsurface emissions data over a large waste area. Results from survey studies can be used to map out waste boundaries in solid waste disposal facilities. Again this data is valuable for remedial action activities.

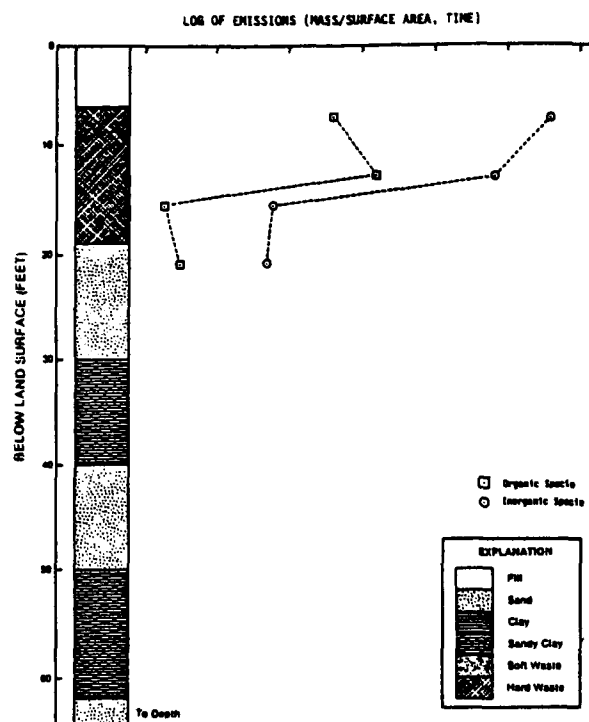


Figure 8(a).

Emissions Results for Vertical Profile in Waste Deposit

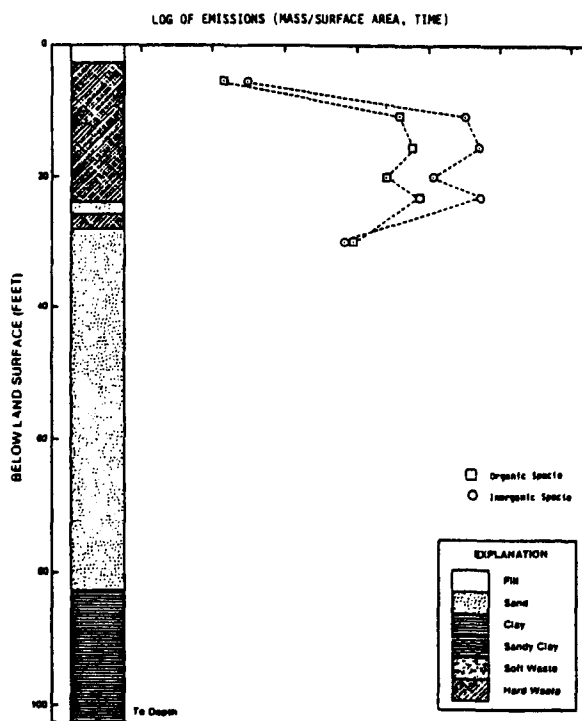


Figure 8(b).

Emissions Results for Vertical Profile in Waste Deposit

Other data that can be obtained using the probes describe the emission potential of waste over long periods of time. If ground probes are left sealed in solid waste beds and monitored daily for long periods of time, an indication of prolonged emission potential can be assessed. A plot of relative emission versus time, as shown in

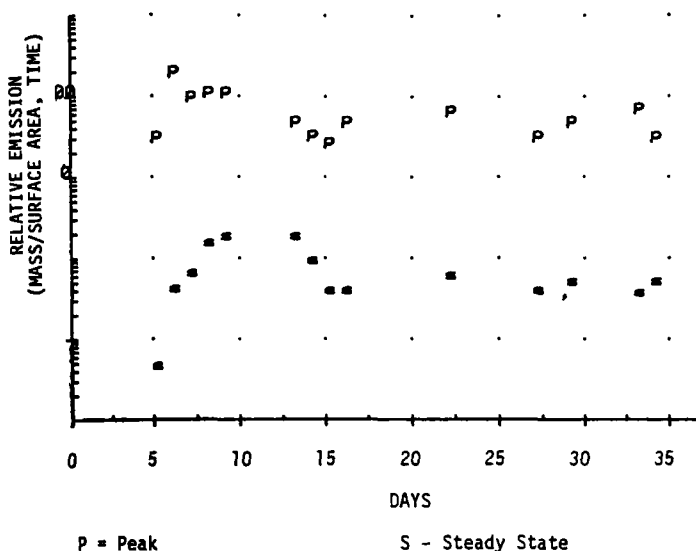


Figure 9.  
Plot of Emissions Versus Time From Ground  
Probe Emission Monitoring

Fig. 9 illustrates this application. Each daily measurement shown reports an instantaneous emission value or peak (P) value and a steady-state (S) value representing an average reading. The trend in emission potential indicates, in this application, a rather steady (but slightly decreasing) emission potential over an extended duration. Depending on the desired information, the ground probe emission monitoring technique can be a valuable sampling tool.

#### Discussion

The single most important advantage to monitoring emissions using enclosures is that a direct measurement is made for an "isolated" emission source where all the necessary parameters, physical and chemical, are controlled. This allows for data that is representative of the emission process under set conditions affording intercomparison of data. Further, the concentration of species of interest in the enclosure outlet stream can be varied somewhat by controlling the chamber sweep air flow rate and exposed source surface area. Another advantage is that meteorological parameters which influence other sampling methodologies have little effect on enclosure sampling because the experimenter has control over the

experimental parameters. The technique can be made specific for a sampling program depending on the emission source type (chamber/source interface) and can be designed for specific operational considerations or sampling requirements. Thus, the enclosure method of direct emissions monitoring offers a specific, reproducible approach to emissions monitoring for applications, such as this one, and is capable of providing a comparable, representative data set.

The disadvantages of the technique are concerned with possibly creating, through the act of monitoring, an artificial emissions condition. The enclosure design and operation must minimize the potential of altering the natural emissions process (by covering the emissions source and introducing a sweep air to the chamber) and the interaction of the emissions output with the enclosure, output manifold and sampling lines.

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# PUBLIC PARTICIPATION IN HAZARDOUS WASTE SITE CONTROL—NOT “IF” BUT “HOW”

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## INTRODUCTION

Environmental problems requiring engineering solutions usually have one thing in common: they are site specific. Site-specific actions have a factor in common: they have local publics which are directly and unequivocally impacted by the action. This is true of any project producing environmental impacts, from highway construction to dam building. For intensity of impact perceived by the public, however, chemical waste disposal facilities—and especially the discovery and attempted reclamation of illegal chemical waste dumps—lead the list.

In undertaking to plan and implement projects with impacted publics, it is wise to take heed of what was stated during a Separate hearing on public participation:

...policies formulated without consulting the interests involved may lead to decisions which are so far outside the reigning or conceivable political consensus, or which make such unacceptable demands on a particular interest group that the resistance will thwart the action entirely.<sup>1</sup>

The overriding emotion and residual distrust which frequently characterize hazardous waste facility siting or dump cleanup, the loss of time, effort, and money invested in unimplementable plans, and the damage to the credibility of the planners may result in serious delays in effective cleanup or establishment of environmentally acceptable disposal facilities.

Everyone who has seriously approached the examination of institutional factors associated with hazardous waste site establishment, cleanup, or control has encountered the exhortations of “shoulds” and “oughts” of how to involve publics effectively. Unfortunately there is rarely any empirical observation to back up these prescriptions. As Wengert<sup>2</sup> has chronicled:

The phrases “public participation and citizen involvement” have many meanings and connotations depending on the situation to which applied.... much of the literature (on public participation), especially that related to governmental programs, has tended to be prescriptive and hortatory, abounding with rhetoric and polemics and resting on unanalyzed premises and assumptions.

Projects involving the manipulation of hazardous wastes involve planning. Where such materials are dealt with, a frequent public perception is that a real and present danger to life and health exists over a wide radius from the proposed activity. Failure to plan adequately can result in accidents or incidents which threaten the ability to implement beyond the time of the mishap. This type of error occurred during an attempt to retrieve a pocket of drummed waste at a defunct landfill which had been accepting hazardous wastes, and which has since been included on USEPA's hotspot list for Tennessee.

### Bumpass Cove Landfill

The Bumpass Cove Landfill is located in upper east Tennessee near Johnson City. It is in a rural, mountainous area. After a

lengthy period (reported by the press to be about 10 years)<sup>3</sup> in which local citizens had fought the dump and petitioned the State for assistance, the owner of the defunct landfill was ordered to excavate an area where the citizens claimed a number of drums were buried in shallow trenches, possibly threatening both groundwater and surface streams. In the process of excavating in mud and winter conditions, several of the barrels encountered were ruptured. Nineteen persons were evacuated with several reported being treated for blistered lips, while others reported respiratory problems.<sup>4</sup> Officials were quoted as downplaying the incident,<sup>5</sup> but eventually admitted to error in planning the excavation for winter conditions.<sup>6</sup> A local State representative blasted the operation as lacking in good sense.<sup>7</sup>

Bumpass Cove has been a particularly good example of polarization of publics versus implementors in planning levels from the example “micro” level all the way through regulatory policy concerning the site. More discussion on Bumpass Cove will follow. The key point is understanding how such situations can be better planned, how citizens can be tapped for the knowledge they have that the planners do not, and how planners can proceed to make the technical decisions they are paid to make without imposing value decisions in which they have a right to no more voice than any other citizen, and perhaps less right than the citizen who must absorb the impact of the decision.

## PUBLIC PARTICIPATION RESEARCH

A research<sup>8</sup> project was implemented to analyze public participation variables for their relationship to environmental project outcome variables. These variables were identified as being common to a majority of 105 case studies of environmental project planning in wastewater management and water development (i.e., flood control, navigation, and reservoir projects, and highways or road construction). Although hazardous waste management siting or cleanup cases were not among the cases studied, personal experience with hazardous waste management, and careful perusal of the hazardous waste case study literature discloses the presence of the same variables in most hazardous waste site-specific controversies. Furthermore, repeated statistical analyses produced no indication of significant differences of participatory characteristics or correlations among the various project types studied. In other words, project planners in these three diverse areas encountered essentially the same planning problems when faced with dealing with public involvement.

### Data Gathering

For this study, the authors first undertook a thorough review of the post-1965 literature. From this, a list of 161 variables was generated to include factors which the literature described as representing the possible social contexts of project planning, the possible factors involved in the process of project planning with public involvement, and the possible outcomes of project planning. The variables collected by this inductive approach were then sorted into clusters representing categories of similar variables. These were

then incorporated into systems components of a conceptual framework of the public participation process.

The conceptual framework with its sets of variables was converted into a worksheet by which the presence or absence of the variables could be documented from case studies. Each variable was given a specific definition for reference during analysis of case studies. After this step, 105 case studies were analyzed. Data collected from the case analyses were analyzed using standard computerized statistical methods. A correlation matrix of all 161 variables computed against each other was prepared along with descriptive statistics and frequency information.

### Data Analysis

The data generated from computer analysis were then used to screen variables to identify the strongest associations between variables identified as independent variables (relating to process and context of public participation) and dependent variables (relating to outcomes of project planning). The variables were screened to assure statistically acceptable frequencies of occurrence for further analysis. Variables showing statistically significant correlations at  $p < .05$  in quantities greater than predicted by chance were retained for analysis and only those independent variables explaining at least 9% of the variance ( $r \geq 0.30$ ) of at least two dependent variables (or for dependent variables, those exhibiting  $r \geq 0.30$  with at least two independent variables). The independent variables and their strongly correlating dependent variables surviving these screenings were then arrayed to disclose their associations (Table 1).

### Results of Study

It was found from the analysis that project personnel actions that isolate planning from interactions with the social environment and inhibit communications tend to result in outcomes that are generally unfavorable to the implementor's interest. It was noted that the array of independent variables showing strong positive correlations with desirable project planning developments (Table 1) was characterized by the presence of effective information exchange mechanisms.

It was also found that those variables associated with restriction of information flow correlated strongly negatively with desirable outcomes.

The importance of exchange of information between project managers and public during project planning is indicated by these findings. Exchange of information functions as a feedback loop whereby information gathered from the project's institutional environment (the potential "stoppers") permits the project system to adjust its actions to enhance its chances of implementation and survival. A project frequently in the courts defending itself against elements of society which have arrayed themselves with the intent of closing it down has allowed many clues from the institutional and social environment to go past unnoticed or unheeded. A few trips to the courtroom, even if cases are won, builds distrust and causes the attraction of new publics to the fray as multi-party interests gravitate toward a polarized conflict of two alliances.<sup>7</sup>

A slight favoring of information flow from public to project, if unavoidable and guileless, will not prevent planners from incorporating informed public desires in planning. This is not to suggest that project planners may be cavalier about dissemination of information to the public. It was concluded from the study that lack of preparation of the public for participation (i.e., failure to provide them with the ability to use pertinent information) frequently is associated with undesirable reactions on the part of the public. It is, however, necessary for the planner to actively seek knowledge concerning the public's desires. If these public desires are thwarted, the public will react with or without company-supplied information.

It seems, from the data, to be particularly important for the implementor to include assessments of public attitudes and needs in its planning activities, and to seek input in identifying alternatives for project plans. This garnering of information seems to enjoy a synergistic enhancement if the agency arms the public with infor-

**Table 1.**  
**Correlations of Variables Drawn from a Sample\* of Case Studies of Project Planning with Public Participation**

Dependent Variable	r	Independent Variable
<b>Desirable Developments</b>		
Information critical to project planning	-0.31	Redistributive policy
becomes available to agency	-0.31	Small project: high social significance
	-0.34	Agency intends to 'sell' premade decision
	0.35	Agency seeks project alternatives
	0.43	Agency seeks information on public needs
	-0.44	Redefinition of public demands
	0.50	Agency seeks public attitude data <sup>2</sup>
Public contributes information probably available only from public	0.38	Agency seeks attitude data <sup>2</sup>
	0.33	Meetings
	0.32	Agency seeks public needs data
	0.32	Pamphlets
Public needs and goals identification	0.55	Agency seeks public needs data <sup>2</sup>
	0.49	Agency seeks public attitude data <sup>2</sup>
	0.44	Agency seeks project alternatives <sup>2</sup>
	0.34	Meetings
	0.34	News releases
	0.33	Agency endeavors to inform public
Inform and educate public	0.49	Agency seeks public needs data <sup>2</sup>
	0.39	Meetings
	0.39	Pamphlets
	0.36	Agency seeks public attitude data <sup>2</sup>
	-0.33	Hearings
	0.32	Workshops
	0.32	News releases
Broad socioeconomic participation	0.32	Meetings
	0.32	News releases
	0.31	Agency seeks public needs data <sup>2</sup>
Enhancement of planning dialogue	0.39	Agency seeks needs data
	0.37	Agency seeks public attitude data <sup>2</sup>
	0.36	Workshops
	0.35	Meetings
	0.33	Agency endeavors to inform public
	-0.31	Hearings
High degree of compromise	0.41	Agency endeavors to inform public
	0.35	Agency seeks public attitude data <sup>2</sup>
	-0.34	Redefinition of public demand
	0.33	Newsletters
<b>Undesirable Developments</b>		
Public opposition develops	0.36	Agency intends to 'sell' premade decision
	-0.34	Low temporal relevance <sup>1</sup>
Participants perceive participatory program to be too limited	0.56	Redefinition of public demands
	0.44	Agency seeks to 'sell' premade decision
	0.39	No education of participants
	-0.31	Low temporal relevance <sup>1</sup>
Inadequate education effort—public unprepared to participate	0.32	Small project: high social significance
	0.32	No education of participants
No resolution	0.46	Agency seeks to 'sell' premade decision
	0.39	Redefinition of public demand
	-0.36	Temporal relevance low <sup>1</sup>
	0.34	Redistributive policy
	0.34	Small project: high social significance
	-0.31	Agency seeks public attitude data <sup>2</sup>

\*N = 105.

1. Project will set no precedents for subsequent projects (highly routine project).

2. Relative to the planned project.

mation that enables the public to return more coherent input to the agency. The data suggest that the planner consider use of news releases, pamphlets, and other information dissemination techniques. Care must be taken to stress information rather than persuasion.

The planner should consider the hypothesis that information disseminated and gathered during real-time, two-way communication episodes such as workshops and open meetings may be the most valuable. The data show strong correlations between these techniques and desirable outcomes to project planning. Not only is information in these instances couched in the immediacy of the expressed needs of both parties, but the atmosphere of free information exchange often enhances the trust shared among participating parties. If initial information exchanges are perceived by the public to come at a point after crucial decisions have already been made, these meetings can be most unpleasant and trust can be difficult to recoup.

Some variables were noted to be associated with undesirable outcomes to project planning. Projects arising from redistributive policy, that is, policy that seeks to take the possessions in the domain of one group to enhance the domain of another group, tend not to be characterized by good flow of information and tend to reach stalemate where no resolution seems forthcoming. Such issues tend to be high conflictual and all parties tend to be drawn into what becomes, inexorably, a conflict characterized by two camps. As stated before, multi-party conflicts tend to become two-sided conflicts<sup>7</sup> and, because a government agency cannot opt out of the conflict involving projects it must permit or regulate, it may be forced to choose sides. This forecloses the agency's capability to manage the conflict.

Data from these cases showed a high association of undesirable outcomes when redistributive policy was present; however, there may be some promising techniques for controlling polarization of the public if action is taken early. The data were not sufficient to document efficacy, but the technique of using project information clearinghouses to dispense accurate information to both camps<sup>8</sup> or the use of third-party mediation<sup>9</sup> may help reduce all but the most rancorous polarization when redistributive policy governs the project. Recent contact with regulatory personnel of the Tennessee Valley States and with some innovative private sector firms underscore this promise.

Another influential variable couched in the context of the project is operative in the situation where a small project is characterized by high social significance. This is often the precise situation characterizing the hazardous waste disposal site cleanup or establishment. In such an instance, an unprepared planner could find literally nationwide attention drawn to a small project. The data show that, for the sample of cases, this situation tended to reduce the flow of coherent information and tended to be associated with stalled projects.

The best approach under these circumstances may be to provide the maximum possible amount of information about the project, especially early in the planning stage. It would seem essential that the public be enlisted in identifying alternatives to what may be a repugnant, although necessary, project.

Redefinition of demand is an action shown by the data to be strongly related to numerous undesirable outcomes, and negatively related to desirable outcomes. When the public states a demand, and the agency responds not in answer to the demand, but with actions that seem to imply, "We know best what you really need," it is reasonable to anticipate a public enraged by patronization, or convinced that the agency simply is not listening. Further, suspicion that the agency is attempting to manipulate public desires will surely poison the communications atmosphere. This action exhibits such broadly undesirable consequences that it should be avoided religiously.

A factor that tended to be associated with undesirable public perceptions of the participatory process was the failure to educate the public to at least the rudimentary technical basis for the project. This deprives the citizen participant of the ability to critically appraise the project and contribute to its planning. Review of failed siting attempts in the Tennessee Valley and conversations with engineers and scientists involved in the attempts reveal a firm belief by these implementors that they have, in fact, provided all the relevant information necessary to show their sincerity in ensuring that as much as possible has been done to ensure safety and mitigate en-

vironmental problems. This is true, but only works in the unlikely situation that all the members of the public are of the appropriate scientific or engineering discipline.

The lay citizen can no more use the elegant information of the engineer than a human being can digest the cellulose in wood, even though it has food value to other animals. The information must be useable and, lest the engineer become arrogant, he or she should review several of the newspaper accounts such as those about Tennessee's Bumpass Cove, where those who ignored the local citizens' advice (couched in readily understandable terms), were later moved to state for the record that they had "erred."

Especially in projects of a highly technical nature, such as hazardous waste management, education is the keystone of effective participation. The instances are well documented of failed participatory efforts giving way to court battles, or extra legal actions such as demonstrations, pickets, and sit-ins. These situations exact great prices in prestige and good will enjoyed by the implementor. Further—and this has been particularly true in the TVA region—geologically and economically feasible locations for hazardous waste facilities are limited. Options for cleanup of abandoned or illegal dumps are limited. Siting and cleanup attempts which fail "spend" the limited resources of sites or cleanup options.

A community mobilized against the presence of a hazardous waste facility because of a bungled citizen involvement process will remain "cocked" for remobilization should another siting attempt be made later at the same site, no matter how sophisticated the second approach may be. Cleanup activities, once perceived as threatening a community interest, create mobilized opposition which for years may forestall effective response, and sustain suspicions that elements of the cleanup team are "in cahoots" with interests antagonistic to the community's welfare. Community mobilization may completely "steamroller" hazardous waste management plans—even though opposition is inspired by the wildest misconceptions about the effects of project implementation.

An additional word should be mentioned about the research findings relating to an old favorite for filling the "public involvement square," i.e., the hearing. Hearings have long been a tool used by agencies to comply with administrative law concepts of "right to be heard." In the cases sampled, though, it was noted that formal hearings had strong negative correlations with several desirable outcomes to participation efforts. The usual conduct of a typical administrative procedure hearing is characterized by a "we-they" bifurcation between public and implementor.

Dialogue is procedural, suppressed, and stilted, if present at all. If large groups are present, the individual with the best insight on a project issue, if timid, will likely never be heard. For the planner truly interested in hearing the public, this technique should be avoided where at all possible. Workshops and meetings, in which favorable group dynamics operate, show promise of producing successful citizen input. Formal hearings are usually antithetical to the promotion of good two-way communication, the key to effective citizen involvement in planning.

### TVA's Concern

With this research as a backdrop, it has been possible to view from TVA's vantage point the institutional processes accompanying attempts to clean up abandoned or illegal hazardous waste dumps within the State, and to site new facilities for sound management of hazardous waste.

TVA is a Federal regional resource management agency with responsibility for integrating the economic development of the region with wise management of the seven-State area's natural resources. It is not a regulatory agency. It has many characteristics of an industry in that it constructs, maintains, and operates the largest electrical generation capacity in the U.S.—a mix of hydroelectric, coal-fired, and nuclear power plants. TVA's involvement in hazardous waste management results from: (1) a need to manage its own industrial waste, (2) its interest in the region's ability to attract industry by providing adequate waste-handling facilities, and (3) its

practice of making TVA expertise available to situations where our assistance can (1) further or (2) enhance the protection of environmental resources of the Valley.

TVA has provided technical assistance in several abandoned dump cleanups in the Valley, and has had the opportunity to observe the ebb and flow of conflict around these attempts.

Bumpass Cove, mentioned before, is one of the abandoned illegal dumps at which TVA has offered specific technical assistance. The controversy at Bumpass Cove, ostensibly a sanitary landfill, began in the mid-1970s when residents claimed hazardous wastes were being surreptitiously dumped in the landfill. Some complained of health effects. The situation reached a crisis in 1979 when heavy rains uncovered barrels and strong odors and suspicious substances were noted in the creek at the base of the landfill. The exasperated citizens, apparently unable to establish a credible dialogue with the landfill operator or regulators, blocked the roads to the landfill, preventing trucks from reaching the fill. Acts of sabotage were dealt with using alternate routes.<sup>10</sup>

In August of 1980, after the earlier-mentioned evacuation of residents and discovery of buried drums, the Tennessee State Health Department ordered the former operators to remove barrels of toxic chemicals from the area, along with soil proven to be contaminated. TVA was called upon as a neutral party to chair a task force of State agencies, the USEPA, and Bumpass Cove citizens.<sup>11</sup> Meetings were held, but true to predictions from research, the lateness of the information exchange has had deleterious effects. Residents have accused health officials of being liars when they claimed lack of knowledge of illegal dumping, but other citizens have been quoted, regarding the task force, as saying, "all we need is someone we can believe in."<sup>12</sup>

The situation at Bumpass Cove is now chaotic. The State recently approved a closure plan that, according to press accounts, has not included nor responded to public demands. A rift has formed in the citizen's group such that lawsuits have been filed among the citizens. The developments over the past decade and the current acrimony which promises to continue are all in keeping with predictions from the research.

Factors which, in this situation, predict undesirable outcomes have included small projects with high social significance; redefinition of public demands; and perception by the public that involved action agencies intend to sell a premade decision.

This last item should be noted particularly. It does not state that responsible parties, in fact, intend to conduct sham public involvement as a post-hoc validation of a decision. It refers, however, to the public's perception that this is what is happening. What the public perceives is the public's reality. What is real and threatening or offensive to the public, the public will act on.

It is absolutely essential that credible information be made available concerning the sincerity of the implementor's desire to involve the public. The public must then have available information, interpreted for their use, which puts them on a factual footing that permits them to appreciate (or reject) the engineer's plans. Impacted citizens must also be able to judge plans and situations from an informed position if they are to play one of their most important roles—providing insight, information, and data which may simply be unavailable to the planner, or which would take great expense to gather or retrieve. Citizen-provided information of this type has certainly played a role in the Bumpass Cove situation.

Hazardous waste managers and disposers have been tarred with the brush of Love Canal, Valley of the Drums, and others. The vast majority of professional hazardous waste managers which TVA has dealt with have been scrupulously honest, meticulous in safety and environmental protection, and very conscious of their responsibility to society. TVA could not continue to operate if they were not, even with the small amounts of hazardous wastes which it employs contractors to handle for us yearly.

New facilities in the Valley would greatly reduce the opportunity for midnight dumpers to tempt customers now faced with expense of long-haul shipping to distant facilities. New facilities would reduce the environmental and safety problems involved in risks of long-haul transport of hazardous wastes. These, among others, are

compelling reasons for facility siting, yet we have observed sincere, competent engineering firms stymied by public opposition to siting of facilities in areas where risks posed by sound operation in geologically favorable sites would be minimal.

There are a few reasons for this which often seem to be neglected by planners. First among these is the failure to recognize that no matter how safe or unobtrusive a hazardous waste facility is, it is still a noxious concept to a lot of people. Those who live near it are subject to an increased risk, no matter how small, and may perceive it as a moderate to great risk (which is, therefore, their reality). They are asked to endure this concentrated negative for a benefit dispersed to a wide public not asked to make the same sacrifice.<sup>13</sup> Citizens must either be given some assurance that their imbalance will be mitigated or redressed (and some interesting examinations of siting incentives aimed at this problem are ongoing),<sup>14</sup> or provided information such that they can participate in making decisions as to what manner and in what form they will accept this risk on behalf of society.

What is often observed in retrospect following a failed siting effort is recriminations by the routed planners that the press destroyed their chances, or a hysterical public never understood. The bottom line, however, is that public opposition renders siting (or any other aspect of hazardous waste management) as infeasible as many technical flaws, regulatory impasses, or physical conditions.

A recent siting effort was documented<sup>15</sup> in a paper by a candid and articulate consulting engineer. It described the intricate care in determining location for best probably physical attributes for a hazardous waste management facility in the Tennessee Valley. It described how the company made no attempt to hide its presence as it made its tests and surveys of a proposed site. It also plainly states, however, that it made no attempt to involve the public or inform the public of its intentions. What occurred was a rapid and unexpectedly sophisticated mobilization of public opposition when the purpose of the survey was discovered. The press covered the developments heavily, receiving most dramatic quotes from the citizen opponents.

Eventually, following heated public meetings, disappearance of previous support from local and State government and opinion leaders, the company abandoned its interest in the proposed site, at a loss of investment in purchase option and survey costs. What is interesting is that the explosion of opposition was blamed in part in the account on too much public participation, too early. The writer described the ongoing controversy as a forum for selfish interests.

The research, however, predicts the strong probability of harsh public reaction if the public perceives that decisions within the public domain have been made with only post hoc involvement of the impacted public. Further, it does no good to bemoan the public's inability to understand the fine points of safety features and sound operating practice. The ability of the public to understand these points is at least 50% the responsibility of the communicator to couch them in terms understandable by the public. To assume that broad operating and construction concepts cannot be communicated to the public by an effective education process is an elitism of its own guaranteed to enrage segments of the public, and ensures the public is unprepared to participate in a planning process where citizens are called upon to separate wheat from chaff in both proponents' and opponents' arguments.

The beginning of technical reliability and legal permitting or licensing of processes in getting facilities sited has been underscored by the efforts of Pyrotech, Inc., of Tennessee. The Pyrotech process for disposal of PCBs has been certified for operation by USEPA and has been tested by independent laboratories such as Battelle, with very favorable results. It cannot find a home, however. It has lost the support of local officials in Pyrotech's home city, where once it had their support. When public opposition developed, political support swung with it. When the company attempted to site in rural Grundy County, it was turned away by unexpectedly well-organized public opposition. It then turned to the outskirts of Chattanooga, an already heavily industrialized city, as a potential site, and again a rapidly mobilized public played a



role in forcing Pyrotech to abandon its hopes to site at its chosen location.

It is difficult to disbelieve that Pyrotech's perceived failure to conduct informational meetings and open discussions as promised contributed to this rejection.<sup>16</sup> Opponents have gone on record as approving of the effectiveness of the Pyrotech process, but have argued against the hazards of truck traffic bearing PCBs into the area with its attendant spill potential, and against the "foot-in-door" possibility of other "noxious" facilities gravitating to the area.

Pyrotech is continuing to explore siting possibilities in Chattanooga, and has opened a dialogue with environmental groups in the area. It will be interesting to follow what appears to be an evolving siting approach.

Again, citizens not trained in applicable science and engineering disciplines do not arrive at conclusions concerning complex technology a priori. The citizens must, if necessary, be taught how to interpret the information before information is presented.<sup>6</sup> Also, as in the Pyrotech situation, if citizens present concerns decrying transportation-related hazards, the research predicts the hazards to effective public participation of redefining this demand by responding with additional assurances of process safety.

A final example of problems with public involvement in waste management involves the inability to engender public involvement when it is needed. This situation exists at this time in a Valley county characterized by several large, unmanaged open dumps. The county is rural and poor, but close to an affluent larger city.

TVA has several interests in assisting the local governments in this county to attack the dumping problem: (1) the dumps are disincentives for in-migration of workers and industry which would improve the depressed economics of the county; (2) one of the large rural dumps is located in an isolated area and suspected of being a midnight dumping site; and (3) a TVA structure is also threatened by burning and corrosion from the nearby dump. TVA has worked with very dedicated county and State health departments to attempt to enlist local government assistance in cleaning up the dumps and designing an effective rural solid waste collection system. The public response, which at first surprised and now frustrates, is the admonition that the dumps have always been there, and always will be, and cleanup attempts will not work.

The apathy has characterized both government and much of the citizenry. Public interest groups in this community are virtually nonexistent. Traditional advocacy organizations such as the Chamber of Commerce are small and avoid public attention of any kind. The situation reflects what opinion leaders in the area describe as a lack of community pride. Meanwhile, the dumps threaten community water supplies with potential pathogens and toxic wastes.

TVA is approaching this problem by first presenting to the local government the opportunity for a TVA program offering selected communities assistance in comprehensive economic planning. The strategy in this case is to target the elevation of confidence and pride in the community's resources and potentials. A major aspect of this is technical assistance in waste management to eliminate the dangerous and ugly dumps, and institute collection systems. TVA economists and community experts working with the TVA Regional Waste Management program are beginning to observe a snowballing of interest in the community's potential. Because this situation of resistance by essentially the entire spectrum of the community toward involvement is uncharted territory so far as predictive models go, we are learning as we progress. Predictions for success at eliminating the dumping sites are risky at this time, but prospects appear much more favorable than the null prospects prior to this TVA assistance program.

## CONCLUSIONS

The research described has alluded to tentative relationships between how an implementor or planner approaches citizen involvement in environmental project planning. Its fundamental finding is that exchange of information early, often, and all the way through

a project is essential. It points out that this information must be usable by the public, and, if the technologist cannot completely convert his science to terms understandable by the man on the street, he must make the effort to provide enough background information to educate the citizen to a level of understanding where the citizen may evaluate the merits of the planners' product without needing to evaluate the fine points of each equation.

The bottom line is that attempts to avoid public participation or to offer sham exercises is counter-productive for the planner. If the citizen is denied the capability to participate, or the opportunity to participate under conditions which respect the viewpoints of all, he will participate in other ways. In the arena of hazardous waste management and facility siting, the odds are on the project opponent's side. The next stop for the engineer may be on the witness stand before a nonengineer judge hearing suit over a partially completed project. Instances are also well-documented of extra-legal interventions which exact great prices in corporate prestige and extremely adverse publicity.

The authors have cited some observations in this paper of siting and cleanup efforts here in the Tennessee Valley. They have been characterized by uncertain or undesirable outcomes. The failures spend the best locations by assuring the victorious citizen opponents that they were correct in their assumptions about hazardous waste management, and assuring that their model for response to siting of management facilities is a mobilized, unflinching opposition. In an area such as the Tennessee Valley, suitable areas for hazardous waste management are limited. It is troubling to observe potential sites "spent."

A reason there are no success stories documented in this paper is that there really are not many to draw on. In preparation of this paper, several of the success-story disposal facilities' managements were called. They were asked about how they had sited their facilities without apparent conflict. The prevalent reply was that procedural requirements of current hazardous waste laws were not in place, and they just "did" it. Such would not be the case today. Students of environmental controversy in the Tennessee Valley have observed surprising awareness and sophistication in mobilizing opposition to a wide variety of environmentally impacting projects, even in some sparsely populated places.

TVA's role in hazardous waste management in the Valley involves a commitment to manage its own hazardous wastes in an environmentally sensitive way, and in accordance with law.

TVA also maintains a surveillance of public attitudes concerning where resources should be applied. TVA documents calls to TVA's Citizen Action Line on topics relating to hazardous waste. TVA also recognizes the relationship adequate hazardous waste management facilities have to the potential for Regional industrial expansion. Moreover, TVA has actively assisted State, local, and Federal agencies in locating, monitoring, and cleaning up hazardous waste dumps. Citizen participation in these same issues remains a process which TVA supports.

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# PUBLIC INVOLVEMENT IN RESOLVING HAZARDOUS WASTE SITE PROBLEMS

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## INTRODUCTION

In 1978, a rather innocuous ditch which had been used as a chemical waste disposal site became the battleground for the initial skirmishes of what was to become the major environmental war of the seventies. Its name, Love Canal, was to become synonymous with public involvement in hazardous waste landfill issues.

Looking back and trying to analyze the Love Canal conflict, one tries to assess what went wrong and gain insight into better ways of handling future situations. The area had been used for chemical disposal, as was the accepted technology of the day; later, the land was developed as a school and residential area, without full appreciation of the potential hazard. Love Canal is significant because it represents a total failure of technologists, regulators, and impacted citizens to communicate effectively with each other.

As the dangers of Love Canal became evident, the conduct of public officials led to an environment of mistrust. Adeline Levine, in her book on Love Canal, states that, "Although residents had been informed by (government agencies), they were not consulted as people who might have important contributions to make about the history of the area or their own experiences, or might have opinions about what should be done to and for them. What the residents viewed as secrecy and their exclusion from vital decision-making was to result in their suspicion that there was a cover-up."

In retrospect, it is difficult to accuse the public health officials of misconduct or insensitivity. They did their job in accordance with the accepted standards of performance of the day. A significant social conflict in the era of technology is the relationship between the professional and the lay public. Does the patient have a vote in the therapy which the physician deems necessary to save his life? Do the poor have any input into the manner in which a benevolent government seeks to raise them to a better life? Can children voice opinions about how they should be educated? Can passengers tell pilots how to fly a plane, and can homeowners influence toxic waste cleanup, when their lives and property values are equally part of the package?

When society licenses or puts trust in a professional, it signifies a willingness to accept that individual as a saviour in technical issues. But society looks at the record and also realizes that the professional is only a human being, and bridges collapse and people die on the operating table in spite of diplomas. As a result, the legislative/judicial system accepts the concept that the public does have a valid right to participate in the decisions which directly affect them.

In this paper, the authors will try to outline some of the mechanisms which can be used to ensure that the public has an input into hazardous waste issues. The process is called PUBLIC INVOLVEMENT and the authors urge its adherence for two reasons:

- Public participation is a proper, socially-mandated procedure,

respecting the rights of the people who are impacted and pay the bill

- Failure to involve the public in a timely manner can lead to delay, increased cost, and unpleasant legal complications

## PUBLIC INVOLVEMENT

The public involvement process can be divided into three phases (Fig. 1). The first is problem identification, the second is strategy development, and the third is the public participation program.

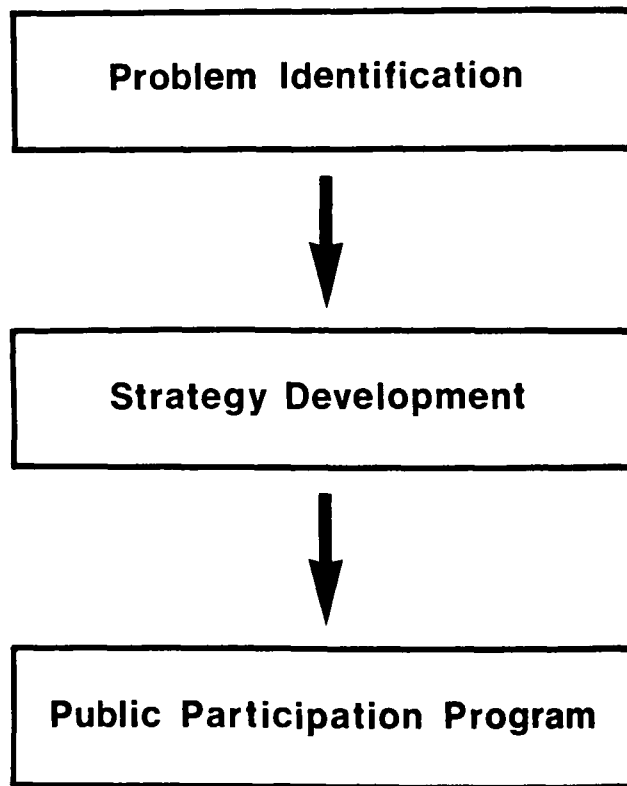


Figure 1.  
Public participation process

### Problem Identification Phase

The problem identification phase is normally considered to be the responsibility of technical and regulatory specialists. The problem generally presents itself in either of two ways. In the first, water or soil is found to be contaminated and the source traced back to a hazardous waste disposal site. This process involves hydrogeologist, engineers, analytical chemists, environmental scientists and other technical people. In the second, the problem site is listed as a violation of federal or state regulations by virtue of past known or alleged dumping activities. This situation involves regu-

latory officials, legal personnel, inspectors and others with appropriate specialized expertise.

There is, or should be, a public portion to this first phase. The activity seeks to resolve initial public concern about the site and the related problems. The danger is, that a little knowledge, either on the part of the technical side or the public, can easily burst into inflammatory perceptions. Therefore, the social scientists who do this phase must be extremely careful in what they say and what they do.

It is best to identify responsible civic leaders early in the process and begin the social problem identification with them. The lowest levels of local government must become involved and kept informed. Experience has shown that these bodies can become powerful forces for progress or obstruction. The worst thing that can be done is to ignore a local group, such as a civic association, or bypass local lines of government structure.

This involvement can be accomplished best by a consultant who has intimate knowledge of the local political forces. In the absence of such a person, the local newspaper or chamber of commerce or bank may be good places to develop a pattern of local leadership. Such leadership may occur in places not commonly suspected. For example, the local volunteer fire department has been the seat of village political power, and, after all, they are logically the protectors of public safety.

A clear differentiation must be made between how the public perceives a hazardous waste issue and how it is addressed by a regulatory agency. The technologist is paid to achieve compliance with standards, laws, regulations, and engineering practices. The police officer who tickets for speeding is not interested in why, but only that a rule was broken.

The local resident is concerned about himself and the people and things he holds dear to himself. He fears cancer and the loss of equity in his most valuable possession, his house. The names of organic chemicals sound to him as the name of horrible deities which early man held in awe, and their minute concentrations are equally as invisibly terrifying. The public is going to react out of fear, and fear is a very powerful force.

The end product of phase one is shown in Fig. 2. A common problem is viewed by two forces with different concerns. Phase two, the strategy phase, seeks to bring these sides closer together toward a common solution.

The planning for public participation must begin early in the process, before issues become inflamed by media and political forces. It takes time. There is a tendency to spend money on construction and to economize on the social issues in a problem. There should be a monument to the phrase, "If we had only listened." The strategy process involves numerous meetings between civic leaders and the technologists.

### Strategy Development Phase

Another phrase which has become synonymous with the seventies is "cover-up." The public must never again have cause to suspect that a hazardous waste problem is being so treated, the industry must learn from the past. The strategy development phase is more than just a planning process. It is also a mechanism for bringing the public into the problem. It is a means of educating them as to their responsibilities, too, because with the right to decision-making participation goes the privilege of being part of the consequences of the remedial action.

Conflict can not be avoided. It is a basic human process. Accept conflict as a reality, and plan for it using the techniques addressed in phase three, the public participation program.

A public participation program promotes conflict resolution by providing opportunities for individuals and opposing groups to explore compromise solutions. Six levels of public participation are identified here. Each represent an increasing intensity of public involvement. Which level or levels are used is a function of the degree of anticipated public interest (Fig. 3).

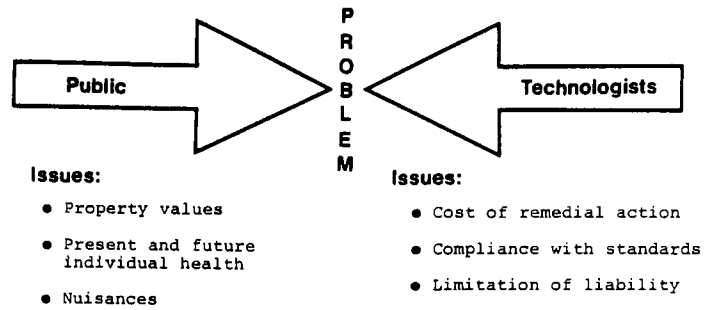


Figure 2.  
Identification of problem and conflicting issues to be resolved

### Level 1—Public Information

The public information component involves merely a dissemination of information to the public through project orientation devices, such as fact sheets, newsletters, and brochures, with distribution in a local area. Press releases and public information announcements may also be prepared for local newspapers and broadcast media.

The purpose of this informational level is to inform the public of hazardous waste issues and to report the progress on projects involving these matters. Although this step is often favored by the technologists as a cost-effective method, it is a one-way flow of information devoid of public input.

Because such a program is one-sided and autocratic, a subsequent public reaction with strong negative feelings about the direction of the project can ensue. Residents reading about a closure of a well near a landfill due to contamination may perceive a greater health threat than actually exists. In the case of the Port Washington, N.Y., municipal solid waste landfill, where media releases concerning methane explosions in homes near the landfill and the presence of toxins in a well and a local school caused residents and civic groups to request a "60 Minutes" investigation which was aired on a major television network. The residents distrusted town and county officials' reports contending that the evidence of leachate and gases in the landfill represented chemicals normally found in a variety of consumer products and did not present a significant health threat.

Residents have alleged, however, that industrial wastes have been dumped at the landfill. Their concerns that the landfill may be "hazardous" and a public health threat has pressured local health departments and the USEPA to conduct additional tests at the landfill. The release of information in this case only created greater public opposition and distrust that the conflict could be resolved.

The other major defect about the one-sided program is that the technologists may be totally unaware of a festering public reaction until it explodes upon them.

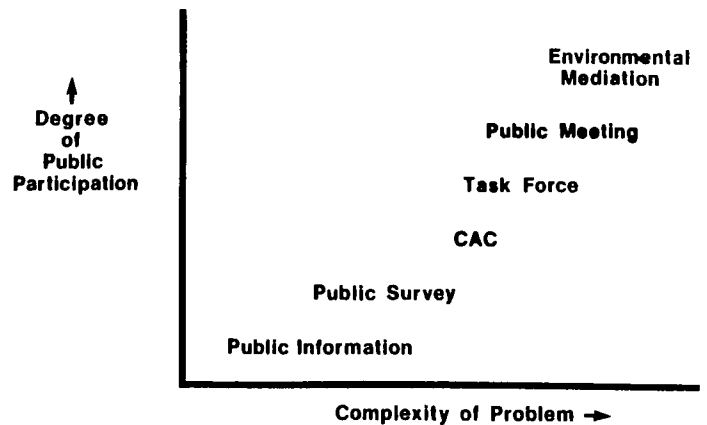


Figure 3.  
Six levels of public involvement

### Level 2—Public Survey

The second level of public involvement is a public survey. A public survey can consist of a written or oral questionnaire which is mailed, conducted by telephone, administered door-to-door or presented at a central location, such as a local supermarket.

The public survey level provides greater opportunity for public involvement than the information level, since it has the ability to input citizens' views. But, public surveys also have several deficiencies. Telephone surveys often cannot be geographically matched to a location. In the case of interviewing persons by telephone who are living near a suspected impact area, it is necessary to also have their address. Consulting a telephone directory for an address is time-consuming and may not resolve the problem.

Responses to mailed questionnaires are usually a small percentage of the total sent, with 10 to 20% representing a normal state of return. Furthermore, the respondent has complete freedom whether or not to respond and as a result, the returned responses may not represent a cross-section of public views, but only those individuals with strong feelings one way or the other.

While surveys provide a method of obtaining some public opinion, they are usually a one-time event. They neither track public perception as a function of time, nor do they produce a mechanism for a dialogue on issues. The public is suspicious of data collection in this manner.

### Level 3—Citizens Advisory Committee

The citizens advisory committee (CAC) is the third level of public involvement. The membership of a CAC should represent a broad base of community interest including residents, elected officials, representatives of special interest groups, and technical and environmental experts. The CAC may make recommendations, assist in the development of a public participation workplan, and participate in public meetings, workshops and seminars.

If properly balanced and adequately staffed, a CAC may ensure functional two-way communication and an on-going link between citizens and agencies involved in resolving a problem. A CAC can be an effective public participation mechanism since community values and goals can be reflected during the planning stages.

The criticisms leveled at CAC's have basically involved two problems. First, CAC membership, instead of being broad-based, is often dominated by persons with the loudest voices and/or those individuals with a special interest in the issues under consideration. Secondly, the role of a CAC is strictly advisory in the decision-making process. Therefore, in order to be effective, this advisory role of the CAC must be clearly defined to the members and the general public. Otherwise, they may perceive their powers to be much greater than they are legally allowed, creating greater polarization of the parties and issues. This may result in the mushrooming of issues beyond a technical level into the political arena.

In the final analysis of the project, the loss of control over technical issues can leave the participants with a greater-than-ever feeling of frustration. At this point, they are organized and have tasted power. They then may seek help in the political arena and when this happens, several consequences follow.

These are:

- Project delay
- Increased costs
- Potentially greater health risk due to lack of immediate remedial response
- Reduction of options
- Mandated remedies which may be neither feasible nor economically desirable.

### Level 4—Task Force or Ad Hoc Committee

A task force or ad hoc committee is the fourth level of public involvement. This body is usually a small group of people who have been assigned to research a specific problem in a limited time frame. Its membership should consist of those with the expertise

necessary for the specific problem. In this respect, it does not represent the broad-based public participation which is desired.

The problem with a task force is that once goals and tasks are decided upon, it may not have the flexibility to anticipate other potential problems. This was a criticism cited by Levine of the Governor's Love Canal Interagency Task Force. Once work routines were established for the task force, she found that production took precedence over flexibility. There seem little, if any, intent to deal with major problems which might occur after these decisions were made and announced.<sup>2</sup>

A task force is usually advisory in its capacity. It has no authority to make binding decisions. While it is more specialized than a CAC, its impact is little better.

### Level 5—Public Meetings and Hearings

The fifth level of public participation is public meetings and hearings. Public meetings and hearings can vary from an informal workshop to a formal, stenographically-recorded hearing. Both afford the opportunity for concerned citizens to present their views, often as part of a project's permanent record or file. Public hearings are sometimes a legal requirement under certain project review and permitting procedures. The New York State Environmental Quality Review Act allows formal opportunity for public comment concerning overall hazardous waste-related programs and policies as well as specific proposals.

Although in theory public hearings are scheduled just before decision-making, in reality they usually take place after major conclusions have already been formed. All too often, the burden is on the public to prove that a different conclusion is warranted. This is not an easy task for citizens. The time frame for citizens to respond to the public record is much shorter than the time taken by consultants and agencies in preparing the programs and projects under review. In an adjudicatory hearing for example, citizens must present expert witnesses to testify "points-of-fact" rebuttals for issues which are predetermined by an administrative law judge. Further, decisions which are made under the adjudicatory process may be binding.

Public hearings have been criticized not only because of the heavy burden of proof on the public to change agency course, but also that they occur too late in the planning process. Officials responsible for public hearings should consider holding a hearing earlier in the decision-making process than is required by regulation. For example, the New York State Department of Environmental Conservation held voluntarily a public meeting in the Town of Ft. Edward to review with local citizens and hear comments on the General Electric Company's engineering plan for remedial actions at the Fort Miller PCB dumpsite.<sup>3</sup>

### Level 6—Environmental Mediation

The highest level of public participation is environmental mediation. Mediation is a process in which conflict is legitimized. It provides a mechanism for the formal settlement of conflict.

However, mediation is entirely a voluntary process. It can occur only when all parties have a genuine desire to find a solution to a problem. The several parties cannot be forced into arbitration, nor can they be forced into agreement. The mediator has no authority to impose a settlement; settlement occurs only when all parties agree. Nevertheless, if the public participation programs previously described have set the stage for a genuine desire to find acceptable remedies, mediation can be effective.

However, conventional methods of conflict resolution are the antithesis of mediation. In court and at hearings, parties are represented by attorneys, whose job it is to be advocates and who are trained to be adversaries. It is extremely difficult to bring sides together after the field of combat has been joined. The entire public participation effort should be directed toward setting an environment for mediation, if this level of conflict resolution is ultimately needed.

Gerald Cormick of the University of Washington's office of Environmental Mediation has made some astute observations about

the mediation process, and these should be incorporated into any public participation strategy.<sup>4</sup> Applying these to hazardous waste situations, the following principles should apply:

- Mediation requires some relative balance of power. Typically, the strength lies with government, as it controls the funds, the permitting authority and the technical expertise. The real power that the public holds is in numerous voices, the press and the ears of politicians. Disaster makes news, and the public participation program should strive to assure that the public does not have to emphasize the potentiality of disaster. This can be done by supporting their side with access to technical data, moral support, and perhaps even financial support or other tangible assistance.
- Mediation must result in compromises. Each side must establish priorities, and be prepared to surrender some issues to gain others.

The problem is that it is legally or politically unwise to compromise standards. At present the nation has adopted water quality standards which have large margins of safety built into them to compensate for poor public health impact data. Nevertheless, the public perceives these standards to be minimal, and taxpayers regard them as being completely accurate when arguing damage claims. Thus, standards are like a ratchet, they are easy to slip in, but impossible to slide out.

If chemical concentration standards cannot be compromised, what is left? Frequently the impact is excessive cost or social dislocation.

- Environmental mediation need not wait, as in labor negotiations, until an impasse has been reached. Environmental issues frequently have a wide range of alternatives, and the doors to all viable alternatives should be kept open until there is agreement on a plan of action.

The environmental mediation process should begin, or at least be part of the planning, as soon as public perception of a potentially dangerous situation becomes significant enough to warrant attention. Reflecting on the landfills on Staten Island, it appears that the public was aware of alleged hazardous waste dumping long before it was recognized or confronted by regulatory agencies. Thus the public was already developing a position and, therefore, they should be part of any technical solution that is developed.

- A third party, impartial and acceptable to both sides, is essential in the mediation process. Neither side may perceive the party as an advocate for either side.

Finding such a party for a hazardous waste negotiation is not easy. The mediator must be more than just an interested party, he

must also be technically competent. This means a good working knowledge of chemistry, health effects, engineering, and a complex legal/regulatory system which few fully understand. On top of this, they need mediation skills, and the ability to inspire confidence.

"Shuttle diplomacy" is a term which has become popular in recent years. The Near East has the same volatility as toxic organics. For every hour that the mediator spends in joint meeting, he may spend ten hours in private conferences with each side, especially if the issues are very polarized. Someone has to pay for the mediator's services. This money should be programmed into the public participation program immediately in inflammatory issues, and set aside as contingency funds in less controversial matters.

## SUMMARY AND CONCLUSIONS

In all of the various mechanisms for public involvement, the public is an important part of the package on hazardous waste issues. Although the concept of working with the public is abhorrent to the technological professional, it is a fact of life. Perhaps many of the problems of society are due to technologists neglecting their social responsibility.

There are no clearly defined black and white solutions to hazardous waste issues. The dangers are frequently poorly defined. People look at the risks as an isolated event, instead of in the context of the general risk of living. They react from fear of the unknown. They crave professional help, and find it lacking and uncaring.

No two hazardous waste situations are alike and therefore the public participation program required will be different and tailored to the specific problem. A good public involvement program must be incorporated into every hazardous waste issue involving land usage. Failure to do so can be dangerous to the social health of the community and the viability of the project and its sponsors.

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# CITIZEN PARTICIPATION IN THE SUPERFUND PROGRAM

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## INTRODUCTION

Since the passage by Congress of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), better known as "Superfund," citizen participation in the program has been a much-studied issue.<sup>1</sup> This paper will discuss the shifting in USEPA policy from "citizen participation" to "public relations" and compare current USEPA policy on community relations to guidelines for public participation developed by concerned citizens living near Superfund dumpsites.

Unlike other programs administered by the USEPA, Superfund is not directly mandated by Congress to provide for public participation. However, USEPA recognized at an early date the need to develop a policy toward public participation for both legal and public policy reasons. Public participation is, in the Agency's opinion, legally mandated by other legislation, such as NEPA.<sup>2</sup> Moreover, events at Love Canal, Stringfellow Acid Pits and other sites had shown that the success of the Superfund program was dependent on effective citizen involvement.<sup>3</sup>

## DEVELOPMENT OF AGENCY POLICY

Development of the Agency's community relations policy began in Apr. of 1980, well before the existence of Superfund, when the Office of Analysis and Program Development (OAPD) outlined what it termed the policy's theoretical parameters and goals. The parameters originally suggested by OAPD included local media and press relations, public participation, local government and local interest group relations, and public information and education. The major goal of the community relations program was to ensure adequate communication between government and local communities in order to facilitate the implementation of cost-effective solutions to hazardous waste problems. Four secondary goals were advanced in order to achieve this primary goal. They were:

- To ensure the local community a meaningful voice in those implementation decisions that the community considers most important
- To establish a program of public information and media relations appropriate to the degree of interest and concern about the site
- To anticipate potential conflict and attempt to avoid conflict whenever possible
- To establish standard operating procedures that ensure extensive interaction between local government officials and federal/state officials<sup>4</sup>

The stated policy explicitly emphasized the importance of citizen participation in decision-making in furthering the Agency's primary goal.

In the summer of 1980, the community relations policy was being tested and expanded by a study of community involvement at 21 hazardous waste emergency operations and Clean Water Act 311 emergency actions.<sup>5</sup> An interim guidance document which reflected this analysis was distributed to the Regional Administrators on Feb. 25, 1981. The document required regions to adhere to the following principles:

- To empathize with local concerns, learning about the local community
- To avoid the generation of unrealistic expectations
- To be open and forthright with information
- To anticipate the formation of ad hoc citizen groups
- To coordinate actions with local officials
- To assign community relation coordinators whenever possible
- To use a variety of participatory techniques
- To consider the establishment of citizen advisory committees at sites and spills having a high degree of citizen concern
- To provide adequate training for Regional staff<sup>6</sup>

Two principles, (7th and 8th), take public involvement into account by asking Regions to consider techniques which enable citizens to participate. This guidance suggests citizen advisory committees may be established and recognizes the importance of providing citizens with timely information. These principles require that regional offices give citizens straight-forward information—though it is not specified whether the information be given prior to decisions. Thus, citizen participation is still viewed as an important component of the community relations program.

In the summer of 1981, the National Contingency Plan (NCP), the cornerstone of the Superfund Program, was drafted. This version of the NCP, unlike the final, provided guidance on citizen participation. This guidance was contained in an annex entitled "Community Relations," which outlined the necessary components of community relations plans (CRPs) at each phase of the Superfund process.

The contents of the CRPs were to be determined by two factors: the degree of technical complexity at the site and the level of citizen concern. While the specific plans would vary from site to site, all plans were required to include mechanisms which ensured some elements of community participation. The Regions had to reflect the emphasis local communities place on remedy selection, and a public hearing at this stage was required. While the Annex structure may not have been elaborate, it provided some handle for citizens to ensure that their concerns would have to be identified and addressed by the Agency.

In July-Aug. of 1981, a draft handbook entitled *Community Relations in Superfund—A Handbook* was sent out to the Regional Administrators, with a disclaimer that it need not represent official EPA policy. In the introduction, this handbook states, "The community relations program should provide the community with a means of influencing response actions but should not be used to alarm a community."<sup>7</sup> This handbook further developed the idea of basing CRPs on the level of citizen concern and degree of technical complexity at the site by providing a matrix which would be used to determine the appropriate contents of different CRPs. The handbook also provided information on various information dissemination and gathering techniques and discussed participatory techniques such as public consultations, hearings, and meetings. However, there were no requirements in subsequent guidance documents on the extent to which this handbook should be used. Therefore, the significance of the document is questionable.



## THE SHIFT IN AGENCY POLICY

On Nov. 18, 1981, William N. Hedeman, Jr., Director of the Office of Emergency and Remedial Response, sent a memorandum to Regional Administrators entitled, "Superfund Community Relations Policy and Guidance." This memorandum outlines the objectives of community relations plans—objectives which are quite different from those of the Interim Guidance document issued in Feb. 1981. The objectives are, in their entirety:

- To establish at each site some means of learning the community's concerns
- To let the affected public know Superfund actions are limited by budget constraints, so that unrealistic expectations do not develop
- To deal constructively with public response to Superfund actions—not to provide undue concern through unnecessary hearings or inflammatory publications
- To contribute to the Superfund program's overall success by decreasing the likelihood of costly delays, cost overruns, and politicization of purely technical issues
- To establish a preventive program—to lessen or avoid public confusion about Superfund remedies
- To stress the interaction of federal, state, and local government in solving local problems<sup>8</sup>

These objectives totally remove public participation from the objectives of the community relations programs. The component of public participation has changed to a public relations objective designed to diffuse, rather than address, public concerns. The language of this memorandum is instructive in its overridingly negative attitude: concern is expressed about "unrealistic expectations," "undue concern," "unnecessary hearings," and the avoidance of "costly delays," and "public confusion." The agency asks each regional office to find its own way to "deal constructively" with what is clearly viewed as the potentially hostile force of the citizens most intimately affected by its decisions: citizens who would attempt "the politicization of purely technical issues."

The limitations of the guidance document are not merely those of tone and general purpose, however. The cover letter states, "There is no set of 'requirements' or a required 'formula' to be applied at each site." The adequacy of each CRP therefore depends on the importance each Regional Administrator assigns to public involvement in the Superfund program, and there is no assurance that there will be consistent and adequate public participation at each site.

The document recommends that, with adequate prior preparation, a public meeting be held at the point when the on-scene coordinator is "ready to recommend a permanent remedy for the site." This recommendation is clearly contrary to the idea that the public should participate in the decisions affecting the site, since the hearing will be held after the decision is already made. At no other point is any technique recommended whose inclusion would allow citizens to become involved in the decision-making process.

A final and central deficiency with this guidance document, though it has existed from the inception of the program, is that there are no provisions whatsoever for citizen involvement during responsible party cleanups or enforcement actions. This lack of guidance further excludes citizens from involvement in the Superfund program, and in precisely those circumstances where, in all probability, most remedial actions will take place. Such exclusions have been encountered at sites such as Woburn, Ma., where citizens were wholly removed from the decision-making process after a responsible party was identified even though relatively good citizen participation techniques had previously existed.

The National Contingency Plan appeared in final form on July 16, 1982. In this document, the Annex which contained specific provisions for citizen participation has been completely deleted. Only two brief sections of the NCP deal with the subject, or with "community relations," as public participation is now labeled. The

first, *Section 300.34(e)*, merely authorizes certain help to the on-scene coordinators in public information and participation during "major responses." The second, *Section 300.61(c)(3)*, reads: "In determining the need for or in planning or undertaking Fund-financed action, response personnel *should, to the extent practicable,...* be sensitive to local community concerns (in accordance with applicable guidance)"<sup>10</sup> [emphasis added]. In effect, these two statements comprise the whole of the Agency's new public participation policy.

The phrase "to the extent practicable" makes it quite clear that even "sensitivity to community concerns" and the use of "applicable guidance" about public relations are matters of choice. Even more revealing, the term "applicable guidance" has no defined meaning and no legal or regulatory status. Thus the guidance may be defined by whatever policies, written or oral, the Agency chooses to call "applicable guidance" at any given time. This version of the NCP shows that the Agency has abandoned the earlier goal "to ensure the local community a meaningful voice in...implementation decisions," which had appeared in the initial OAPD statement. The plain truth is that neither the NCP nor the November policy document obligates the Agency to anything in the way of citizen participation.

Currently, the term "applicable guidance" refers to the Hedeman memo of Nov. 18, 1981.<sup>11</sup> Since the Hedeman guidance document directs Regions to manage community relations programs on a site-by-site basis, we turned to the Community Relations Plans (CRPs) actually developed in the field to gauge Agency policy. These give some documentary evidence, though it is virtually impossible to determine the extent to which the plans are actually being carried out at the specific sites, since the Agency has no internal checking system.

## ANALYSIS OF COMMUNITY RELATIONS PLANS

EDF examined 23 of the 25 CRPs submitted and approved at Headquarters. (Appendix 1.) The stated objectives of each plan differed greatly, varying from merely informing local officials to stating that citizens would be ensured a meaningful voice in the decision-making process.

Despite explicit requirements for submitting community relations plans,<sup>12</sup> EDF found a number of sites where community relations plans have not been developed in a timely manner. For example, a community relations plan is just now in the draft stage for Bruin Lagoon, Bruin, Pa., although there has already been a feasibility study and a remedial option selected at this site. The ad hoc procedures which were followed without such a plan included, as we have been informed by local residents, a public hearing announced in a newspaper from a city over 30 miles away and a period for review and comment of the feasibility study by the public of only 9 days. A detailed screening for those techniques which are compatible with an active rather than a purely passive role for citizens showed:

- Out of the 23 plans reviewed only one made specific provisions for notification/comment periods. (Woburn, Ma.)
- There were only three sites where a citizen's advisory committee or task force was established by the State. (Woburn, Ma.; Tar Creek, Ok.; Luminous Processes Site, Ga.)
- Only ten sites had any provisions for public input before a final remedial option was selected through public consultations, meetings or hearings. (Woburn, Ma.; Olean Fields, N.Y.; Luminous Processes site, Ga.; Gratiot County Landfill, Mi.; Colbert Landfill, Wa., Aidex, Ia.; Chem-Dyne, Oh.; Tar Creek, Ok.; French Limited site, Tx.; Bio-Ecology, Tx.)
- Three other sites stated that a public meeting would be *optional* before the selection of a remedial option. (Motco, Tx.; Arkansas City, Ak.; Summit National Services, Oh.)
- At three other sites where plans include public meetings, it was impossible to determine at what point in the process they would be held. (Winthrop, Me.; Keefe Environmental Services, N.H.; Gilson Road site, N.H.)
- Only four plans made any provisions for documenting citizens

concerns and the Agency response to these concerns. (Woburn, Ma.; Winthrop, Me.; Tar Creek, Ok.; Colbert Landfill, Wa.)

The picture presented by these plans is that USEPA's attitude toward public participation in each Region is highly variable. In general, the plans contain a minimum of specific techniques which invite any actual participation. The CRPs at two sites stated that a public meeting would be held only after the selection of a remedial option. (Ellisville, Mi.; Burnt Fly Bog, N.J.) The plans as a whole indicate that without an explicit structure for citizen involvement, with a set of minimum guidelines to be adhered to by each Region, citizens will continue to be excluded from participating in the decisions of the Superfund program. It was this that inspired one group of citizens active at Superfund sites to develop its own guidelines for citizen participation.

### ORIGIN OF THE CITIZEN STATEMENT

On June 4-7, 1982, Environmental Defense Fund (EDF) held a national conference entitled, "Superfund: Promise and Reality," attended by 31 citizen representatives from 22 Superfund sites across the country. The participants met with USEPA's Administrator Anne Gorsuch to discuss the situation at their respective sites. The major concern aired by the participants was their lack of involvement in the decisions being made about their sites. They noted, among other things, that technical reports were unattainable, that public hearings were either announced in cities far from their sites or were not timely, and that there was little real communication between the Regional Offices and local citizens. Furthermore, the citizens noted that they were not even aware the Agency had a policy on community relations or that specific community relations plans had been developed for their sites. After hearing these concerns, Mrs. Gorsuch invited the group to develop its own set of guidelines for public participation in the Superfund program. In a letter sent on June 7th, the participants formally accepted her invitation and outlined nine basic principles of effective citizen participation.

In the following three months, the citizens continued work on the document in small regional meetings, by phone call, and by letter. On Sept. 7, 1982, their "minimum guidelines for citizen participation," were sent to Administrator Gorsuch, where they now await disposition.

### SPECIFIC GUIDELINES FOR PUBLIC PARTICIPATION

In this section, the citizen's nine principles of public participation are presented. They are the best available index of what citizens living near Superfund sites wish to see—in order better to identify the deficiencies in the Agency's existing policy on community relations. Under each principle, the minimum requirements specified by the citizen's needed to ensure effective involvement are identified. Following this, the pertinent provisions under the Agency's existing community relations policy are listed.<sup>13</sup>

**Principle 1:** Participation from beginning to end of the decision-making process.

- **Minimum Requirements**—The citizens want on-going educational workshops, public meetings, and public hearings to be held upon their reasonable request. This includes the liberal use of comment periods on important materials.
- **Agency's Existing Requirements**—The only provision for public input in existing USEPA guidance is the discretionary public hearing to be held before a remedial option is selected.

**Principle 2:** Timely notification of all steps in the Superfund process before they are taken, with reasonable time allowed for comment and other response.

- **Minimum Requirements**—Citizens want to be notified at least 30 days in advance of all significant actions. Such actions may include the completion of reports, scheduled workshops, meetings, hearings, and pending Administrative Orders or voluntary settlements.

- **Agency's Existing Requirements**—There are no requirements for notification and comment periods in the existing guidance documents.

**Principle 3:** Explicit structure for public participation in development of the CRP.

- **Minimum Requirements**—Citizens want to be consulted when site-specific community involvement plans are being developed. Suggested techniques are, for instance, that the Agency hold workshops to discuss the plan prior to its development, or that citizens may request a public meeting to discuss the plan before it becomes final.
- **Agency's Existing Requirements**—Existing guidance does not provide any structure for public participation since the only requirement is that a plan be developed. Furthermore, community relations plans are being developed without citizen input in many cases. Citizen interviews are suggested by the Agency to determine the public's concerns, but there are no requirements that the public be involved in the actual development of the plan.

**Principle 4:** Opportunity to participate in each decision, including settlements with responsible parties, before finalization.

- **Minimum Requirements**—Citizens want to be involved during responsible party cleanups. This involvement may include citizen observers at negotiation sessions, citizen access to data and other information exchange between the agency and a responsible party, and citizen comment on Administrative Orders or voluntary agreements before they become operative.
- **Agency's Existing Requirements**—Neither the NCP nor existing guidance document address the issue of citizen involvement during a responsible party cleanup.

**Principle 5:** Early, immediate, and complete access to all information.

- **Minimum Requirements**—Citizens want the Agency to set up a local depository at each site where at least one copy of all past and present reports will be placed.
- **Agency's Existing Requirements**—Existing guidance does not discuss whether any reports or information about the site should be publicly available. The draft handbook provides assistance on information dissemination techniques but does not discuss what material should be disseminated. Furthermore, there are no requirements that a local depository be established at each site.

**Principle 6:** Access to appropriate technical expertise through government or other sources in advance of government action.

- **Minimum Requirements**—Citizens want access to State, Agency, and responsible party experts through telephone and/or workshop contact. Also, when technical issues are in dispute, citizens want the ability to hire independent expertise and be reimbursed by the Agency.
- **Agency's Existing Requirements**—The role of the Agency's technical consultants is not discussed in existing guidance on community relations beyond that of assisting the Agency during a public meeting. The extent to which a technical consultant could participate in citizens meetings on technical issues is unknown.

**Principle 7:** Convenient, timely public hearings held at locations reasonably accessible to concerned citizens prior to any decisions.

- **Minimum Requirements**—Citizens want public hearings normally to be conducted only after there has been a thorough background educational effort via small workshops, and informal meetings. These hearings should be held throughout the Superfund process in response to reasonable citizen request. As a minimum, there must always be a hearing held before a remedial option is selected.
- **Agency's Existing Requirements**—Existing guidance suggests that a public hearing be held before the selection of a remedial option. This is the only discussion of the time at which a hearing

should be held.

**Principle 8: Provide citizens with progress reports on site activity. Make provisions for citizen comment on the reports.**

- **Minimum Requirements**—Citizens want monthly reports which summarize past work and details of upcoming work at the dumpsite.
- **Agency's Existing Requirements**—There is no mention of progress reports in any of the existing guidance or policy documents, let alone the ability for citizen comment.

**Principle 9: Provide complete listing of government contact persons (with telephone numbers).**

- **Minimum Requirements**—Citizens want the on-scene coordinator, public affairs office personnel, consultants, responsible parties and project officers at Headquarters to be identified along with a telephone number where they can be reached. The citizens also want a toll-free Regional hotline to be established.
- **Agency's Existing Requirements**—Existing guidance does not require that a contact list be developed or made publicly available. There are no toll-free Regional hotlines where citizens can call to voice their concerns or complaints.

## CONCLUSION

In this paper, the authors have documented an explicit change in the nature of USEPA's community relations program from a program whose stated objectives were to involve the public in the decisions of the Superfund process to one whose objectives are to diffuse public reaction to that process. Guidelines and criteria for public participation developed by citizens living near Superfund dumpsites have been presented.

The differences between the citizen guidelines and the Agency's existing community relations policy clearly show that the policy does not meet, and does not promise to meet, the needs of citizens living near Superfund dumpsites as they perceive them. The central guidance document of the Agency states: "All available evidence indicates that the success of the Superfund program depends in large measure on the Agency's ability to implement an effective community relations program."<sup>14</sup> It is difficult to conceive of an effective program which does not meet in some significant measure the perceived needs of the population toward whom it is principally aimed.

## REFERENCES

1. The extensive work undertaken by the Agency is examined and in part referenced by Cohen, S., Ingersall, T., and Janis R. "Institutional Learning In A Bureaucracy: The Superfund Community Relations Program," *Proc. of the National Conference on Management of Uncontrolled Hazardous Waste Sites*, Oct. 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland, 405-410. In the same volume appear: Goggen, B., Rappaport, A. "The Community Hazardous Waste Coordinator Program," pp. 411-414, and Shaw, L. Milbrath, L. "Citizen/Government Interaction At Toxic Waste Sites: Lessons From Love Canal," 415-420.
2. Internal memoranda indicate that the Agency recognized the legal reasons for requiring public participation in the Superfund program. An August 17, 1981 memorandum from William N. Hedeman, Jr. entitled, "Guidance on Superfund/NEPA Policy: Areas of Responsibility," equates the studies and reports which are generated for clean-up in the Superfund program to an environmental impact statement. The memo then states that the public participation requirements under NEPA should be carried out in accordance with existing guidance on community relations in the Superfund program. Likewise, a September 1, 1982 memorandum from the Office of General Counsel to Administrator Gorsuch and Regional Administrators ("Public Participation in Remedial Actions Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) states, "...in order for the functional equivalent exception to apply, it will be necessary for remedial actions to incorporate comment on environmental issues before the final selection of a remedial alternative. One such standard is public participation in decisions regarding remedial action." Furthermore,
- Headquarters realized that RCRA requirements for public participation may be invoked when hazardous waste is generated, treated, stored or disposed as a consequence of the remedial option selected.
3. ICF, Incorporated, *Analysis of Community Involvement In Hazardous Waste Problems*, A Report to the Office of Emergency and Remedial Response, U.S. EPA, July 1981.
4. Cohen, S., Ingersall, T., and Janis R. "Institutional Learning In A Bureaucracy: The Superfund Community Relations Program," *Proc. of the National Conference on Management of Uncontrolled Hazardous Waste Sites*, Oct. 1981, Hazardous Materials Control Research Institute, Silver Spring, Maryland. 405-410.
5. ICF, *op. cit.*
6. Cook, M., Deputy Assistant Administrator, Office of Hazardous Emergency Response, "Interim Community Relations Guidance for Site Clean Up," EPA Memorandum to Regional Administrators, Feb. 25, 1981.
7. *Community Relations In Superfund—A Handbook*—Draft USEPA, Sept. 1981. p.1.
8. Hedeman, W. Jr., Director, Office of Emergency and Remedial Response, "Superfund Community Relations Policy and Guidance," USEPA Memorandum to Regional Administrators, Nov. 18, 1981.
9. *Federal Register*, 47, No. 137, July 16, 1982, 31210: "The USCG Public Information Assist Team (PIAT) and the EPA Public Affairs Assist Team (PAAT) may help OSCs and regional or district offices meet the demands for public information and participation during major responses. Request for these teams may be made through the NRC."
10. *Op. cit.*, 31214. The responsiveness of the Agency itself to public comments does not sort well with the final version of the NCP. In its discussion of the comments on public participation the Agency states, "Several commentators questioned the adequacy of [this section] and pointed out that it is important to keep the public informed and to include them in the decision-making process. Specific comments included...strong advocacy of greater emphasis on public participation....In order to indicate that the Agency has issued guidance in this area...that it is necessary to be sensitive to local concerns 'in accordance with applicable guidance' " (*Federal Register*, 47, No. 127, July 16, 1982, 31198). As we have seen, the guidance can not be thought to be responsive to a "strong advocacy of greater emphasis on public participation" nor of including the public in "the decision-making process." The addition of the stringently qualifying phrase that sensitivity to community concerns be "to the extent practicable" is also passed over in silence in the Agency's explanation.
11. Personal communication with William N. Hedeman, Jr., Director, Office of Emergency and Remedial Response, Apr. 30, 1982.
12. Hedeman, W. Jr., Director, Office of Emergency and Remedial Response, "Superfund Community Relations Policy and Procedures," USEPA memorandum to Regional Administrators, March 31, 1982.
13. The complete set of guidelines can be obtained by writing to: Toxics Chemical Program, Environmental Defense Fund, 1525 18th Street, N.W., Washington, D.C. 20036.
14. Hedeman, November 18, 1981, *op. cit.*, p. 1.

## Appendix 1: Community Relations Plans Included In Analysis

Region 1	Winthrop Town Landfill, ME Keefe Environmental Services, NH Gilson Road Site, NH Mark Phillips Trust, MA	Region 6	Motco, TX French Ltd. Disposal Site, TX Bio-Ecology Systems, Inc., TX
Region 2	Olean Well Fields, NY Burnt Fly Bog, NJ	Region 7	Tar Creek, OK Aidex Corporation, IA Arkansas City Dumpsite, KS Ellisville Site, MI
Region 3	McAdoo Associates, PA	Region 8	
Region 4	PCB Spill, NC Bluff Road Site, SC Luminous Processes, GA Whitehouse Waste Oil Pits, FL	Region 9	
Region 5	Summit National Services, OH Chem-Dyne Site, OH Fields Brook, OH Gratiot County Landfill, MN	Region 10	Colbert Landfill, WA

# PROGRESS IN MEETING THE OBJECTIVES OF THE SUPERFUND COMMUNITY RELATIONS PROGRAM

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## INTRODUCTION

The USEPA's Superfund program is an ambitious attempt on the part of the federal government to help solve the problems created by uncontrolled hazardous waste disposal sites in the United States, as well as to respond to the thousands of releases of hazardous substances into the environment each year. These problems have grown steadily throughout this century with increases in the production, distribution, storage, and use of hazardous chemicals.

It is difficult to estimate the size of the hazardous waste problem, but the Agency has been notified of a significant number of sites which are at least potential problems. While the Superfund remedial program will not address most of these sites, those that present the greatest threat to public health and welfare will receive some kind of response action. In addition, Superfund will provide the resources needed to respond promptly and effectively to emergencies caused by releases of hazardous substances during their transportation, storage, or disposal.

Early in its administration of the Superfund program, USEPA realized that special attention would need to be given to public concerns and fears in communities located near hazardous waste sites or releases that have been targeted for response. Accordingly, USEPA has established a community relations program designed to provide communities with accurate information about problems posed by releases of hazardous substances and at the same time, to seek local officials' and citizens' input into the decision-making process used to select a technical solution to site problems. The Superfund community relations program, in short, is an information and communications program aimed at meeting the special needs created by hazardous substance problems. USEPA insists that an effective community relations program must be an integral part of every Superfund-financed action.

## PROGRAM DEFINITION

### Why a Community Relations Program is Important

A release of hazardous substances poses both human and technical problems. While the issue to the engineer may be one of the technical feasibility of a proposed response, to concerned citizens living near the site the issue is their health and the health of their children. Citizens may also see the value of their property as well as the threatened image of their community. Consequently, any hazardous substance problem is inherently sensitive. It must be managed with attention given to public attitudes and fears. If a proposed response to a release of hazardous substances is to be successful or even, sometimes, to be completed at all, the local community must have an accurate understanding of the nature of the threat and of the various alternatives that may be presented for dealing with it.

Local opposition to government actions may be motivated by fear of the effects the hazardous substance problem will have on the quality of life in the community and by distrust of industry and government. Often, the local media and local public officials

will state these same fears and concerns. All too frequently, the result is public excoriation of the company(ies) involved, rejection of reasonable response plans (or unrealistic expectations from them), obstructionist tactics, and even the forced closure of existing sites.

The level of sensitivity and public interest need not be related to the technical complexity of the problem. In addition, it can be intensified by limitations in the resources available for a single Superfund response. People who have lived with a hazardous waste problem for years are likely to want—and expect—the federal and state governments to remedy the problem immediately. Removal actions or initial remedial measures will sometimes result only in interim, on-site solutions. Furthermore, cost-effectiveness stipulations in the Superfund statute, as well as National Contingency Plan requirements for detailed analysis of remedial alternatives, must be satisfied before off-site remedies can occur. An effective community relations program will help explain these kinds of considerations to the concerned local public, and will help the citizens understand the technical and financial limitations of the national response program.

### Objectives

Specifically, then, the objectives of the Superfund community relations program are as follows:

- To collect information about the concerns of the community.

A community relations program provides a vehicle of exchange among USEPA, the state, the public, and local government. It enables USEPA and state staff to identify citizen leaders, public concerns, and relevant social and political considerations. Sometimes it can also yield technical information useful in planning a solution to a site's problems.

- To inform the public of planned or ongoing actions.

The program should inform the public of the nature of the environmental problem, the remedies under consideration, and the progress being made.

- To give citizens the opportunity to be involved in decision-making.

The program should enable citizens to express opinions about decisions that will have long-term effects on their community. A course of action stands a greater chance of public acceptance if citizens have had a voice in its planning.

- To focus and define issues and to help resolve conflict.

Conflict may be unavoidable in some circumstances, but it can be constructive if it brings into the open alternative viewpoints based upon solid reasons for criticism or dissent. A community relations program channels conflict into a forum where it can serve a useful purpose.

## PROGRAM REQUIREMENTS

There are three kinds of Superfund response actions:

- Immediate removals are undertaken to prevent or mitigate immediate risk of harm to human life or health or to the environment.

Immediate removals may last for as little as a few days.

- Planned removals are either a continuation of an immediate removal or a separate cleanup action at an unranked site, limited in time and cost.
- Remedial actions are those responses to releases at national priority sites that require longer term and possibly more expensive cleanup efforts.

Because every hazardous waste site is likely to have unique circumstances and issues of local concern, requirements for designing and implementing the community relations program have been kept minimal and flexible. The program relies chiefly on the ability and perceptions of regional and state staff. The key requirement is the submission, by the USEPA Regional Office or the state, of a "community relations plan" for each remedial action and for each removal action which last more than a few days. The community relations plan must carefully consider the specific needs of an individual site and must ensure that community relations activities are closely coordinated with technical work being contemplated or performed.

For example, while a particular site may be the focus of a high degree of vocalized public concern, the health or environmental threat it poses may not be so acute as to demand an immediate removal. Instead, there may be sufficient time to plan and implement a more lengthy remedial action. Clearly, such a situation would require early extensive community relations activities preceding any selection of alternatives in order to explain the more time consuming, albeit prudent, approach.

All community relations plans should be based on on-site discussions with local officials, community leaders, and involved citizens to identify local concerns or sensitive issues. USEPA should be aware of any lengthy history of problems at the site that may provoke public concern or influence local attitudes. For example, in developing a community relations plan for a site during the past year, USEPA found that the site owner had threatened nearby residents and made them reluctant to seek help from the government.

The importance of the on-site visit cannot be stressed too strongly. From the beginning of the Superfund program, USEPA has recognized that a local community's concerns cannot be adequately measured from a distance. All of the best examples of USEPA's community relations plans are based on an accurate understanding of community concerns gained through personal visits by USEPA staff and its contractors.

When the USEPA decides to fund a Superfund response, the Agency develops a cooperative agreement or a contract with the state; this agreement establishes responsibility for information and communications activities at the site. The responsible agency then develops a community relations plan that includes four key points:

- How citizen concerns will be identified at the site
- How accurate information on problems associated with the release of hazardous substances will be distributed and explained to the community
- How citizens will have an opportunity to comment on ongoing and proposed site work
- How the proposed technical solution will be explained to the community

Specific methods listed in the plan for soliciting citizen input and distributing information will vary from site to site, depending upon the level of citizen concern and the nature of the site's technical problems. However, smaller scale, informal methods, such as living room gatherings with citizens and local officials, are generally emphasized. The responsible agency will then implement the plan in close coordination with other interested agencies.

## CURRENT STATUS OF THE PROGRAM

In the past year, there has been some progress in all areas of the community relations program. Some major accomplishments are represented by the following:

- More than 40 community relations-related site visits have occurred

during the preparation of community relations plans and related analyses since the program's inception

- A policy for community relations in Superfund has been completed by Headquarters and communicated to all the Regions
- A detailed handbook on community relations in Superfund has been published; the handbook lays out specific options which might be followed in carrying out community relations programs
- Twenty-five community relations plans have been reviewed at Headquarters and approved

These successful developments mainly represent continued progress in publicizing the program, refining program objectives, and accumulating information. While all of these steps are necessary to ensure a good program, adequate plans have not yet been produced for all scheduled remedial actions.

Of the accomplishments listed, the site visits represent the most visible indication to the public that USEPA is giving concerted attention to community concerns. The visits show concrete movement toward a solution of the locality's problem. Overall, such visits enhance the public image of USEPA's commitment to the Superfund program.

In addition, site visits provide significant educational benefits to staff who will conduct response activities. Interviews with citizens and local officials compel Regional Office and state staff to think carefully about community concerns and needs—preventing blunders with sensitive local issues.

Site visits have been useful for identifying or resolving policy issues. For example, the visit to Commencement Bay, Washington, highlighted a major Superfund policy issue: how to treat hazardous waste sites located on Native American lands. The problem involves the responsible management of these lands as well as their classification for the purposes of Superfund.

The site visits also confirmed the value of the decentralized, flexible nature of the community relations program. Through site visits, the USEPA or state officials conducting community relations activities at the local level have obtained an immediate awareness of what methods are likely to be most useful. This local orientation should increase in effectiveness as officials expand their community relations experience.

Another significant step was the development of a policy and guidance document. The policy establishes USEPA goals and procedures for the community relations program, and requires Regional Project Officers to carry out a program that is consistent across the nation.

The program is supported by the community relations handbook. Having gained greater confidence as a result of field experience, USEPA now has a detailed, step-by-step guide to community relations activities and methods that can be followed in any kind of response action. Specific techniques are presented, showing instances when they might be most appropriate. For instance, the timing of briefings, citizen group meetings, community information interviews, and media appearances are discussed as they relate to various problems and to the different stages of a particular cleanup activity. For example, community interest often peaks at the stage of a remedial action in which cleanup alternatives are developed and selected. Thus, a sensitive community relations effort is especially important at this point. The handbook recommends briefings for local officials and small, informal meetings as among the appropriate activities.

USEPA has implemented several Superfund community relations programs, but there remain goals yet to be achieved. One goal is a full briefing of Regional USEPA staff on the design and implementation of community relations programs. At the same time, Headquarters will conduct a detailed program review to determine whether requirements are being met, and to determine whether any unforeseen problems have been encountered at sites.

## PROBLEMS AND IMPLEMENTATION

Apart from specific cases where insufficient attention has been paid to community relations during a response, the Superfund community relations program has faced several general problems

that arise from the structure of the program. Institutional barriers present the program with difficult management and policy problems. The fact that different levels of government have different concerns, different pressures, and different constituencies causes some slowdowns and inefficiencies even in the smoothest of relationships.

A second problem which remains manageable, but is difficult nonetheless, arises in cases of enforcement against responsible parties. Public release of information can complicate negotiations with responsible parties to finance cleanup operations. If USEPA reveals too much information in response to community requests, the responsible party may feel threatened and become intransigent, closing off continued negotiation. USEPA and Justice Department attorneys are justifiably reluctant to disclose anything about negotiations. The result of secrecy, however, may be public suspicion and increased requests for information. In short, providing citizens with information about legal proceedings (or even about a situation subject to legal proceedings) can complicate those legal actions. Yet citizens have a right to know what is going on. A balance needs to be maintained.

A further point where balance is necessary is in the amount of influence citizens may have on the decision-making process. While citizen input is necessary (indeed, that is the point of the community relations program), USEPA's response decisions must rest, in the end, on the judgment of qualified experts in engineering, public health, and environmental sciences. Furthermore, the problems addressed by Superfund are nationwide in scope: the pro-

gram's costs and benefits are distributed across the country. The concerns of a locality, however, are usually more narrow. The responsible agency must consider local concerns and recommendations and respond to them. The Agency does not believe, however, that Congress intended for citizens and local officials to make final decisions on response actions. USEPA must balance its requirement to respond to a local situation with its responsibility as a national agency with national management requirements and demands.

In early September of this year, the Agency received a set of community relations guidelines prepared by citizens who live near certain sites around the country. The guidelines contain specific recommendations from these citizens on how to improve the community relations program. The Agency appreciates these comments and is now reviewing the recommendations to see where they may make useful additions to the current program.

Such "grass-roots" input is of significant value both in program planning and insofar as it symbolizes the essence of the Superfund community relations program: that hazardous substance releases cannot be adequately dealt with without a real cooperative effort among all concerned. In the past, communications between citizens and cleanup officials have at times been inadequate, causing difficulty for both groups and interfering with effective response activities. Similar situations must be avoided in the future. The progress of the Superfund community relations program indicates that USEPA does understand the complexities of the challenge and is working toward solutions.

# SPILL INCIDENTS AT HAZARDOUS MATERIAL STORAGE FACILITIES: AN ANALYSIS OF HISTORICAL DATA FROM THE PIRS AND SPCC DATA BASES

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## INTRODUCTION

Spills of hazardous materials from storage tanks and associated equipment may result in significant environmental damage through the direct effects of the material on the environment and through fires and explosions precipitated by the spill event. Through analysis of a large number of reported spill events from storage tanks and their associated equipment, it should be possible to determine:

- The relative probabilities of failure events attributed to different causes or points of failure
- The relationship of spill size to cause or point of failure

As part of a current project being performed by JRB Associates under contract to the USEPA, Office of Solid Waste (OSW), over 4,000 reported spill events from storage tanks and associated equipment were analyzed for spill size and cause or point of failure. The resulting data are to be used, in conjunction with other information being developed under this project, by OSW in further refining regulations for tank storage of hazardous waste.

## DATA SOURCES

Two primary data sources, containing information on a sufficient number of storage-related failure incidents to allow for a probabilistic analysis, were identified. These data sources are the Spill Prevention, Control, and Countermeasure (SPCC)<sup>1</sup> data base, maintained by USEPA, and the Pollution Incident Reporting System (PIRS)<sup>2</sup> data base maintained by the U.S. Coast Guard. These data bases contain information on all spills of oil and hazardous substances reported to the Federal government under Section 311 of the Federal Water Pollution Control Act (FWPA)<sup>3</sup>. Spills to inland waters are reported to EPA and are entered into the SPCC data base. Spills to coastal waters and navigable inland waters are reported to the Coast Guard and entered into the PIRS data base. While both systems are similar, they do differ in the types of information available, accessibility, and format.

### Pollution Incident Reporting System

Spills that would affect coastal waters and navigable inland waters (such as the Mississippi River and Great Lakes) are reported to the Coast Guard under the FWPA and incorporated in the PIRS system. Additionally, spills reported to USEPA that eventually require litigation are also incorporated in PIRS, since the Coast Guard is responsible for determining extent of damage in such cases. Spills that would be reported include those resulting from transportation, loading, and unloading operations, production processes, and material storage.

Computer files for approximately 2000 "Onshore Bulk Storage Facility" spill cases reported to the Coast Guard for the year 1975 through 1980 were accessed and analyzed. Each case file included the following information:

- |                |                    |                    |
|----------------|--------------------|--------------------|
| •Date of spill | •Size of spill     | •Cause             |
| •Location      | •Substance spilled | •Type of operation |

The format of the PIRS data base made it possible to access only those spills which originated from storage operations (tanks and ancillary pipes, pumps, and valves). The ability to distinguish between spills originating from pipes, pumps, and valves associated with storage and those associated with a specific process or with transportation is obviously important to an analysis of this type.

The data available from the PIRS data base have a number of important limitations affecting the reliability of the data:

- Only spills which may affect surface water bodies are required to be reported to the Coast Guard (or USEPA) under Section 311 of the FWPA.
- It is not possible to determine what percentage of spills are unreported, and whether percentage of reporting is biased toward any particular type or cause of failure. Additionally, it is likely that small spills in particular are underreported, biasing results toward large spills, since small spills are generally more likely to be contained.
- Spills occurring within the confines of a secondary containment structure are unlikely to be reported.
- The data lack any description of such important factors as tank capacity or tank construction materials.
- Approximately one-third of the retrieved cases lacked a critical piece of information (e.g., spill size) and had to be dropped from the data pool.
- There is no means of identifying the size of the universe of potential respondents.
- Size determination is based generally on the judgment of the spill investigator.

### Spill Prevention, Control, and Countermeasure Data Bases

At the time of this analysis the SPCC data base contained between 20 and 30% of all spills affecting inland waters reported to EPA between 1975 and 1980. USEPA is entering the remaining incidents for that period as resources permit; the order of entry is random for the parameters of concern in this analysis, and therefore, should not bias the results.

Incidents reported include transportation, production, and storage related spills. Printouts were received from USEPA's SPCC Office for all 10 Regions (data provided for Region 7 was incomplete) containing those cases reported as onshore non-transportation spills of petroleum products, hazardous chemicals, and other substances. Spills occurring at industrial plants, marketing distributors, refineries, power plants, hazardous waste sites, and other storage facilities have been included. Information included in the data base includes:

- |                              |                  |
|------------------------------|------------------|
| •Facility name and locations | •Source of spill |
| •Data and time of spill      | •Cause of spill  |
| •Water body affected         | •Size of spill   |
| •Material spilled            |                  |

Unfortunately, the design of the SPCC data base does not allow for retrieval of information on spills from storage tanks and an-



cillary equipment due to the categorization used. The category accessed (onshore non-transportation spills) encompasses spills from process tanks, pumps, piping, valves, etc., as well as for storage tanks and ancillary equipment. This is indeed a limitation of these data in view of the purpose of this analysis.

In addition to this limitation, the SPCC data base has similar limitations to those of the PIRS data base.

## METHODOLOGY

Both the PIRS and SPCC computer printouts were manually reviewed to select all applicable cases. From these cases, all data on size and cause of spill were entered onto the PIRS or SPCC Regional Data Compilation Form designed to facilitate later quantification of probability. Cause descriptors were grouped into four "failure point" categories:

- Containment device—structural failure of tank or drum
- Operations—all human error with tank overflow highlighted as the most frequent and germane
- Ancillary Equipment—structural/equipment failure other than tanks or drums
- Other—fire, explosion, vandalism, acts of nature

The PIRS and SPCC data include spill reports on many different materials, such as petroleum, petroleum fuel and non-fuel products, and organic and inorganic chemicals. In order to obtain a sufficient number of data points for analysis, spills of all materials were combined under the assumption that the occurrence and size of spills was independent of the material stored. To check this assumption, SPCC spill data from USEPA Region IV (one-third of the total storage-related SPCC spills currently in the data base) were broken out to compare spills of bulk stored petroleum products used as fuel with spills of chemicals and non-fuel petroleum products.

The differences between results for the two groups were compared and found to be statistically but not highly significant ( $\chi^2 = 11.16$ , 3df.). The percentages for chemicals and non-fuel petroleum products were then compared to those obtained for all SPCC recorded storage spills for all regions (Table 2) and again differences were found to be not significant ( $\chi^2 = 6.51$ , 3df.). Given the uncertainties and limitations associated with the data (as previously discussed), it was decided that fuel and chemical spills should

be regrouped and treated as one data set for the remainder of the analysis.

Finally, the data from all regions were combined and probabilities (percent of total number of spill incidents) were calculated and graphed for PIRS and SPCC.

## ASSUMPTIONS

Due to limitations in the descriptive ability of the PIRS and SPCC data bases, and deviations in reporting, certain assumptions were developed to enable analysis of the data. The most salient of these are as follows:

- That, due to the fact that failures in pipes, pumps, and valves reported in the SPCC system could not be attributed in all cases to storage, the PIRS data only would be relied upon for final analysis. SPCC data would be presented for comparison only.
- That tank overflow is a result of human error and, therefore, belongs under Operations. As explained by investigators' reports, the majority of overflows are due to operator error, but this category will likely contain some incidents caused by mechanical failure as well.

## RESULTS OF THE ANALYSIS

The existence of two systems, designed to record spill incidents reported under the FWPA, offers a unique opportunity to compare the two sets of data. The SPCC system contains inland water-related spills while the PIRS system contains coastal navigable inland water-related spills plus those USEPA cases carried to litigation (USCG sets civil penalties in litigated cases). The exact degree of this overlap is not known and, therefore, the data were not combined. The systems are treated as two separate data sets expected to correlate strongly, except that the SPCC data would be expected to show more failures related to pipes, pumps, and valves since these items were not limited to storage-related uses.

### Comparison of Bulk Stored Petroleum Products Used as Fuels and Storage of Chemicals and Non-Fuel Petroleum Products

Region IV provided approximately one-third of the SPCC data for hazardous materials storage. Spill incidents from this Region were grouped to compare data on spills from bulk storage of petroleum products used as fuels with data on spills from storage of chemicals and non-fuel petroleum products (Table 1). Of the Region IV spills, 73% involved petroleum products. In Table 2, the petroleum and non-petroleum cause-of-failure percentages are compared.

The higher percent of spills during operations for fuel storage reflects a higher relative number of tank overflows. The higher "Other" percentage for chemicals reflects a higher relative number of fires and explosions.

### Data Presentation

Raw data for the failure incident reports are presented in Tables 3 (PIRS) and 4 (SPCC). These data show that, by an overwhelming amount, spills are most likely to be the result of operational errors or ancillary equipment breakdown.

The data were analyzed to determine if spill size could be related to point of failure. Initially, the percentage of failures in each cause category were developed for each size. These data are presented in Tables 5 (PIRS) and 6 (SPCC). From these percentages, probability curves were developed for certain cause categories of regulatory interest.

Table 1.

Fuel/Chemical Breakdown of Region IV SPCC Spill Incidents

	Amount Spilled (gallons)								
Cause	0-49	50-99	100-249	250-499	500-999	1000-10,000	>10,000	TOTAL	%
CHEMICALS & NON-FUEL PETROLEUM PRODUCTS									
Containment	5	1	5	1	2	8	2	24	8
Operations	21	3	12	8	13	20	3	80	28
Ancillary	19	10	18	11	11	46	14	129	45
Other	30	4	5	5	0	6	4	54	19
TOTAL	75	18	40	25	26	80	23	287	100
BULK STORAGE OF PETROLEUM PRODUCTS USED AS FUELS									
Containment	14	8	12	5	3	14	3	59	7
Operations	95	31	63	34	38	46	4	311	39
Ancillary	87	42	71	32	46	80	5	363	46
Other	5	7	12	4	8	16	11	63	8
TOTAL	201	88	158	75	95	156	23	796	100
GRAND TOTAL	276	106	198	100	121	236	46	1083	

Table 2.  
Summary of Spills by Cause

Cause	Fuels	Chemicals
Containment	7%	9%
Operations	39%	28%
Ancillary	46%	45%
Other	8%	19%

Results of this analysis for failures of the containment vessel are presented graphically in Figs. 1 and 2. From these graphs, it can be determined that the mean size failure for containment devices is in the 300 to 350 gal range, and that only 9 to 10% of spills from this source exceed 5,000 gal in size.

The results of this analysis for operations (divided into tank overflow and other categories), are shown in Figs. 3 and 4. From these graphs, it can be determined that the mean size for overflows is 150-175 gal, and that only between 2 and 5% of spills from overflows exceed 5,000 gal. For other operations, it can be determined that the mean is 90-150 gal, and that between 2 and 5% of these spills are over 5,000 gal.

The results of a similar analysis for ancillary equipment are given in Figs. 5 and 6. For pumps, the mean spill was between 80 and 180 gal, and between 4 and 10% of spills were above 5,000 gal. For pipes, the mean was between 35 and 250 gal, with between 3 and 5% of spills over 5,000 gal. For valves, the mean ranged from 200 to 400 gal, with between 7 and 9% of spills above 5,000 gal. For the other category, the mean ranged from 25 to 150 gal, with between 2 and 3% of spills over 5,000 gal.

The other category, as shown in Figs. 7 and 8 has a mean size of between 30 and 300 gal for fires, explosions, flooding weather, and other natural disasters. This spread is to be expected since the

Table 3.  
Spill Incidents from PIRS Data Base (1974-1980)

Amount Spilled (gallons)

Cause	0-49	50-99	100-249	250-499	500-999	1000-9999	>10,000	TOTAL	(%)*
<b>CONTAINMENT DEVICE</b>									
Tank Rupture/Leak <sup>1</sup>	10	1	5	4	7	9	3	39	3
Tank Corrosion	2	1	3		2	3	2	13	
SUBTOTAL	12	2	8	4	9	12	5	52	4
<b>OPERATIONS</b>									
Tank Overflow <sup>1</sup>	32	12	27	21	14	27	3	136	10.5
Other <sup>2</sup>	177	48	67	40	28	88	24	472	36.5
SUBTOTAL	209	60	94	61	42	115	27	608	47
<b>ANCILLARY</b>									
Pipes <sup>3</sup>	125	16	41	22	17	33	9	263	21
Pumps <sup>4</sup>	14	6	9	3	3	7	3	45	3
Valves <sup>5</sup>	11	12	10	7	9	14	4	67	5
Secondary Containment <sup>6</sup>	3					1		4	
Other <sup>7</sup>	87	12	15	12	13	28		167	13
SUBTOTAL	240	46	75	44	42	83	16	546	42
<b>OTHER</b>									
Fire/Explosion						1	2	3	
Adverse Weather	4	1	6	1		4	1	17	1
Natural Disaster		3	1		1	1		6	
Other <sup>8</sup>	21	5	10	1	5	22	11	75	6
SUBTOTAL	25	9	17	2	6	28	14	101	7
TOTAL	486	117	194	111	99	238	62	1307	100
Percent of Total Spill Incidents	37%	9%	15%	8%	8%	18%	5%		

#### \*Relative Probability

- Minor damage; other casualty, design fault; material fault; structural failure.
- Personnel error; improper maintenance; overpressurization; capsizing; overturning; collision; grounding; improper installation; hose, pipe or loading arm cut/twisted; improper valve operation; flanges improperly secured.
- Minor damage; excessive wear; corrosion; design fault; material fault; other.
- Minor damage; excessive wear; corrosion; material fault; design fault; other.
- Minor damage; excessive wear; corrosion; material fault; design fault; other.
- Dike rupture or leak due to material fault or design fault.
- Gasket failure due to minor damage, excessive wear, material fault, corrosion, other equipment failure.
- Container lost intact or other structural failure due to other or unknown factor.

categories do not exactly correspond with the PIRS and SPCC systems for these areas. Spills of over 5,000 gal accounted for between 9 and 13% of spills for these categories. For the vandalism category, the mean size was approximately 500 gal, with 10% of spills over 5000 gal.

Table 4.  
Spill Incidents from SPCC Data Base (1975-1980)  
Amount Spilled (gallons)

Cause	0-49	50-99	100-249	250-499	500-999	1000-9999	>10,000	TOTAL	(%)*
<b>CONTAINMENT DEVICE</b>									
Tank Corrosion	15	4	19	6	13	25	2	84	3
Tank Rupture	16	7	13	8	9	35	19	107	
Tank Leak/Seeping	18	7	14	4	6	12	2	63	2
Drum/Rupture/Leak/Rotted	5	2	2		1	1		11	
Underground Leak/Tank	1	1	2					4	
Leaking Bladder	2							2	
TOTAL	57	21	50	18	29	73	23	271	9
<b>OPERATIONS</b>									
Tank Overflow	162	62	126	58	68	113	17	606	20
Other <sup>1</sup>	114	40	50	30	40	77	16	367	12
TOTAL	276	102	176	88	108	190	33	973	32
<b>ANCILLARY</b>									
Pipes <sup>2</sup>	181	94	192	131	130	232	43	1003	33
Pumps <sup>3</sup>	31	10	12	9	12	16	10	100	3
Valves <sup>4</sup>	30	24	29	24	37	68	19	231	8
Secondary Containment <sup>5</sup>	6		2			3	5	16	1
Other <sup>6</sup>	31	9	16	6	8	25	2	97	3
TOTAL	279	137	251	170	187	344	79	1447	48
<b>OTHER</b>									
Fire	12	3	11	1	1	8	3	39	1
Explosion	27	1	9		1		6	44	1
Vandalism	20	10	14	13	16	40	11	124	4
Flooding	21	4	10	5	4	14	3	61	2
Other <sup>7</sup>	23	6	8	10	6	17	5	75	3
TOTAL	103	24	52	29	28	79	28	343	11
GRAND TOTAL	715	284	529	305	352	686	163	3034	100
Percent of Total Spill Incidents	24%	9%	17%	10%	12%	23%	5%		

#### \*Relative Probability

#### SPCC INCIDENT FOOTNOTES

- Valve handling, collision with vehicles, improperly secured flange, bucket spilled, student broke jar, punched drum, car hit pump hose, truck knocked valve open, line overload, cut hose line, construction work, excavation, open valve, tank cleaning, improper hose connection, improperly sealed, carelessness/improper/inadequate handling, negligence, loose cap, spillage, trash can tipped, poor/improper maintenance, improper cleaning, overflow spillage due to inattention, cleaning, personnel, operations, overturned drum, emptying tank, oil bucket overturned, backhoe dug up pipeline, pump was run over, forklift poked hole in tank, tank trailer dropped, pumping tank out, pump left on, tractor ran over pipe, drop tank while moving, uncoupling, off loading, improper valve handling, overpressurization, tank plug missing, unloading error, operator error, human/personnel error, overfilled container tank overturn, forklift punctured drum, hand truck failure, hit by crane, backflow, poor housekeeping, welding spark, oil put in wrong tank, overturning.
- Frozen line, regulator malfunction, pipeline corrosion, hose/pipeline rupture, collar broke, line plugged, line/flowline leak, hose break, transport hose, disconnected hose, flowline break, pipe/piping system leak, plugged siphon line, injection line rupture, cooling line coil crack, clogged pipeline, leaky union, pipeline flange leak, cracked/faulty line, plugged/line/leak, kinked hose, pipe blockage, pipeline leak.
- Pump failure rupture, leaking seal, broken/ruptured casing, leaking packing, cracked siphon, hyd. pump, broken pump, ruptured pump seal, frozen pump.
- Defective valve, blown valve packing, installing valves, valve rupture, leaking stop.
- Defective sump pit, dike failure/leak, dike washout/broke, drainage system failure, overflow catchment bod, broken dike, sump overflow, sump pump.
- Automatic shutdown, alarm failure, break in coupling, nozzle malfunction, other connection, broken fitting, gauge malfunction, loose plug, control malfunction, pressure release, welding spark, pressure blowoff, leaking flange, broken coupling, faulty/gasket/blow, equipment malfunction/failure, broken hose coupling, coupling leak/failure, loose fitting, fitting failure/leak, broken joint, tub rupture, disc rupture, gasket rupture, gasket leak/failure, seal failure, seal blowout, nozzle failure, gauge failure/leak, metering system, alarm failure, bushing failed.
- Weld failure factory/field, freezing, heavy winds/rains, lightning, hot weather, natural disaster (rockslide, lightning, earthquake, landslide), seam failure, other rupture, corrosion.

Table 5.  
PIRS Spill Percentages (1974-1980)

Amount Spilled (gallons)							
Cause	0-49	50-99	100-249	250-499	500-999	1000-10,000	>10,000
CONTAINMENT DEVICE							
Tank Rupture/Leak <sup>1</sup>	26	3	13	10	18	23	8
Tank Corrosion	15	3	23		15	23	15
OPERATIONS							
Tank Overfill	24	9	20	15	10	20	2
Other <sup>2</sup>	38	10	14	8	6	19	5
ANCILLARY							
Pipes <sup>3</sup>	48	6	16	8	6	13	3
Pumps <sup>4</sup>	31	13	20	7	7	16	7
Valves <sup>5</sup>	16	18	15	10	13	21	6
Secondary Containment <sup>6</sup>	75					25	
Other <sup>7</sup>	52	7	9	7	8	17	
OTHER							
Fire/Explosion						33	67
Adverse Weather	24	6	4	6		24	6
Natural Disaster		50	17		17	16	
Other <sup>8</sup>	28	7	13	1	7	29	15

Table 6.  
SPCC Spill Percentages (1975-1980)

Amount Spilled (gallons)							
Cause	0-49	50-99	100-249	250-499	500-999	1000-10,000	>10,000
CONTAINMENT DEVICE							
Tank Corrosion	18	5	23	7	15	30	2
Tank Rupture	15	7	12	7	8	33	18
Tank Leak/Seeping	29	11	22	6	9	19	3
Drum/Rupture/Leak/Rotted	45	18	18		9	9	
Underground Leak/Tank	25	25	50				
Leaking Bladder	100						
OPERATIONS							
Tank Overflow	27	10	21	10	11	19	3
Other <sup>1</sup>	31	11	14	8	11	21	4
ANCILLARY							
Pipes <sup>2</sup>	18	9	19	13	13	23	4
Pumps <sup>3</sup>	31	10	12	9	12	16	10
Valves <sup>4</sup>	13	10	13	10	16	29	8
Secondary Containment <sup>5</sup>	38		13			19	31
Other <sup>6</sup>	32	9	16	6	8	25	2
OTHER							
Fire	31	8	28	3	3	21	8
Explosion	61	2	20		2		14
Vandalism	16	8	11	10	13	32	9
Flooding	34	7	16	8	7	23	5
Other <sup>7</sup>	31	8	11	13	8	23	7

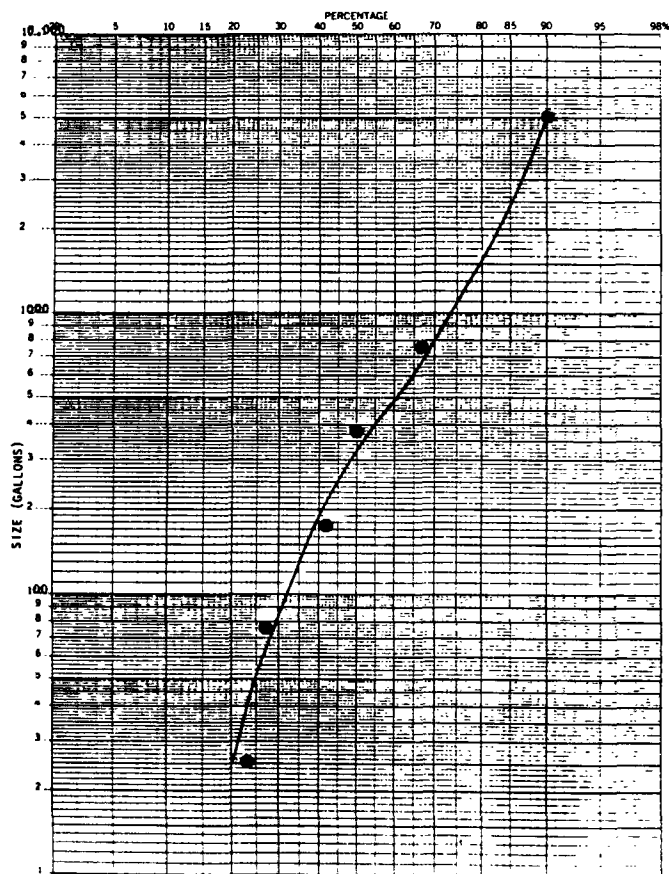


Figure 1.  
PIRS Containment Failure Probability Curve

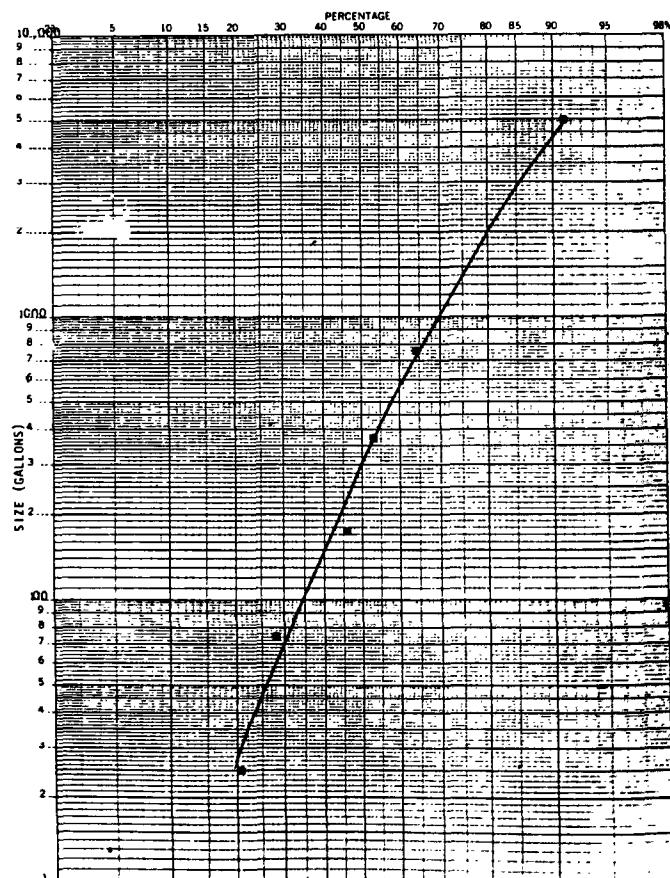


Figure 2.  
SPCC Containment Failure Probability Curve

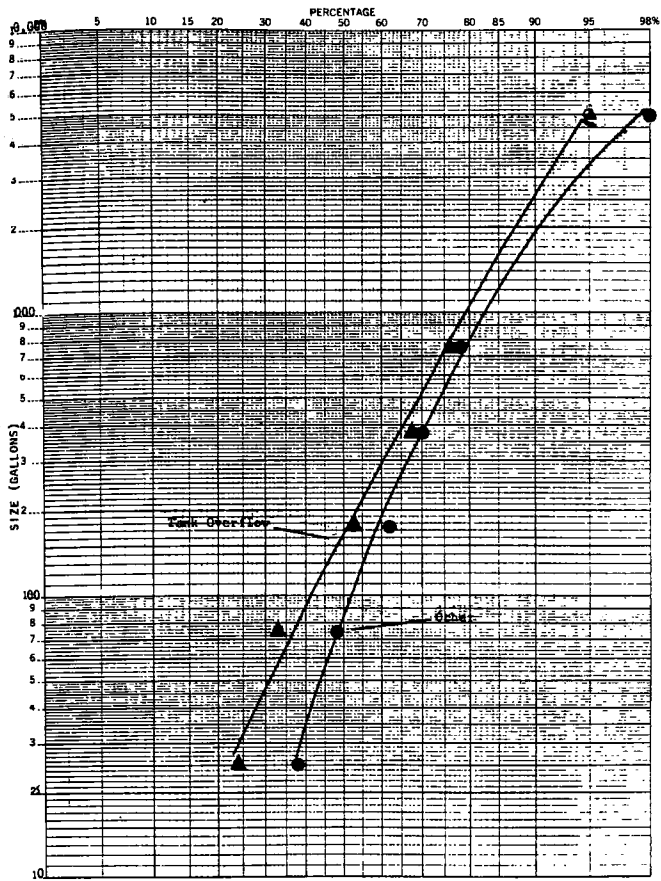


Figure 3.  
PIRS Operations Failure Probability Curve

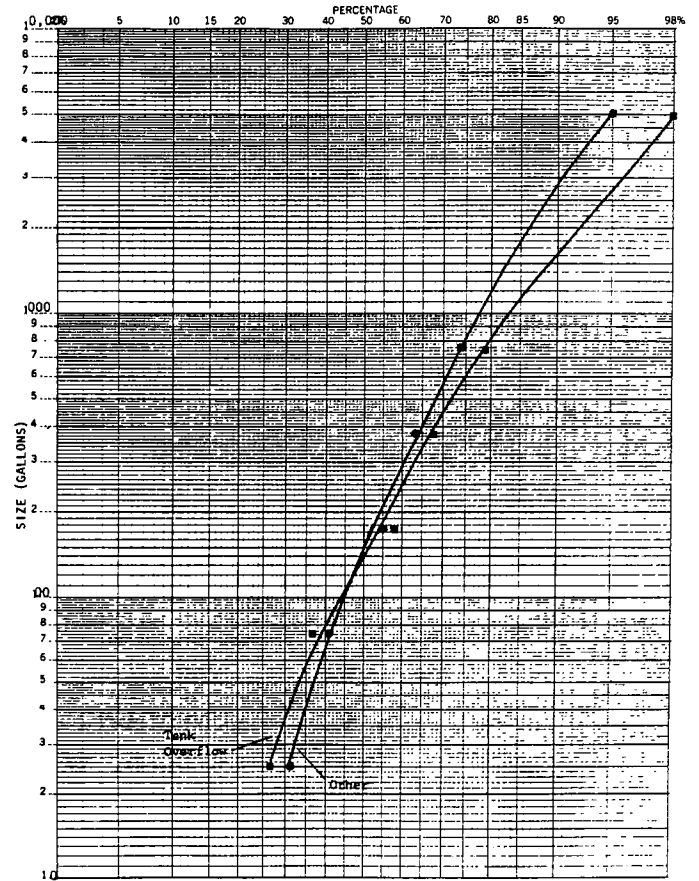


Figure 4.  
SPCC Operations Failure Probability Curve

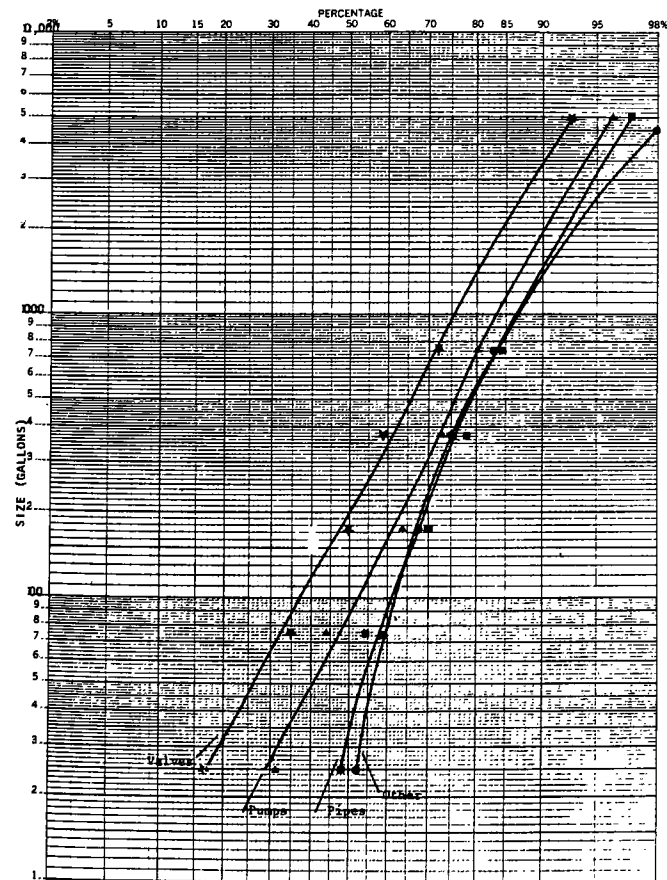


Figure 5.  
PIRS Ancillary Equipment Failure Probability Curve

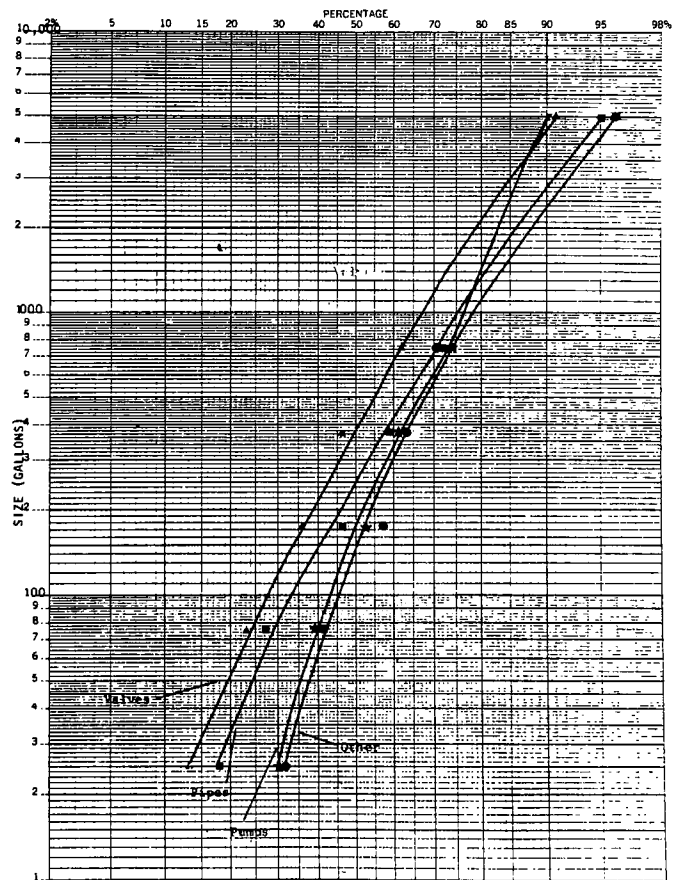


Figure 6.  
SPCC Ancillary Equipment Failure Probability Curve

### Analysis of Results

PIRS data were analyzed to determine if spill size distribution was correlated to cause or failure point.

For containment device failures, spill size was not found to vary significantly by cause (tank rupture or corrosion) ( $\chi^2 = 2.104$ , 5df.). For pipe, pump, and valve failures, spill size was also not found to vary significantly by point of failure ( $\chi^2 = 12.95$ , 10df.). However, for operation failures, size distribution for tank overfill and other categories were found to vary significantly ( $\chi^2 = 17.75$ , 5df.).

Further comparisons were made of data on containment device failure, tank overfills, and pipe, pump, and valve failures. The size distributions for these categories were found to vary significantly by cause ( $\chi^2 = 45.4$ , 10df.).

"Other" categories (except "other" under operations) were not further examined because they represented a very large number of different causatory events, each with a very low probability. "Other" failures under operations represented a large number of unusual failures directly attributable to human error.

### CONCLUSIONS

Based upon this analysis of historical spill data for tank storage, the following conclusions can be made:

- The major causes of spills from tank storage operations are operator error and ancillary equipment failure, which together account for 89% of storage related spills in the PIRS data base.
- Spills from the tank itself, due to tank failure, overfilling, adverse weather, or fires and explosions, account for only 16.5% of spills. However, tank failures and spills due to adverse weather or fire and explosion (5% of all spills) are significantly larger on average than other spills.
- The large number of spills (55.5% of the total) falling into the "other" subcategories within the containment device, operations, ancillary equipment, and other categories, indicated the extremely diverse nature of accidents.
- The size of the spill is at least partially dependent upon cause or

point of failure. Unfortunately, the data base does not have information on the capacity of the storage equipment involved in the failure, so it does not allow for analysis of spill size dependence on this factor. However, it is likely that spill size is primarily dependent on capacity of the storage system and only secondarily dependent upon cause or point of failure.

The implications of these results in terms of developing regulations to protect human health and the environment from adverse effects of hazardous waste tank storage have not been fully analyzed in light of other information being developed on this project. However, these data do indicate that good design of primary containment systems (tanks, pipes, pumps, valves) may not solely provide adequate protection for the environment due to the numerous possible causes of spills which are largely unforeseen at the time of design. This situation reveals a need for mitigative measures, such as secondary containment around storage areas and the limitation of ancillary equipment to the secondary containment area to the extent practical, to adequately protect human health and the environment from potential adverse effects of hazardous waste storage.

### ACKNOWLEDGEMENTS

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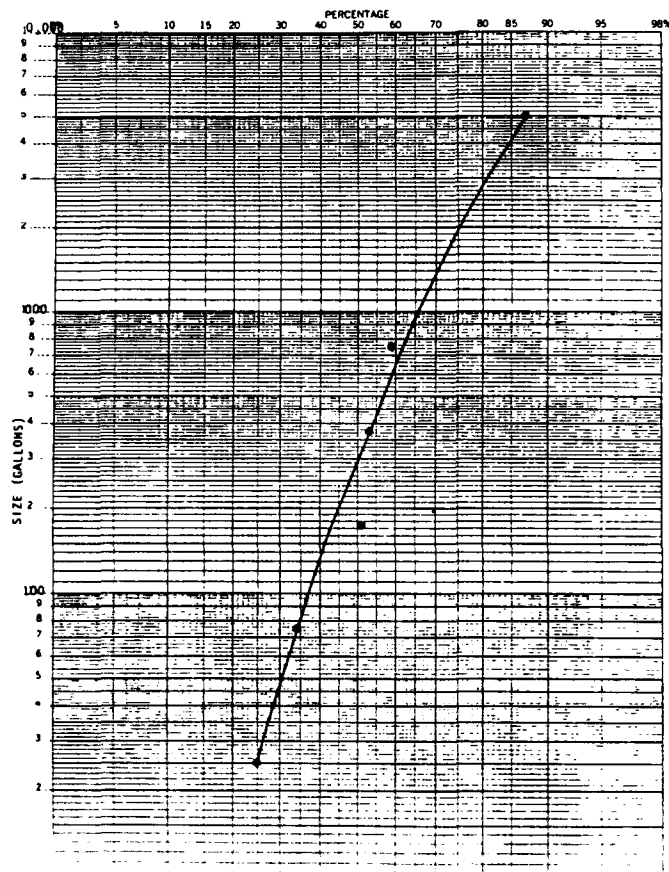


Figure 7.  
PIRS Other Failure Probability Curve

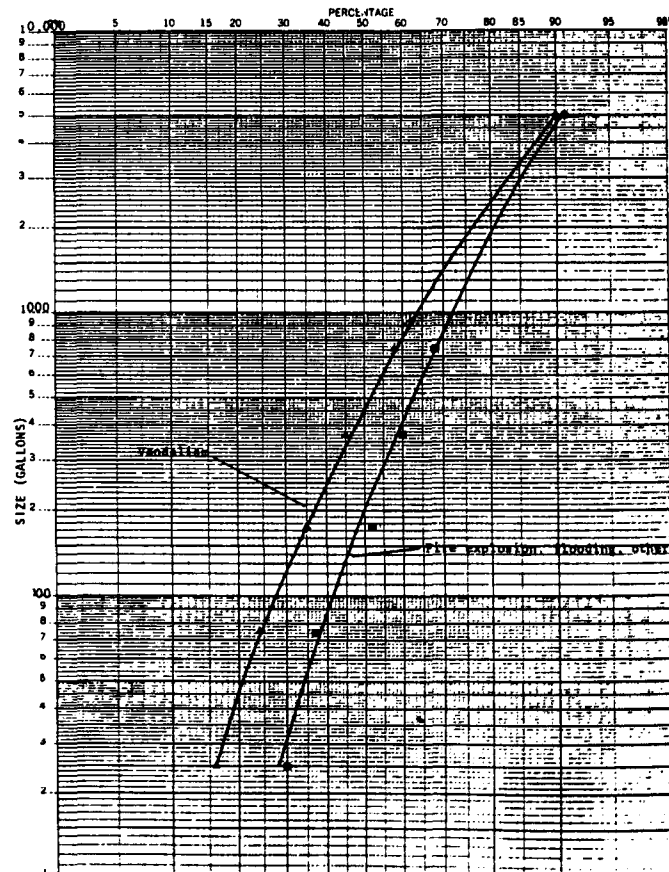


Figure 8.  
SPCC Other Failure Probability Curve

# THE HAZARDOUS MATERIALS TECHNICAL CENTER

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## INTRODUCTION

The Hazardous Materials Technical Center (HMTc) was established in June 1982 by the Defense Logistics Agency (DLA) to provide a center of expertise on technology and regulations related to handling, storage, transportation and disposal of hazardous materials. The need for an HMTc began with the assignment of responsibility to DLA for managing most of the hazardous wastes in the Defense Department (DOD). To help in carrying out this responsibility DLA decided to establish a contractor operated Hazardous Materials Technical Center. Through competitive procurement the Dynamac Corporation of Rockville, Maryland was selected to establish and operate this Center.

This presentation discusses the purpose, potential users and functions of the HMTc. The Center is an Information Analysis Center operated for DLA with technical supervision by the U.S. Army Environmental Hygiene Agency and DLA.

The purpose of the HMTc is to provide a single location as a source for information on all aspects of hazardous materials technology and regulatory requirements. It will consolidate many scattered information resources and other pertinent data which are currently available. The initial users will be primarily DLA and the Military Services with information provided to other Federal, state and local government agencies and the commercial/industrial sector on a non-interference basis.

The specific functional activities and the potential informational needs that will be met are shown in the following table:

<i>Activity</i>	<i>Need(s)</i>
Occupational Safety and Health	Information on all aspects of safety, health, handling and regulatory compliance for safety and health surveys
Shipping, Receiving and Traffic	Information on containerization, storage compatibility, transportation, spill cleanup and recoupment
Warehousing	Information on containerization, storage compatibility, spill cleanup and recoupment
Facilities	Information on handling and disposal
Environmental	Information on disposal, spill cleanup, recoupment and regulatory compliance

## FUNCTIONS

The HMTc is organized along two functional lines: development of the Disposal File for the Hazardous Materials Information System (HMIS) and other products and services. The first functional area to be discussed is the HMIS Disposal File.

The data files and the data elements currently in HMIS are described in the following overview, setting the stage for discussion of the proposed data elements for the Disposal File.

## AN OVERVIEW OF THE EXISTING HMIS

The HMIS currently has two data files:

- Safety and Health File—for which the information comes primarily from the Material Safety Data Sheets (MSDS) provided by the supplier of the material
- Transportation File—for which information is prepared by the person developing the data for the HMIS based on the MSDS and other data

A third file for the HMIS, primarily concerned with disposal information, will be developed by the HMTc in close coordination with the users of the HMIS.

Starting in 1976, Federal government agencies were required to obtain Material Safety Data Sheets (MSDS) for all procured hazardous materials. The MSDS contains health and safety information pertaining to that particular hazardous material. To provide a comprehensive and organized repository for the data in the MSDS's, DLA established the Hazardous Materials Information System (HMIS) in 1978. HMIS was also intended to assist in compliance with pertinent regulations in the areas of safety, health and transportation. The HMIS is operated and maintained by the Defense General Supply Center (DGSC) in Richmond, Virginia with input from the several agencies within DOD.

The Safety and Health File is comprised of four major sections: (1) Identification and Logistics, (2) Chemical Properties, (3) Safety and Health Properties, and (4) Storage, Spill, Leak and Disposal Procedures. The Identification and Logistical data section contains key items for products (such as National or Local Stock Number, Federal Supply Code For Manufacturers, NIOSH Code, Focal Point Indicator, etc.) which are unique to the product and may serve as links to the other files (Transportation and Disposal). These data elements may also serve as a basis for retrieving information from the Safety and Health File. The Chemical Properties section provides the file with information about the chemical components and the physical and chemical properties of the material.

The Safety and Health Properties section contains information on such items as explosive concentrations, threshold limit value (TLV), first aid procedures, hazardous decomposition products, protective equipment, etc.

The Storage, Spill, Leak and Disposal Procedures section provides the user of the product with guidance on action to take in storing the product and how to handle a spill of the product and then in what manner the contained, spilled or leaked material should be disposed. The waste disposal referred to here is for the disposal of materials used to clean up spills and is very general in nature. A typical instruction is "Place material in suitable container for shipment to disposal area". Obviously, this instruction is not enough to insure compliance with regulatory requirements for routine hazardous materials disposal.



Similarly, the Transportation File has an Identification and Logistical set of data elements in addition to Transportation data elements. The Identification and Logistical data in the Transportation File serve the same purpose as those data in the Safety and Health File. However, the Transportation data pertains exclusively to the manner in which hazardous materials are shipped. Beginning with the product measurement data and special chemical classes in regard to shipping and ending with the different avenues of shipment (road, water or air), the transportation data provide the user with a comprehensive source of information. This information is used to determine transportation restrictions, shipping modes, packaging requirements, labeling requirements, manifesting requirements, etc.

The final data file is the Disposal File which will be developed by the HMTc in close coordination with the using activities and based on their experience.

### HMIS—PROPOSED

It is proposed that five major sections of data will comprise the Disposal File. These sections include:

- Mandatory Data Elements
- Disposal Criteria
- Special Characteristics
- Transportation Data
- Supplementary Data

The Mandatory Data Elements Section will be comprised partly of those data elements which are similar to the Identification and Logistical data for the existing Safety and Health file and Transportation file of the HMIS. These data elements will be included in this file so that it will be able to stand alone. There will also be several new data elements in this file. For the purposes of this discussion, only the new proposed data elements are presented for consideration.

The first new data element proposed [Mandatory Data Elements] is:

- Is it reportable to Defense Property Disposal Office (DPDO) by DTID (Disposal Turn in Document)?

DOD policy has established eight categories of hazardous materials such as:

- Biological/Chemical Warfare Agents
- Unique R&D wastes
- Municipal wastewater sludges, etc.

that are not reported to DPDO for disposal. DOD policy is that these materials will be the responsibility of the generator of the material. This first new Mandatory Data Element would indicate whether or not the material is in any of those categories.

The second data element [Disposal Criteria] is:

- Is it reportable to DPDO for services only?

This information will indicate those items for which DPDO will provide disposal assistance even though they are not required to formally accept the item, i.e., a service contract to dispose of industrial sludges.

The third data element [Special Characteristics] is:

- Can hazardous property bypass all or part of disposal cycle?

This information is of prime importance to materials which are considered hazardous waste upon generations. Therefore, if the answer is yes, it will normally be followed by a qualifier statement in the supplemental data field such as:

“It is a waste upon generation”, e.g., spent solvents.

“Do not sell or donate”, e.g., PCB transformers.

The next data element [Transportation Data] is:

- The EPA Hazardous Waste Code

This code is assigned by EPA in the subtitle C, Hazardous Waste Regulations for implementation of RCRA and is needed on manifests to identify a specific type of waste. Some examples are:

PO37 for dieldrin

KO47 for red water from TNT operations

Similarly, the next data element [Supplementary Data] is:

- The EPA Hazardous Characteristic(s)

This data element gives the characteristic that caused the material to be declared hazardous, i.e., ignitability, corrosivity, reactivity or toxicity.

A closely related data element that is proposed is:

- Is it an Acute Hazardous Waste?

Designation as an Acute Hazardous Waste results in requirements for special and more restrictive disposal methods and handling of storage containers.

The final proposed new Mandatory Data Elements are:

- Is an Environmental Impact Statement (EIS)/Environmental Assessment (EA) available:
- Has a Categorical Exclusion been granted?

Certain chemicals such as DDT has had an EIS prepared for its disposal. Certain wastes may have Categorical Exclusions from the EIA/EA requirement granted by the Council on Environmental Quality.

The next major section in the Disposal File is Disposal Criteria. The first proposed data element in this section is:

- Disposal Restrictions

This data element will be a narrative that describes policy and regulatory restrictions such as:

- Can the material/waste only be sold to licensed persons? e.g., pesticides
- Can the material be resold overseas but not in the United States or vice-versa?
- Special pre-processing needs may be identified, e.g., fixation of an inorganic heavy metal sludge prior to disposal.
- Qualifier's for IFB's (invitation for bid).
- Is the hazardous material/waste covered by another regulation(s), e.g., TSCA, FIFRA?
- Special DOD or DLA policy restricting disposal of certain items.

The second proposed data element in the Disposal Criteria is:

- Technical Disposal Code

This will be an alpha numeric code which will reference a DOD handbook, which will be prepared for technical disposal instructions. The complete disposal procedure is not included in the data element since only a limited number of disposal options are available and the inclusion of these options in each data file would result in excessive repetition. In addition, some instructions may be very lengthy and would be better referenced. Furthermore, this data element would also have information on preferable and acceptable methods for disposal and any technical restrictions in regard to disposal methods or procedures.

The next section in the Disposal File is Special Characteristics. This section highlights those characteristics of a hazardous waste which require special attention in the data elements such as:

- Handling/Storage Precautions:

- avoid heat or cold or water that could change the characteristics of the material/waste and make it more hazardous
- special caution for materials that change on aging
- spill residue handling which would indicate the material used in cleanup becomes a RCRA controlled hazardous waste

- Storage Compatibility

- chemical characteristics to be aware of that would require storage restrictions, e.g., not storing acids near poisons, etc.

- LD<sub>50</sub>/LC<sub>50</sub> Information

- this data would provide additional information on those materials designated as Acute Hazardous Wastes

These elements are the proposed new data for the HMIS Disposal File. The information for the data elements in the Transportation section of the Disposal File will primarily come from the existing



HMIS Transportation File, and the information in the Supplementary section will be used to amplify any information in the other data elements regarding further clarification.

As was previously discussed, this approach to the Disposal File is a starting point. Work will be done with the users to fully define their needs and how they can best be met.

Although the data elements proposed for the Disposal File appear primarily administrative and logistical in nature, they are synthesized from extensive scientific and technical information on the hazardous materials to ensure the procedures recommended are technically sound, meet all environmental and health regulations, and are implementable.

For example, the following factors are considered in the development of these data elements:

- Potential degradation due to long term storage, e.g., picric acid will produce explosive crystals
- Environmental transport mechanisms and environmental fate determined by the chemical/physical properties of the material and specific site characteristics
- Treatment technology evolutions such as biodegradation, micro-organism acclimatization, chemical neutralization, fixation and solidification, slow and rapid oxidation
- Industrial hygiene and engineering control technology as parts of a safety and health program for disposal workers

These are some examples of the scientific and technical considerations which go into the developing of the Disposal File.

#### OTHER PRODUCTS AND SERVICES

The second major functional area of HMTC is Other Products and Services. This function includes the development of products such as:

- Handbooks—general guidance documents on broad topics  
Potential topics might be: Organic Solvent Disposal  
Pesticide Disposal  
Storage of Hazardous Materials
- State-of-the-Art Reports (SOAR)—more specific and limited than

handbooks and can be considered monographs targeted to an experienced technical audience. Some potential topics are:

Hazardous Waste Exchanges  
Disposal of PCP (pentachlorophenol)—  
impregnated ammo boxes (which might  
include the identification of potential  
substitute chemicals)

- Critical Reviews/Technical Assessments—are similar to State-of-the Art Reports but even more specialized.
- Abstracts and Indices—prepared quarterly by HMTC. The Center will compile all the new abstracts of the pertinent literature added to the Center's repository on a quarterly basis. HMTC will also prepare an annual publication of all the abstracts for that year. In addition, the HMTC will provide detailed responses to technical inquiries which can be made by phone or letter. Furthermore, the Center will prepare bibliographic reports upon request. Finally, a catch-all category of special studies is included in case some project does not fit into any of the other categories for products or services.

To provide rapid access to the information HMTC has developed, an IBM System 34 will be used to catalog and store the data. HMTC will not duplicate existing data bases or information networks, but will make use of them. The Center's system will be limited to information which is not available from other easily accessible sources.

#### PRODUCT/SERVICE DELIVERY

The delivery of these HMTC products and services begins with the processing of a customer request received by mail or phone. A routine technical inquiry or request for readily available material will be processed in three days. A technical inquiry requiring preparation of a custom tailored response and requests for bibliographic reports will be completed in ten days. The generation of a new product such as a handbook or SOAR may take a year or longer. For this effort, a detailed scope and cost estimate are prepared for the client's approval before proceeding.

# DOCUMENTATION FOR COST RECOVERY UNDER CERCLA

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## INTRODUCTION

Section 107 of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)<sup>1</sup> authorizes the Federal Government to recover cleanup costs, costs of Federal employees' efforts, and costs of damage to or loss of natural resources from a responsible party. Documentation to recover these costs begins with the notice that release of a hazardous substance has occurred.

Section 103 of CERCLA requires that persons in charge of vessels or facilities, as well as owners or operators, report releases of a hazardous substance and the conditions of the release. Section 103 of CERCLA provides for response actions consistent with the National Contingency Plan (NCP) to remove and remedy the release as necessary to protect public health, public welfare or the environment.

Whenever the government undertakes a response action, various information gathering activities must be included in order to document the existence and extent of the release, the source and nature of the hazardous substance, the extent of hazard to the public or the environment, and the responsible party. CERCLA §107 authorizes recovery of funds spent on response actions from a responsible party and such a cost recovery action will be anticipated in all cases by the collection and preservation of appropriate evidence and documentation. While not all costs will be recoverable (e.g., cleanup of a federally-permitted release), all costs will be documented pending a later legal determination.

In the documentation of critical facts and response costs, it is important to demonstrate:

- Conditions that existed at the site at the time of release
- The association between the site and the owner/operator, transporter and/or generator
- The rationale and physical evidence justifying a removal and/or remedial action
- The development of a remedy not inconsistent with the NCP and its cost-effectiveness
- The total costs including Federal employee expenses paid to clean up the site

These facts will be included in a site file which is established at the outset of any identification of a release of a hazardous substance. The file will be organized by phases and contain the documents which record the major decisions made during each phase. Each of the documents will be signed and dated by the preparer for authentication. Those involved in data collection and decision-making will be identified by name, qualifications, and how they may be contacted. Although the original of each document will be collected, copies of pertinent documents are acceptable as long as the preparer can substantiate that a signature had been affixed to the original. At each step or phase, records which are required to support a cost recovery action will be added to the file. The compilation of facts in this manner provides both a complete file and efficient document control (chain of custody of the documents).<sup>2</sup>

The phased approach for documentation of a cost recovery action described here follows the phased approach used by the program office at USEPA to investigate sites and design remedial actions. Generally, surveys, studies, and information searches are initially conducted to document the responsible party and the areal and vertical extent of contamination. Based upon these data, a removal and/or remedial program is devised, for the purpose of isolating and/or cleaning up the contamination to protect the public health, welfare and environment.

In order to determine the effectiveness of the remedy, a detailed monitoring program may be implemented. If required to insure the continued effectiveness of the remedy, operation and maintenance may continue. Health and safety programs may also be implemented. Documentation of the decisions made in each phase are made a part of the site file as they are generated.

These phases are outlined in Subpart F of the NCP.<sup>3</sup> In this paper, USEPA tracks those phases, not so much to describe the procedures employed, but to describe the documentation necessary in each phase. These documents become the factual and evidentiary information to support a cost recovery action. Documentation includes not only descriptions of what was done but also the rationale for a particular choice of response action, and how it is consistent with the NCP. The documentation will include records that a release is threatened or has occurred, conditions at the site, the link between a responsible party (if any) and the site, the technical justifications for the removal and/or remedial action, and the total costs and claims paid to cleanup the site consistent with CERCLA and the NCP.

Cost recovery may begin after the completion of any phase. Therefore, it is essential to maintain documentation at the outset of the investigation and as the cleanup proceeds.

The development and preservation of evidence for a cost recovery action require a concerted technical effort that must be accompanied by good bookkeeping and record collecting techniques. Standardization of data collection, use of site specific account numbers for all Federal expenses related to site work, chain-of-custody and document control such as those described by the USEPA National Enforcement Investigations Center's document control system, will greatly aid the Agency's ability to recover funds spent.

## PHASE I—DISCOVERY OR NOTIFICATION

In the discovery or notification phase, record of a release of a hazardous substance will be documented. The discovery may take place as a result of a compliance investigation conducted by government authorities in accordance with the inspection authority of CERCLA or other statutory authorities pertinent to governmental agencies. Discovery may also occur as the result of inventory efforts or random incidental observations by government agencies or the public.<sup>4</sup> Notification may occur in accordance with section 103(a) and (c) of CERCLA which require persons in charge of a vessel or facility and owners or operators of a facility to notify the National Response Center (NRC) and USEPA respectively, of any

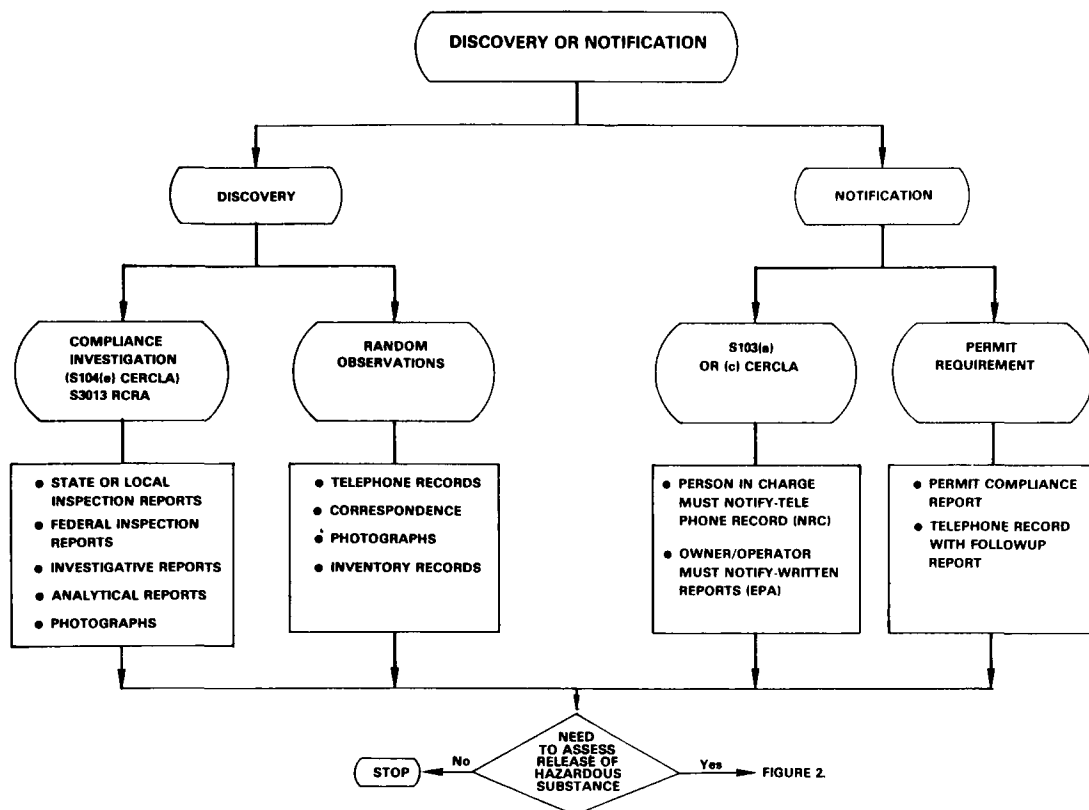


Figure 1.  
Discovery or Notification Flow

release. Notification may also occur as a result of Federal or State permit requirements.

This discovery or notification scheme is depicted in Fig. 1 and examples of records necessary to document the discovery or notification are included in the flow. In the case of a compliance investigation, documentation of a release may be presented in local, State or Federal compliance inspection reports or in reports prepared by owner/operators of facilities. Accompanying the investigative report may be the results of chemical analyses and an analytical report describing the constituents of the waste. The investigative report may also include a statement on the toxicity of the waste and its association with the site. Of course photographs of the site and its conditions are a vital record to document a release.

Documentation of random observations may include records such as telephone conversations, correspondence from facility employees or private citizens, private photographs, and inventory records. These random observations will need to be corroborated by evidence provided by an appropriate governmental agency or the respondent.

Notification under section 103(a) of CERCLA would normally be documented by a telephone record at the NRC and record of conveyance of the information to appropriate governmental agencies. Notification under section 103(c) would normally be by a written report submitted by the owner or operator of the facility. It should describe the existence of the facility that is or has stored, treated or disposed of a hazardous substance.

Notification may also come from a Federal or State permit holder as a compliance requirement of the permittee to notify the appropriate governmental agency of the release of a hazardous substance. This normally will be in the form of a specified, periodic report or an immediate telephone call followed by a report submitted to the appropriate governmental agency.

Once discovery and notification documents have been compiled, a decision will be made as to whether further investigation of the release of a hazardous substance is needed. Reports from the NRC,

the On Scene Coordinator, and investigative agencies will be used to make that decision.

The next phase assesses the data compiled during discovery, defines additional data needs, identifies the responsible party and determines whether a response action is necessary.

## PHASE II—PRELIMINARY ASSESSMENT

The preliminary assessment will be based on information collected during data and record reviews, investigations and inspections. The assessment depicted in Fig. 2 is designed to evaluate the magnitude of the hazard, identify the source and nature of the release, identify the responsible party, and evaluate whether immediate response action is necessary. Additional information may be needed to complete the assessment, and data gaps will be identified and filled during this phase.

In order to evaluate the magnitude of the hazard, documentation of management practices employed at the site, literature searches on the physical and chemical properties of the hazardous substance, their toxicological characteristics, and demographic or ecological data on areas adjacent to the site are necessary. To augment these data, interpretation of historical aerial photographs and results of on-site and off-site inspections are desirable.

To further focus the assessment, an evaluation of the source and nature of the release will be necessary. Field notes, photographs of the site, hydrogeological reports, environmental samples and laboratory analyses will all be valuable. Witness accounts from employees, private citizens and even owners or operators recorded as signed statements or affidavits will aid in the evaluation of the conditions at the site that might have led to a release. In the event of an off-site spill, sample results correlated with available inventory records, bills of lading or manifests will document that the hazardous substance originated at the site. It should be emphasized that collection of this information will be initiated immediately when a response action is anticipated. Photographs before, during, and after the response action will be desirable to describe the course and results of the response action.

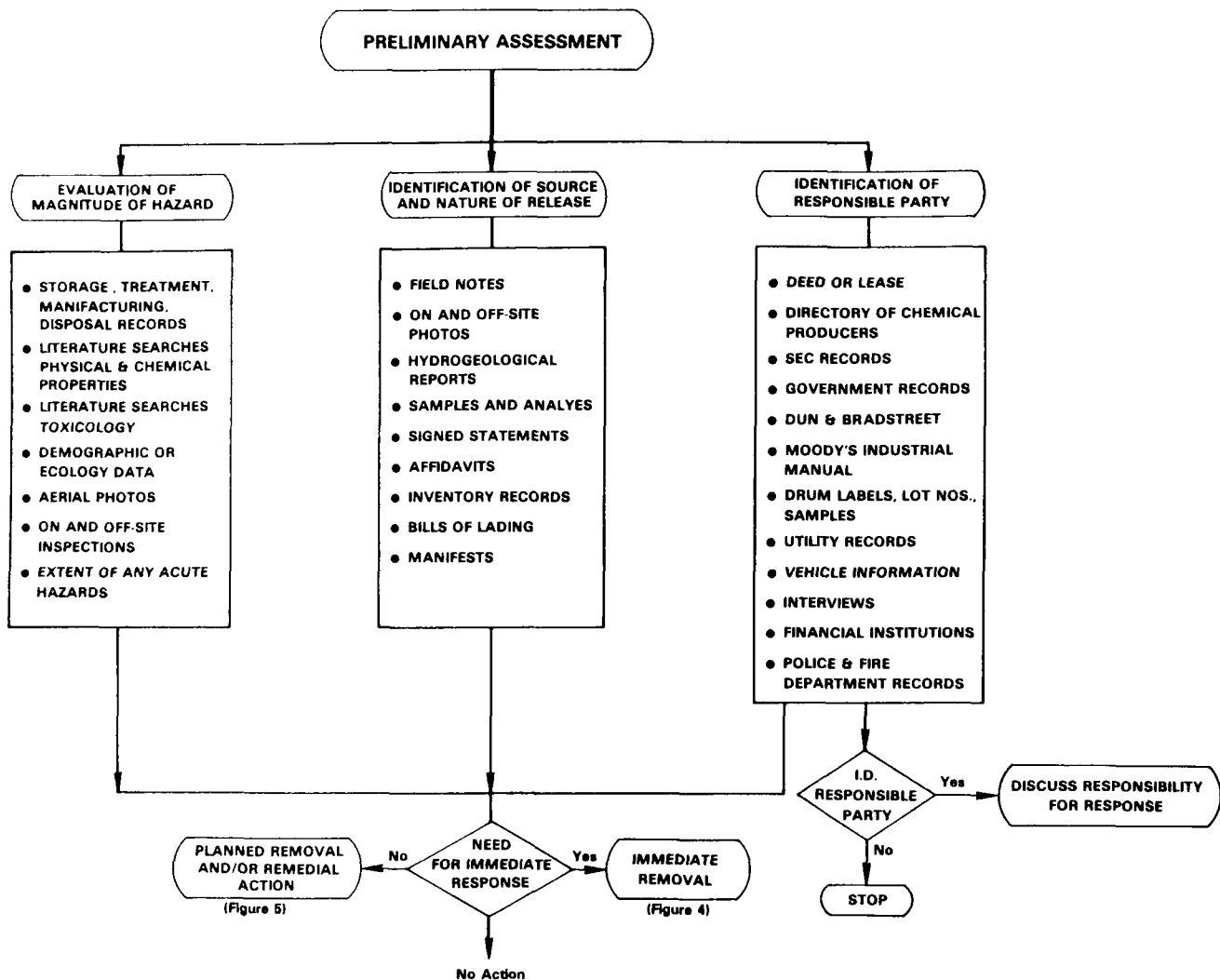


Figure 2.  
Preliminary Assessment

An example of the detailed evaluation employed at each step in the preliminary assessment phase of a cost recovery action is depicted in Fig. 3. In this figure, the flow and documentation necessary to identify a responsible party are shown.<sup>4</sup> To establish the link between a responsible party and the site, legal documents of public record such as a deed or lease are needed.

In order to fully explore identification of a responsible party, information searches may be conducted to determine the type of industrial production, ownership details, and financial solvency. Field investigations, both on-site and off-site, may help to identify the responsible party. Such investigations serve to identify responsible parties through observations such as drum labels, inventory records, samples showing a "fingerprint" of hazardous substances associated with a particular firm, utility records, vehicle identification data, interviews with nearby residents or employees, interviews with local industry competitors, leaders or public officials, banks and mortgage loan firms, incident report records from local police and fire stations, and other local sources.

Evaluation of the documented information collected during the preliminary assessment phase will lead to a decision as to whether immediate response action is necessary due to acute situations, or whether planned removal, remedial action, or no action is required. Some factors to be considered in acute situations include contamination of the food chain, contamination of drinking water, and fire and/or explosion hazards. Documentation of exposure to food chain plants, animals and/or humans may be provided by assessment reports that evaluate the chemical concentrations of the

hazardous substance in various environmental media. Fire and/or explosion hazards may be documented by reference to appropriate scientific or technical literature and by field tests or observations for such characteristics as flash points and the proximity of incompatible wastes.

### PHASE III—IMMEDIATE REMOVAL

If an immediate response action, outlined Fig. 4 is necessary, the third phase of documentation begins. Engineering and scientific planning documents and reports will be compiled to outline the immediate responses considered and estimated costs. Technical documents that describe the actions chosen such as alternative water supplies, limiting access to the site, controlling the source of release, and moving the hazardous substance off-site are needed. Claims for costs will include receipts for money paid for goods and services, cancelled checks, contracts and any amendments, purchase orders, invoices, records of time spent and hourly rates, travel records and vouchers, records of all correspondence or communication regarding actual costs, and work progress reports themselves.

### PHASE IV—EVALUATION OF PLANNED REMOVAL OR REMEDIAL ACTION

During this phase of the response action and documentation for cost recovery, a determination is made of the appropriate response action needed in light of the information outlined in Fig. 5. Records documenting such a decision include State cooperative

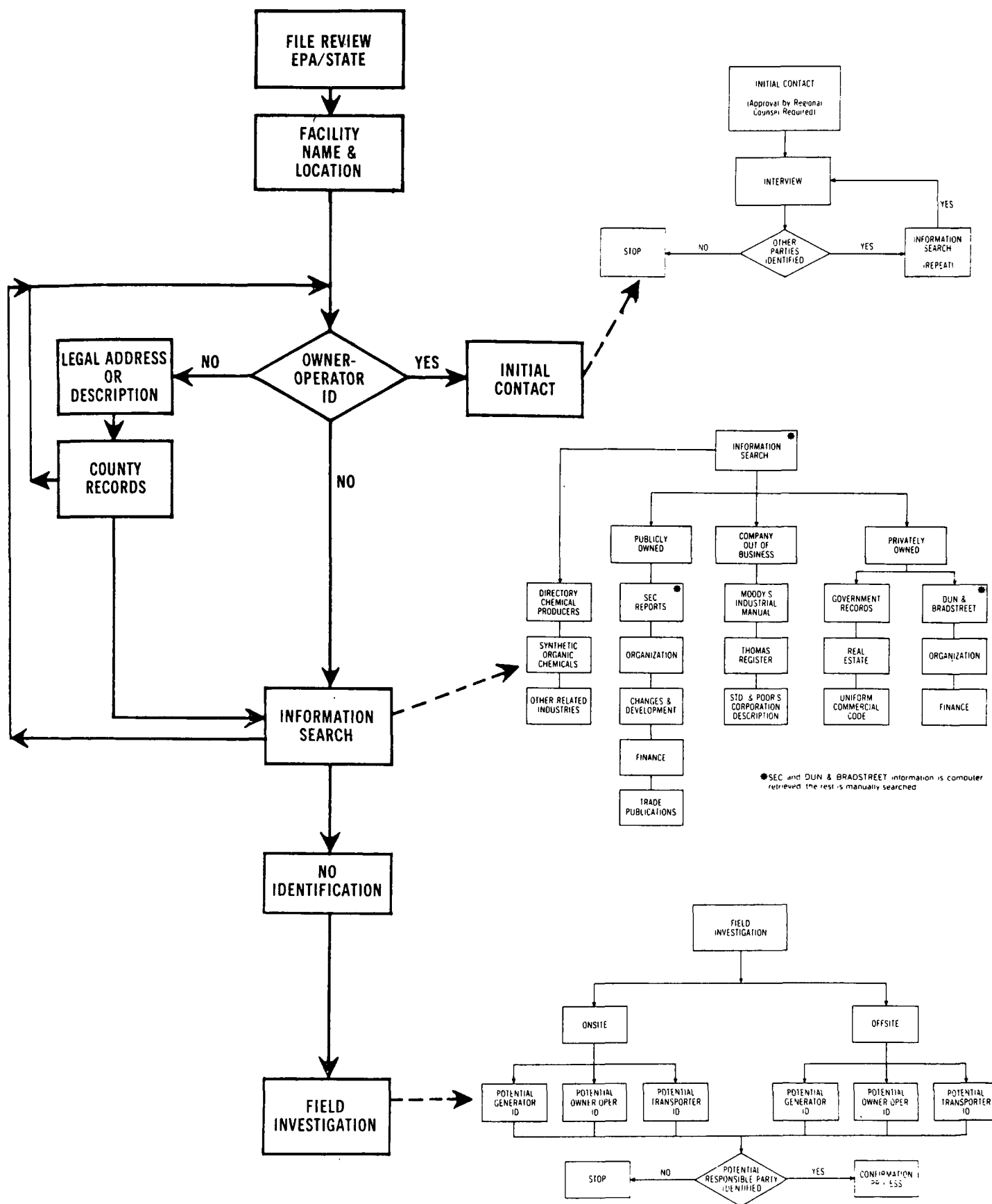


Figure 3.  
Procedure to Identify Responsible Parties<sup>4</sup>

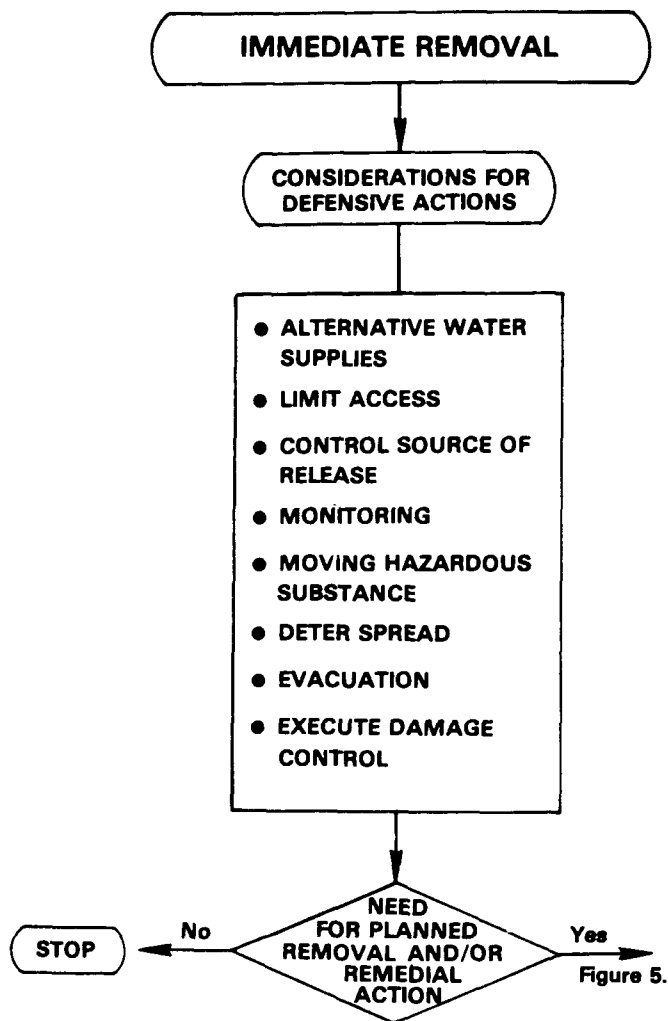


Figure 4.  
Immediate Removal

agreements, contract documents with contractors, USEPA action memoranda, and feasibility studies. Estimates of costs of response will be outlined in such documents.

The NCP indicates that "an inspection will be undertaken to assess the nature and extent of the release and to assist in determining the priority for fund-financed response". In accordance with section 104(b) and (e) of CERCLA, Federal and State officials may conduct such an inspection to investigate, monitor, survey, test and conduct other information gathering. The record of this inspection should clearly document the confidence in the data collected by outlining the quality assurance and quality control used in collecting and evaluating the data. Documentation of such information as analytical detection and quantitation limits as well as precision and accuracy limits should be expressed. During this inspection, particular attention should also be paid to situations which may represent an immediate danger to persons living or working near the site.

The documentation of the decision to use a particular response action must be in accordance with provisions of the NCP; that is, the action must be a cost effective response, and the decision to use a particular response action must be balanced between the need for protection and availability of the fund to respond to other sites. Such decisions are currently documented in "record of decision" memoranda. Supporting documentation is also needed. Supporting documentation may come from records collected by the Hazard Ranking System used to set priorities for use of the CERCLA fund. Documentation and preservation of evidence is critical during this phase.

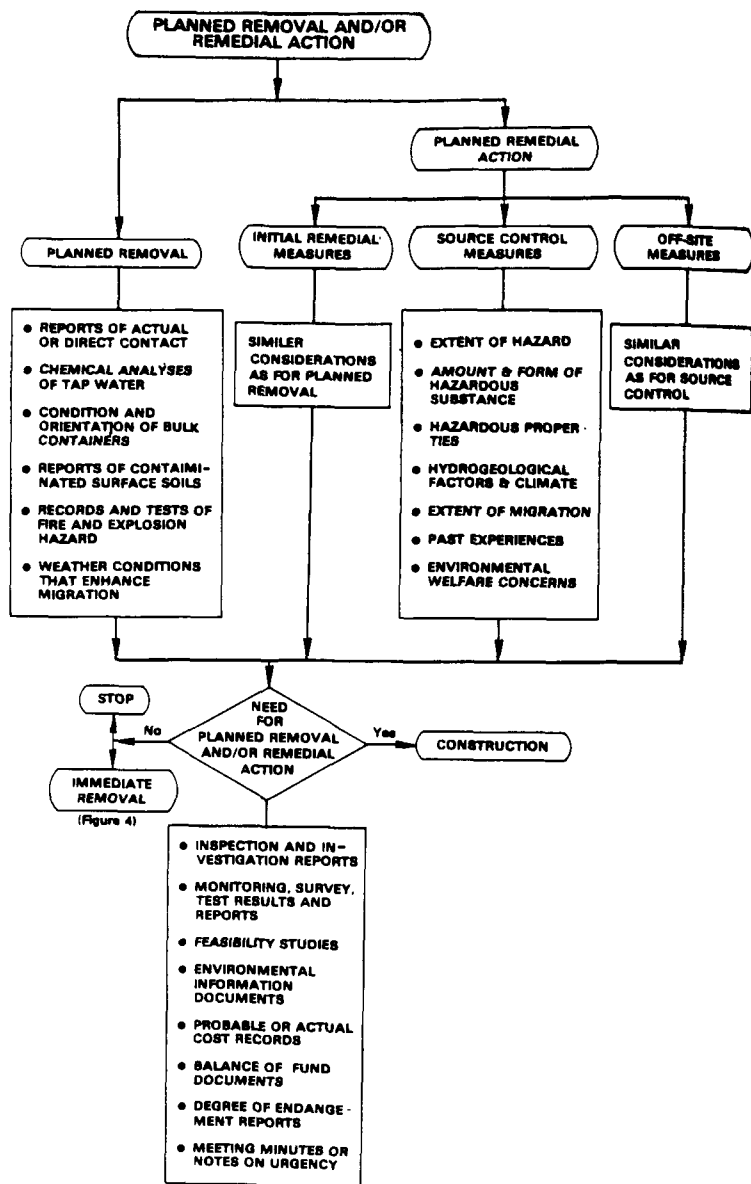


Figure 5.  
Planned Removal and/or Planned Remedial Action

Documentation must be compiled to show that the action was within the category of those permitted by sections 101(23) and (24) of CERCLA defining removal and remedial actions, respectively. The documents must show that the action was not inconsistent with the NCP is performed by a governmental agency or was consistent with the NCP is performed by a third party. The documents must show that the action was a cost effective response. Supporting documents include environmental information documents prepared by contractors which describe the technical feasibility for various remedial approaches and the probable costs associated with those approaches. Other documents include the actual use and costs of similar response actions at other sites, and the balance of the fund in light of these other response actions.

The degree of endangerment and the imminence or urgency of a release need to be documented in order to justify the response action. Expenditures for this phase, including costs, bills and contractor tasks for inspections and response design must also be documented. These studies, reports, letters, memoranda, notes, and meeting minutes will provide documentation for this phase as well as the response actions for planned removals and/or planned remedial action.

## PHASE V—PLANNED REMOVAL

Planned removal is not unlike the immediate removal phase from the standpoint of the documentation that is compiled to justify the cost recovery action. Several records necessary to justify a planned removal include: documentation of the threat of direct contact with hazardous substances by a nearby population, chemical analyses showing contaminated drinking water at the tap, photographs, chemical analyses, and inventories of hazardous substances in bulk containers that are in such condition and orientation to pose a serious threat, chemical analyses, photographs, and reports that document the existence of contaminated surface soils that pose a threat to the public health, welfare or environment, records and tests that document a serious threat of fire or explosion, and, description of weather conditions that may enhance migration of the hazardous substances. These facts will be documented by the cost and scientific/engineering records.

As during the immediate removal phase, documentation of the action taken and the costs associated with the action need to be compiled. Documents involving the planning, legal, fiscal, economic, engineering, architectural, and other studies or investigations necessary or appropriate to plan, direct, conduct, and enforce the response action are needed.

## PHASE VI—REMEDIAL ACTION

Remedial actions are those consistent with permanent remedy that are taken instead of or in addition to removal actions. The purpose of the remedial action is to prevent, minimize or mitigate the release of a hazardous substance into the environment so that it does not migrate to cause a hazard to present or future public health, welfare or the environment.

During this phase, documentation will be compiled that assesses a limited number of alternative remedial measures and investigates the feasibility of employing those measures. Three major types of remedial measures will be considered; initial remedial measures, source control measures, and off-site measures.

An investigation may be initiated to gather the facts outlined under each major type of planned remedial action. This investigation will seek to assess whether the release can be controlled at or near the source or whether off-site remedies will also be necessary. A feasibility study outlining alternative approaches will be developed. This study will assess the costs of each alternative, the effects of the alternatives, and the availability of acceptable engineering practices to achieve the desired results.

Documentation for initial remedial measures track those that have been discussed previously for an immediate or planned removal. Documentation of the consideration of such measures as drainage ditches for effective drainage control, an alternative water supply to eliminate contaminated tap water, capping or excavation, and drum removal needs to be compiled.

Source control remedial measures will be required if inadequate barriers exist to retard migration of a hazardous substance from where they were originally located. Off-site measures may be required when the hazardous substances have migrated beyond the area where the substance was originally located. Considerations that need to be documented include: the extent of hazard which encompasses risk to the population, amount and form of the hazardous substances, hazardous properties, hydrogeological factors, and climate; extent of migration or natural containment; historical experiences with the remedial measures at other sites; and, environmental effects and welfare concerns.

## CONCLUSIONS

Documentation for the various phases of the response and parallel cost recovery action must be compiled at each step or phase of the action. The overwhelming number of documents discussed in this paper can not be effectively compiled at the end of the response action in preparation for a cost recovery action. Documents are lost, and memories lapse. The site file must be compiled sequentially in order to provide efficient document control. Use of the management system outlined in this paper will provide for effective document control in support of a cost recovery action under CERCLA.

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# DEVELOPMENT OF A FRAMEWORK FOR EVALUATING COST-EFFECTIVENESS OF REMEDIAL ACTIONS AT UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Many uncontrolled hazardous waste sites across the nation are currently being "cleaned up" or are slated for remedial action implementation in the near future. Some of these remedial actions are being funded by the parties responsible for the site, some by state governments, and others by the federal government under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

An initial step in any remedial action plan at hazardous waste sites is identification of potential remedial alternatives, followed by the selection of the most appropriate one. The formality required in this identification/selection phase may be dependent on the source of funding for the remedial action. For example, CERCLA requires that remedial action conducted using Superfund monies be demonstrated to be the cost-effective alternative that adequately protects human health and the environment. Whether state agencies or private contractors use a cost-effectiveness assessment *per se*, some procedure is necessary to select the most appropriate plan from a list of potential alternatives.

Radian Corporation, under contract to USEPA's Municipal Environmental Research Laboratory in Cincinnati, Ohio, is developing a methodology for assessing cost-effectiveness of remedial action alternatives. The project, initiated in June 1982, will be completed in early 1983. In this paper, the authors discuss progress to date and current thinking relative to methodology development. At completion, the project will provide a convenient, accurate and readily implemented methodology for conducting cost-effectiveness assessments that can be used by regulatory agencies, decision-makers, and others involved in remedial action selection.

In the first part of this paper, the authors discuss the concepts related to cost-effectiveness and their applicability to assessment of remedial action alternatives. After reviewing these concepts, the development of a specific methodology for systematic, accurate assessments of potential remedial action plans is outlined.

In developing a methodology for assessing cost-effectiveness, the objectives and criteria which must be met should be well defined. One major purpose of the cost-effectiveness framework is to promote consistency in decision-making while maintaining applicability to widely varying situations. The methodology must be simple to apply, requiring only minimal instructions on its use. In this regard, the analysis should be based on the smallest possible number of independent variables that address all relevant concerns. Because of the nature of the problem at uncontrolled hazardous waste sites, the methodology must not be dependent on large amounts of information, either on site conditions or on the remedial alternatives being considered. However, the method must readily allow for consideration of newly obtained information if it becomes available. In addition, it should not be overly quantitative or impose a precision on the analysis that is inconsistent with the degree of knowledge about the problem or expected results. Finally, the methodology should incorporate a means for deter-

mining the sensitivity of the analysis to judgements made in applying it.

## RELATED APPROACHES

Risk assessment, cost/benefit analysis, cost-effectiveness analysis, decision tree analysis, trade-off matrices, and sensitivity analysis have all been applied to various types of alternatives evaluation, including assessment of environmental controls. Certain elements of these evaluation techniques may be applicable to cost-effectiveness assessments of remedial action plans, and they are characterized below.

However, systematic assessment of remedial action alternatives for uncontrolled hazardous waste sites presents challenges which are not characteristic of other applications of these analytical approaches. Probably the most significant of these challenges is the lack of a well-defined clean-up objective by which the remedial alternatives can be compared on a consistent basis. USEPA defines the cost-effective alternative as "the lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare, or the environment". Although this guidance promotes consideration on sites on a case-by-case basis, it does little to pinpoint what will be considered an acceptable level of cleanup. Further complicating the evaluation is the fact that the ability to predict the expected results of a particular alternative is limited by several factors including:

- lack of information on waste characteristics
- lack of information on the physical system
- lack of knowledge of long-term performance of remedial technologies
- inability to quantify expected results

Remedial alternatives may have widely varying timeframes over which they are functional, and, in many cases, this timeframe may be unknown due to a lack of experience with some technologies. Finally, cost-effectiveness evaluation of remedial alternatives must incorporate a number of factors which are subjective, difficult to quantify and for which a common metric, such as dollars, cannot be established.

## Risk Assessment

A risk assessment involves the definition of the risks to the environment and human health of continued pollution from the site. The most inexpensive remedial action that reduces the risk to an acceptable level could be considered the most cost-effective. Techniques similar to risk assessments have been used in the regulation of pesticides and food additives.

The use of risk assessments for assessing the cost-effectiveness of remedial action alternatives would be a straightforward technique if risk levels to the environment and populace could be determined quantitatively for the remedial actions under consideration. For example, if a risk assessment were being used to assess cost-effectiveness of remedial action alternatives at a site contain-

ing PCBs, the levels of risk to human health (or to a receptor population) associated with differing levels of emission of PCB-contaminated leachate would have to be estimated for the alternatives being considered.

One alternative for remedial action at the site might involve containment of the site using a slurry wall, whereas another might consist of extraction wells to intercept the contaminated plume. An estimate of the levels of leachate emission from the two techniques would be required as a first step in a risk assessment. The slurry wall would allow some leachate to enter the environment, and the extraction wells might not intercept all of the contaminated flow. The level of emission and its characteristics, the size and characteristics of the receptor population, pollutant pathways, the types of harm the leachate might do, the probability the leachate will cause that harm, and the consequences of that harm are all estimates that would be required to conduct a formal risk assessment.

Although one might infer, from the previous discussion, that release of contaminants from a disposal site and the resulting consequences are caused by a single event, this is not necessarily the situation. Often a series of events will lead to the release, exposure and impact of emissions from a site. To fully characterize this series of events, a decision or event tree may be necessary. The probability of occurrence of each event, the exposure to any release from that event, and the impacts of that exposure must all be identified. Thus, a risk assessment of an alternative remedial action would actually involve the identification of several emission release scenarios and an assessment of each one.

The costs associated with each remedial action would then be calculated and the action with the highest *acceptable* risk and the lowest cost would be considered the most cost-effective. Unfortunately, the use of risk assessments has several disadvantages including:

- Detailed information about the probability of release of emissions, the quantities of emissions, characteristics of emissions, effects of emissions on population-at-risk, size of population-at-risk, characteristics of population-at-risk, etc. must be known so that a formal risk assessment can be conducted; or many assumptions must be made to fill in data gaps.
- Developing the data or making assumptions and conducting the formal risk assessment is time-consuming and requires extensive knowledge by the decision-maker of risk assessment techniques and the functional relationship between the probability of a negative consequence and the value of that consequence.
- Someone must identify and quantify the highest acceptable risk. (Which may be difficult for a public agency in that it is similar to placing a value on human life.)

If a series of assumptions is required to fill data gaps so that a formal risk assessment can be conducted, it is important to have a sensitivity analysis for documenting how changes in those assumptions affect the overall cost-effectiveness rankings. Because of the nature of formal risk assessments, the conduct of such an analysis would be tedious.

### Cost Benefit Analysis

Cost/benefit analysis involves the identification of all consequences of an action so that comparisons between its costs and benefits can be made. It is most often used as a tool for allocating public and private expenditures. In classic cost/benefit analysis, a project is considered appropriate if its benefits are equal to or greater than its costs. In order to make that judgement, all positive and negative consequences of an action must be identified, measured and translated into a common standard of measure, usually dollars. The remedial action alternative with the lowest cost/benefit ratio, or the greatest difference between benefits and costs could be considered the most cost-effective.

A distinctive trait of cost/benefit analyses is the fact that they can be conducted on a single alternative, independent of any other alternatives. A true cost-effectiveness analysis assesses alternatives in relation to each other, such that it is meaningless to conduct a

cost-effectiveness analysis on one remedial action plan. The use of a technique similar to a cost/benefit analysis would be burdensome because of the necessity to identify and assign dollar values to all consequences of each action. For example, there will be benefits that accrue because of the remedial action, such as reduced health risk to the adjacent population, for which assigning accurate dollar values would be extremely difficult.

### Cost-Effectiveness Analysis

Cost-effectiveness analyses discussed in this section are related to the studies done to develop New Source Performance Standards for reduction of pollutants in air emissions, and wastewater discharges. This type of cost-effectiveness assessment can be considered a modification of cost/benefit analysis. It usually compares the costs of alternatives with some measure of their benefits. The alternative that produces the most benefit for a given cost, or produces a desired benefit for the lowest cost is considered most cost-effective.

In environmental applications, cost-effectiveness assessments have typically been concerned with situations in which alternative treatment scenarios for a given waste stream (either air or water) were being assessed. In these cases, the timeframe for needed treatment, the waste stream characteristics, and the amount of pollutant to be removed was the same for all alternatives. Estimates of the amount of pollutant removed by each of the alternatives and the associated capital and operating costs can be made readily. With those estimates available, it is a relatively simple matter to express cost-effectiveness as the dollars required to remove a pound of pollutant, or the dollars required to treat a volume of waste stream. Selection of the most cost-effective alternative is then a straightforward matter of identifying the alternative with the minimum cost for pound of pollutant removed or volume of waste stream treated.

For most situations involving uncontrolled disposal sites, the timeframe of the various remedial action alternatives functionality may not be the same. Furthermore, for many of the alternatives there may be no treatment *per se*, it may be difficult to quantify the amount of pollutant that is being emitted to the environment, or the volume of waste stream to be treated. These obstacles make it difficult to apply cost-effectiveness analysis involving calculation of cost per pound of pollutant removed or volume of waste stream treated to analysis of uncontrolled disposal sites.

### Trade-Off Matrix

A fourth technique for comparing alternatives and identifying cost-effective options is the trade-off matrix. It has been used by many different disciplines in various industrial and governmental applications. In this method, various alternatives are rated against each other relative to various measures of effectiveness or cost. These ratings are made by the evaluator or a team of evaluators. If the team of evaluators is used (for assessing remedial alternatives, this team may consist of the individual responsible for the preparation of the cost-effectiveness assessment plus associates with expertise in hydrogeology, civil engineering, environmental engineering, public health, etc.), then it is probably most appropriate to use a method of obtaining and refining judgments required from a group, such as the Delphi technique.

The use of a team of experts is particularly valuable when dealing with situations in which exact knowledge is not available and, therefore, professional judgments are needed. Use of the technique usually involves acquiring responses from the team members (in this case rating of the various alternatives relative to effectiveness) and the compilation of a single response from the group responses. A step that sometimes is inserted between the two mentioned above is that of an interaction or feedback step. The feedback step may occur after the team leader or head evaluator reviews the inputs and decides that a particular input is inconsistent, unexpected, or an extreme value. Consultation among the evaluation team is carried out to clarify the situation and establish whether that individual had a special insight that would be valuable to share with the entire team.

The single response compiled from group responses can take the form of identifying the median or the mean of the responses. The median is closer to the true parameter than at least half of the individual estimates, whereas use of the mean places greater emphasis on extreme estimates.

### Sensitivity Analysis

Regardless of the methodology selected for use in cost-effectiveness analyses for disposal site remedial action plans, the results

of the assessment will be subject to criticism. An important consideration, therefore, when selecting a methodology, is the ease with which sensitivity analysis can be carried out to account for uncertainty or judgments made in the process. Any methodology developed will require that judgments be made. A well conceived methodology/sensitivity analysis combination can quickly assess the effect of changing any of the judgments on the overall cost-effectiveness ranking of the remedial action alternatives being considered.

Disposal Site Remedial Action Plans, the Results																	
Alternatives	Weighting Factors	Cost Ratings				Generic Effectiveness Measures				Site-Specific Effectiveness Measures							
		Construction	Operation & Maintenance	Other	Σ Cost Ratings	Level of Cleanup/ Isolation Achievable	Time to Achieve Clean-up/Isolation	Technology Status	Usability of Land After Action	Capability of Action to Minimize Community Impacts During Implementation	Capability of Action to Minimize Adverse Health & Environmental Impacts During Implementation	Risk of Failure	Impact of Failure	Ability to Minimize Impact on Adjacent Residents	Usability of Downstream Lake After Action	Σ Effectiveness Ratings	
Encompassing Slurry Wall with Cap																	
Downgradient Slurry Wall with Extraction Wells, Treat with Carbon																	
Extraction Wells, Treat with Carbon																	
Extraction Wells, Treat with Biox																	
		Σ Effectiveness Ratings				Σ Effectiveness Ratings				Σ Effectiveness Ratings							
		Σ Cost Ratings				Σ Effectiveness Ratings				Σ Cost Ratings							

## Methodology Framework

Based on an examination of the advantages and limitations of the techniques described above, some form of trade-off matrix approach appears to offer the best means of addressing the objectives and problems associated with evaluation of cost-effectiveness of remedial alternatives at uncontrolled hazardous waste sites. One advantage of the technique is the fact that the trade-off matrix approach requires the least "reeducation" of the evaluator, because it requires only that he rate various alternatives based on his knowledge of the situation.

The trade-off matrix, completed by a team of experts and in conjunction with a sensitivity analysis, is the methodology that appears best overcomes the disadvantages inherent in the other techniques. It is as useable for situations in which few data are available as in cases where extensive background data exist. In fact, it can be used at more than one point in the project to update assessments as more data become available. For example, if new information becomes available which would change some ratings in the matrix, the rankings of alternatives can be easily re-evaluated to measure the sensitivity of the rankings to those changes. Finally, the technique does not require that a common measure be placed on all benefits, so that in essence a comparison of "apples" and "oranges" can be made based on experts' judgments.

## METHODOLOGY FRAMEWORK

In developing a trade-off matrix for cost-effectiveness evaluation of remedial alternatives, the elements of the matrix must be selected carefully in order to ensure that the evaluation considers all relevant concerns. However, equal care must be taken to avoid selection of evaluation criteria that are not independent, such that a specific consideration can affect ratings for several of the criteria, possibly creating a significant bias in the analysis. The matrix should include both cost and "effectiveness" measures against which each of the alternatives under consideration can be rated or scored. An example of a trade-off matrix that might be used in assessing cost-effectiveness of remedial alternatives is given in Table 1.

### Cost Measures

Evaluation of remedial action alternatives at most sites will be conducted before detailed design information or cost data are available. However, because of the importance of cost in the evaluation, it is necessary to develop cost estimates of sufficient accuracy for comparison of alternatives. The trade-off matrix includes construction cost and operation and maintenance costs as separate evaluation criteria.

In addition, other cost factors can be considered if site-specific considerations warrant. For example, in some cases it may be appropriate to include consideration of the effect on property values as a measure of cost of various alternatives.

### Generic Effectiveness Measures

Certain criteria for assessing "effectiveness" of a remedial plan can be considered applicable to the large majority of situations. These generic effectiveness measures are identified in the example trade-off matrix. These measures have been selected to address the range of concerns which must be considered in selecting a remedial plan, including:

- How clean will the site be after completion?
- How long will cleanup take?
- How well will the remedial action reduce health and environmental impacts?
- What are the impacts of performing the remedial action?
- Can the site be used after cleanup?
- Is the technology proven and feasible?
- What is the risk of failure?
- What would be the impacts of failure?

A cost-effectiveness assessment can be performed for most sites using only these cost and generic effectiveness measures. How-

ever, the methodology is designed to allow incorporation of additional criteria to address specific conditions dictated by a particular case.

### Site-Specific Effectiveness Measures

In certain cases, there may be factors dictated by conditions or clean-up objectives unique to a specific site which are considered significant enough to be used as distinct effectiveness measures. For example, if a waste site has resulted in severe impacts to a downstream lake and cleanup of the lake is considered to be a major objective of the remedial action, the degree to which the alternatives mitigate impacts to the lake may be added as a measure of effectiveness. This measure may be used in addition to the generic factors or may substitute for one or more of them.

### Weighting Factors

The trade-off matrix technique enables the user to conveniently account for the fact that some measures of effectiveness are more important than others. This can be done through the use of weighting factors that are applied to each of the measures of effectiveness. These weighting factors typically range from 0.1 to 1.0 and will be multiplied by the ratings that each alternative has relative to each measure of effectiveness.

## EVALUATION PROCEDURE

There are several distinct steps involved in conducting the cost-effectiveness assessment using the method outlined above. These steps are:

### 1. Compile background data on the site.

The first effort for any assessment of remedial actions involves collecting information about the site. This information should include descriptions of the types and volumes of waste disposed, geologic aspects of the site (e.g., depth to groundwater, soil types, lithology and depth to confining stratus), and any other data that may exist. This information will be needed when defining appropriate remedial action alternatives and in building a data base to aid in judging the effectiveness of the alternatives.

### 2. Identify appropriate remedial actions.

Based on the outputs of Step 1, viable remedial action alternatives are identified. There is a possibility that some or most of these alternatives will have been defined before the evaluator becomes involved in the assessment process.

### 3. Identify appropriate measures of effectiveness.

The measures against which the various alternatives will be assessed are then selected by the evaluator. The generic measures, because of their nature, will probably be identified for the evaluator. The site-specific measures will depend on the site characteristics, waste type, surrounding environment, and alternatives being considered.

### 4. Assign weighting factors.

The relative significance of all the measures of cost and effectiveness is established, typically by a consensus of the evaluators. Appropriate weighting factors are then assigned to the various measures to reflect their importance.

### 5. Rate alternatives.

Each alternative is rated (e.g., 1 to 5) relative to its ability to satisfy each measure of effectiveness. The evaluators will depend primarily on their expertise and knowledge of the situation to make appropriate judgments. Additional technical information can be provided to the evaluation team prior to the rating exercise.

### 6. Calculate final ratings.

The final rating for each measure of effectiveness for each alternative is then calculated by multiplying the ratings by the appropriate weighting factor. This step enables the evaluator to factor the relative importance of the various measures of effectiveness into the analysis.

### 7. Sum the final ratings for each alternative.

The sum of all the effectiveness ratings for each alternative is calculated. This step involves summing all the final ratings in a row, each row corresponding to a different alternative (Fig. 1).

#### 8. Estimate costs.

The costs for construction, operation and maintenance, and any other identifiable costs, are estimated. These estimates may be developed independently by the evaluator or they may be derived from available engineering studies or standard references.

#### 9. Calculate cost ratings.

Cost ratings are calculated by expressing the cost estimates in millions of dollars (e.g., a cost estimate of \$753,000 has a corresponding cost rating of 0.753). Appropriate weighting factors may be applied as required. Ratings for each cost measure (e.g., construction, and operation and maintenance) should be calculated.

#### 10. Sum the cost ratings.

Cost ratings for each alternative are summed, as was done for the effectiveness ratings.

#### 11. Calculate cost-effectiveness "scores".

The cost-effectiveness "score" for each alternative is calculated by dividing the sum of the effectiveness measures (Step 7) by the sum of the cost ratings (Step 10) for each alternative. The results of this step provide the final overall cost-effectiveness score for each alternative. The alternatives with the highest scores are those that are most cost-effective.

#### 12. Recalculate trade-off matrix to check sensitivity.

There will be instances in which it will be desirable to assess how the overall cost-effectiveness rankings change if certain elements within the trade-off matrix change. A recalculation of the affected scores will give an indication of the sensitivity of those scores to the changes. Elements of the trade-off matrix that may change are costs, individual ratings or weighting factors. These changes may be induced by an increased knowledge on the part of the evaluator or member of the evaluation team, different assumptions, or the investigation of the sensitivity of changes may be necessary to alleviate concerns of members of the public. The use of such a sensitivity analysis to assess the changes in overall cost-effectiveness rankings of the alternatives should be considered an essential element of the methodology.

### Selection of Preferred Alternatives

After all remedial alternatives have been rated by each member of the evaluation team, there are several procedures available to identify the most cost-effective alternative. The mean or median ratings for each effectiveness measure can be identified and then those values summed for each alternative. Or the individual ratings for each member of the evaluating team can be summed, from which the mean or median sums can be determined for each alternative. Either method will result in a composite effectiveness score for each alternative which is then divided by the sum of the cost ratings for each alternative to calculate a composite cost-effectiveness score.

In principle, the alternative with the highest score can be considered most cost-effective. Actually, however, it is probably worthwhile to consider several of the highest-ranking alternatives as equivalent based on cost-effectiveness assessments, particularly if the numerical scores are almost equal.

### CONCLUSIONS

The trade-off matrix offers a flexible but valid approach to cost-effectiveness evaluation of remedial action alternatives at un-

controlled hazardous waste sites. The techniques can be used in widely varying situations but can be tailored to meet site-specific needs. Because of its simplicity, the technique is not so time-consuming as to preclude examination of a relatively large number of alternatives. The approach is easily understood by non-technical persons and does not require extensive evaluator education. By relying heavily on the judgments of experts, the method is not dependent on extensive site data although a good data base undoubtedly improves the confidence level of the evaluation. In addition, the methodology readily allows examination of the sensitivity of the analysis to judgment or assumptions made in the evaluation process.

A possible drawback to this approach to cost-effectiveness evaluation is that the technique is essentially subjective and therefore may be subject to evaluator bias. However, care in selection of the evaluation team and use of the Delphi technique to deal with outliers in the ratings can minimize this problem. In addition, the method is not mathematically rigorous which may affect its credibility in some cases. However, in general the information base and prediction capability supporting decisions about remedial actions are insufficient to warrant rigorous quantitative evaluation.

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# NEGOTIATIONS: THE KEY TO COST SAVINGS

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## INTRODUCTION

The stakes, both legal and financial, are high in a Superfund or hazardous waste study or cleanup project. The consulting engineering profession has long prided itself on its ability to develop sound engineering and technical solutions which are cost-effective. A consulting engineer or scientist often spends days and sometimes weeks in performing calculations and evaluating alternatives to determine the most cost-effective technical solution to a problem. However, the profession has not been as aggressive in sharpening its skills to deal with the public, political figures, and agencies to assure that the investigative studies, work plans and remedies that may be imposed on a client are reasonable and necessary.

The author believes that proper evaluation and negotiation of the scope of technical studies can provide cost savings of the same order of magnitude that a thorough technical evaluation can produce. In this paper, he provides strategies and guidance to assure that a client is properly represented in the negotiations of an acceptable proposal or work plan as well as in the actual technical evaluation of a project.

## Proposed Problem

Assume that a hazardous waste problem or site has been detected. This could be the discovery of an abandoned disposal area or the determination that past industrial practices have created problems at the plant site. Contamination of the environment has been detected and a regulatory agency, either the USEPA or the State Environmental Agency has determined that an engineering evaluation and potential corrective action is necessary. This determination to take action at a particular site may, or may not, have been influenced by the keen interest of a citizen group in the area, and/or the interest and attention of political leaders, at the local, state and perhaps federal levels. Usually, the generator of the waste has been identified, has been notified he is being held responsible and has indicated a desire to conduct reasonable investigations and possibly cleanup activities.

The proposed investigation and potential cleanup will be supervised and finally approved by a government agency. The agency will determine the nature, extent and thoroughness of the assessment, investigation, the need for cleanup, and the type of remedial action to be implemented. The agency will also be responsible for answering the ultimate question associated with site cleanup: "How clean is clean?"

The potential for a classic confrontation now exists. On one side is a government agency that is demanding a proper and complete work plan. An agency which is driven by laws and its own regulations and which must be responsive to political and public pressures. On the other side is a company who recognizes the need for a responsible work plan but is being driven in the opposite direction by costs and other concerns.

Reaching agreement may appear hopeless, but upon careful examination, the situation actually provides a favorable climate for negotiations. An element present that both the governmental agency and the client desire, is an efficient and effective work plan

which solves the problem at hand. The consulting engineer must have the confidence of both parties if he is to build from the common element a study which will meet the needs of his client as well as the agency.

To properly protect a client and to establish a technically adequate program, exclusive of unreasonable requirements, the consulting engineer must understand the regulatory agency, its people, and its pressures, i.e., an agency adopts its own regulations and requirements but the implementation and interpretation of these regulations is accomplished by staff who frequently are motivated by the political community and the public at large. The agency envisions itself as the public's protector and wants to be seen as tough but fair.

In the case study proposed here, the cost for the investigation does not come from the agency's budget and hence there may be a tendency to require more, instead of less, work. Conversely, the client may, with an eye on costs, and perhaps the fear of uncovering damaging information, tend to propose less, instead of more, work. Moreover, in most regulatory agencies, the costs for pursuing litigation often come from departmental budgets outside of the agency or at least a section of the budget not controlled by technical personnel and can be viewed by some as a beneficial option—either as an example to others or as a measure of strength.

Negotiations can only be successful if a common goal exists, i.e. to design a reasonable work plan, and each party respects the other. This may be an oversimplification, but it will be used in this paper. The key to successful negotiation depends, in large part then, not only on the consultant's technical expertise, but also upon his ability to deal with the agency personnel. On the basis of considerable personal experience in government service it is the author's opinion that the general public and consulting engineers, in particular, may tend to stereotype government employees as being difficult to deal with, unreasonable and sometimes unmotivated to solve problems. Some government employees fit that description, but the author's service in government has convinced him the opposite is true. Most government employees are intelligent and motivated; they are interested in solving problems and in seeing positive results; they are motivated by the same issues that move people in the private sector; they are anxious to excel, develop professionally, and to bring about successful solutions to problems. However, frequently they lack hands-on technical experience. Most consultants have extensive experience and therefore must fully utilize this quality.

A hypothetical problem has been presented and the basic qualities of the agency staff who are responsible for its solution have been outlined. Based on this scenario, a procedure to successfully manage the negotiations required for the project will now be developed. Manage is the key word and will be the principal thrust of this paper in which the author assumes that the consulting engineer has all of the basic skills and experience necessary to effect a successful remedy; therefore the author treats the aspects of negotiations rather than the technical details of the solution. It is also assumed that the agency personnel are reasonable and anxious to find an acceptable solution.

Before the consulting engineer can discuss a project with the regulatory agency, he must have the confidence of his client and should be a true partner in the effort to find a solution. He must understand any limits on the client's participation in the project and the latitude given to him to negotiate on the client's behalf. He must also have a sound understanding of the legal liabilities and ramifications of the case.

A five step procedure is proposed for negotiating with the regulatory agency. These steps can represent five separate meetings or can be consolidated into one meeting depending upon the magnitude of the problem and the complexity of the situation. Depending upon the dynamics of the situation, various elements of these steps can be interchanged or omitted. The five basic steps are:

- Preliminary project evaluation
- Initial agency meeting
- Presentation of a proposal
- Reception of agency feedback
- Final negotiations

### PRELIMINARY PROJECT EVALUATION

Before meeting with the agency, the engineer should do as much investigation as possible to assure he has a complete understanding of the site and its history. He must visit the site, review whatever has been written about the site and discuss this information with knowledgeable individuals, both within and outside the company. He should make a preliminary evaluation of the extent of contamination and the potential for off-site migration. It will be useful to understand the nature of the public and political interest in the project and the individuals who are leaders in these efforts. The engineer should also have a sound understanding of the agency's position including the people and the forces which will be directing its decisions. This preliminary evaluation of the problem will form the basis for a meeting with the agency staff.

### INITIAL MEETING

On his first approach to the agency, the consultant should attempt to constrain the discussions to technical issues. He must avoid threats and posturing which would lead the negotiations toward legal, rather than the technical solutions. He must convince the staff that his client is seriously seeking a solution and is willing to accept reasonable requirements.

The engineer, at this meeting, should also present his qualifications to do the work required. This should be done in a positive manner, and in such a way that agency personnel accept his credentials as a measure of experience and competence and not one of arrogance. The engineer should take every opportunity to refer to previous work he has accomplished, and to point out the similarity of past work with the problems at hand. Gaining the agency's confidence at the onset of negotiations is extremely important and must be accomplished in a manner which is not considered threatening to agency staff.

The consultant should solicit as much information as possible. This should include any reports, studies, correspondence or other documentation available as well as any on-site experience agency personnel may have had. He should evaluate the agency's urgency and direction. The engineer should solicit advice and attempt to obtain as clear an understanding as possible of what the agency considers an adequate solution to the problem. If the agency does not articulate a strong position, it may be wise at this time, to allow the staff to be vague to prevent the need for a change of its position later. This meeting is not intended to make final decisions as to what is, or is not, needed for the study. Its basic purpose is to understand the situation, the agency and its people.

### PRESENTATION OF A PROPOSAL

It is extremely important that the presentation of a proposal to the agency by the engineer should be well planned and executed. During this phase, the engineer should reinforce his previous presentations of technical qualifications and competence, again referencing similar successful work.

The proposal should be complete and contain sufficient detail to allow the agency to properly evaluate it. It should include maps, charts, and other visual aids to facilitate understanding and acceptance. The proposal should be structured to provide answers to the questions the agency is asking. An effective way of evaluating the many unknowns of a hazardous waste project is to provide intermediate decisions points so that both the client and agency will have an opportunity to decide, after evaluation of data, whether additional information is required. The program should be constructed so that it builds upon itself and therefore have various stages so that information from each step can either trigger an additional step or allow an activity to cease. The engineer should be prepared to give detailed explanations of his proposal, the technical reasons for each decision and the choices available at each intermediate decision point.

After the presentation there should be time allowed for questions to clarify the engineer's intent. Evaluation and judgment is best delayed, to permit the agency to conduct a comprehensive and thoughtful review. The agency should be given sufficient time for proper review, but a deadline for comments should be established at the onset. The engineer's willingness to clarify points over the telephone should be expressed.

### AGENCY FEEDBACK

After the agency has had an opportunity to carefully review the proposal, a meeting should be arranged to discuss and evaluate the agency's comments. Recommended additions or deletions to the proposal which will not impact technical viability or costs should be quickly accepted and incorporated into the proposal. If the agency drastically alters the proposal, or demands additional costly requirements, the engineer must determine the reasonableness of these modifications.

It is essential that the engineer listen carefully to the reasons given for these changes and show respect and understanding for the agency's position. He should also attempt to evaluate the technical background of the person proposing the change. Skillful handling of this situation can avoid a confrontation, or the need for a face-saving concession. Quiet, objective listening at this point will facilitate the negotiations which must follow. It may be wise to accept the agency's comments for further study and postpone substantial discussion to the negotiation session which is to follow.

### FINAL NEGOTIATIONS

The entire thrust of this meeting is to build cooperation instead of irritation. The engineer must approach the agency with a feeling of confidence in his own abilities and respect for the abilities of agency personnel. Each issue raised by the agency must be addressed. It is frequently beneficial to refer to simple visual aids such as maps, schedules and schematics, to assure that agency personnel have a full understanding of the engineer's plan. The engineer must be certain that he understands why the issue was raised and how deeply committed the individual or agency is to the point. Working on a non-negotiable issue is senseless.

A schedule of issues ranging from the simplest to the most difficult is often advantageous so it may be wise to reorder the agenda so that non-controversial and inexpensive issues are discussed first. This builds understanding and confidence in both the agency staff and engineer in solving problems. It develops a sense of compromise, and allows the engineer to educate agency personnel in areas where technical weaknesses may have been observed.

As these issues are resolved, the engineer should also develop a sensitivity that will allow him to anticipate and address questions and concerns before they are raised. By working from the easiest to the most difficult issues, agency personnel will acquire a better understanding for the sophistication and experience of the engineer. Dangers in ordering the negotiations to address the simplest problems first, include the risk of mounting frustrations on both sides and using up time scheduled for the negotiation ses-



sion before the important issues are addressed. Thus, the engineer should maintain sufficient control over the session to prevent either or these situations from occurring.

In resolving the most important conflicts, care must be taken to assure the agency personnel that their position is worthy of discussion and will not be dismissed out of hand. If major conflicts are identified, the engineer is responsible for presenting his arguments and reasoning in a logical and technically sound manner. Hopefully the basic premise that both sides desire a reasonable, workable, cost-efficient plan, will prevail. If, however, the engineer is unable to convince the agency that his proposal is adequate, then the fall-back position of accomplishing additional work in increments, with intermediate decision points, should be utilized. If possible, objective and measurable criteria for a "go" or "no go" decision should be established at this time.

In summary, to effectively deal with an agency it is necessary that the engineer: know the site, its history, and the problems envisioned by the agency, understand the agency's motivation and the pressures that it is experiencing, understand and respect individual staff members, their needs, experience and motivation, be competent and be thoroughly experienced in the area of discussion, and prepare a plan which recognizes the problem and provides the means to find a solution.

The engineer's proposal should be complete and should include as many of the agency's concerns as are reasonable. The plan of study should be methodical and developed to allow each step to build on the previous steps, thereby allowing the engineer and agency to curtail or abandon investigations which are unnecessary. The plan must provide intermediate decision points to allow agency staff sufficient flexibility to accommodate unknowns.

The strategy described here has been greatly simplified in the interest of time and space. Obviously, there is much more to suc-

cessful negotiation than has been discussed. Any professional person, with the experience and background which qualifies him for such important negotiations, has learned a great deal over the years. He is skilled in anticipating concerns, interpreting people's reactions and body language, and exerting the self-control and discipline needed in any bargaining session.

## CONCLUSIONS

How effective will the scheme described here be? Let me recount a particular situation that I have been involved with.

Perkins Jordan, Inc. was requested by a large industrial firm to represent them at a particular hazardous waste site. The agencies involved had determined that hazardous waste contamination existed, had notified the company it was responsible and had established an overall budget of nearly \$650,000 for the necessary engineering investigation. In following the procedures previously outlined, with emphasis on the collection of available information, the need to become thoroughly familiar with the site, we were able to develop an investigative study to evaluate the situation.

The study was divided into several phases. For Phase I, which had been previously estimated to cost over \$208,000, an investigation, basically using the same rates, but costing less than \$104,000 was proposed. Subsequent negotiations between the engineer and the agency, as described in this paper, resulted in additional work being added to the original proposal, bringing the total cost to approximately \$117,000. The agencies responsible for this project agreed that the proposal, as finally negotiated, was adequate and would fulfill their needs. Though this project did not proceed because of reasons unrelated to those discussed here, it is an excellent example of how sound engineering, skillful proposal preparation and negotiation can produce substantial savings and satisfy the needs of all concerned.



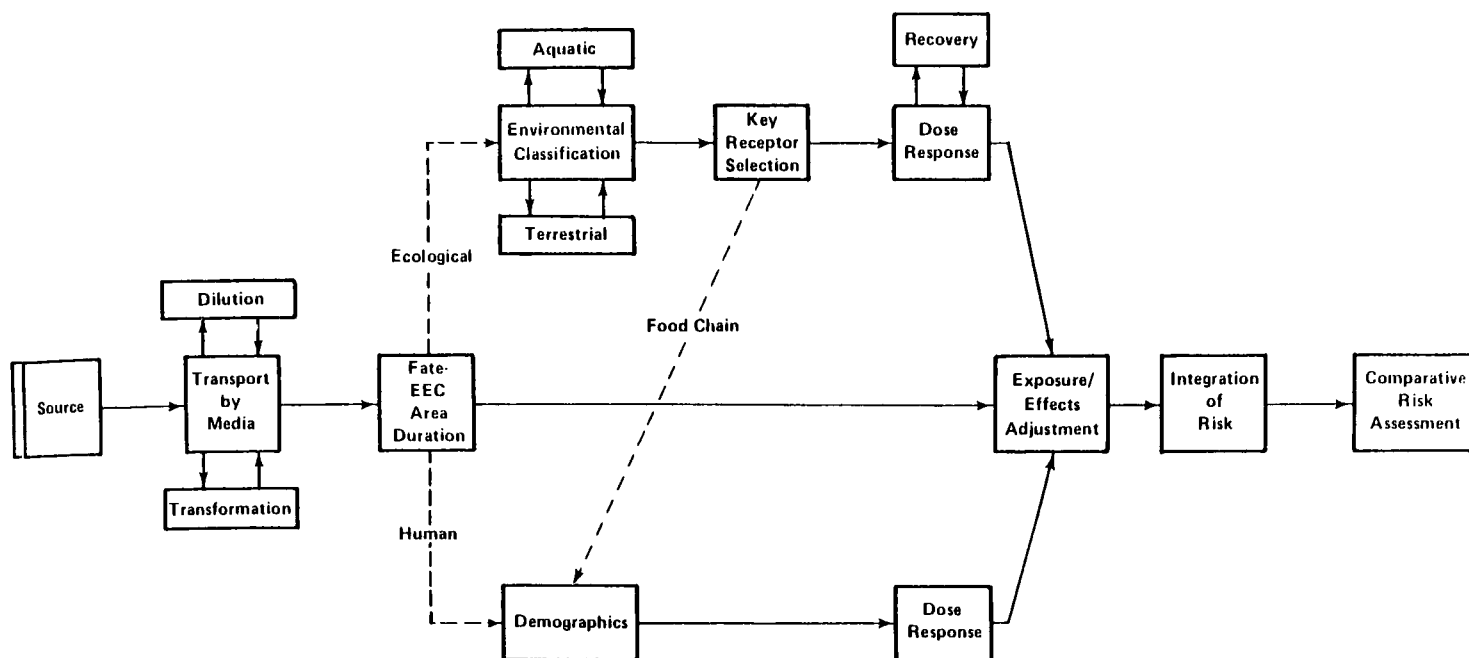


Figure 2.  
Overall Environmental Risk Assessment Scheme

Regarding source, the location, type of release, and rate of release are all important aspects of this characterization. An uncontrolled hazardous waste site in the middle of a large city would present a risk different from the same facility located in a remote forest. The type of release also determines the type of subsequent work that would follow. For example, a situation of an occasional release of a compound of low toxicity dictates an approach different from a situation where highly toxic materials are being released continuously into not only the surface water and air but also the groundwater. Of course, the quality of pollutant and the rate at which it leaves the source are other important aspects of the source characterization.

Pollutant releases from hazardous waste sites can range from those resulting from explosions and accidents to those associated with day-to-day operation and maintenance. Sources can be further classified by size of the site, type of hazardous material, soil characteristics and efficiency of control systems.

The transport or movement of a pollutant from its source through the environment to a receptor can be in the air, water, and/or soil. The pollutant can also move from one medium to another. For example, a pollutant can first be released into and transported by the groundwater, only to be used on land (e.g., irrigation) and subsequently transported back to the groundwater or evaporated into the air. Many of these interactions are discussed in such sources as Horne.<sup>9</sup>

Because hazardous waste sites can result in transport-through-soil problems, the narrative will focus on soil. Transport through soil is the least understood of the three media. Nevertheless, there are processes about which some knowledge is available. These processes are leaching, percolation chemistry, percolation volume and time, groundwater movement, percolation chemistry, percolation volume and time, groundwater movement, percolation mixing, and groundwater chemistry. Models of movement of materials in soil range from the relatively simple to the relatively complex.<sup>7</sup> For example, the least complicated models assume one-dimensional movement relative to a general water table, slope, gradient, and soil permeability whereas the most complicated are time-dependent and use three dimensions. In these models, the soil is organized into spatial and temporal boxes, each with input/output functions.

More research to improve models of material movement in soil and especially to expand our knowledge of the reactivity of pollutants with soil *per se* will result in improved transport models for the soil medium. Bloom *et al.*<sup>1</sup> discuss other transport models.

Another important aspect of transport involves transformation models. Transformation models focus on complex changes in molecules as they move in the environment. These models are more difficult to organize because of the requirement for knowledge about these complex changes in molecules, especially organic molecules. This lack of data (as opposed to lack of mathematical prowess) is a stumbling block, especially for pollutants that interact with carbon-based substrates. The simplest modeling approach to the question of transformation of pollutants is to bypass it, by limiting the model to materials where transformation is not important, e.g., heavy metals. For materials where chemical or other transformation cannot be ignored, the simplest approach is to assume a constant time rate of transformation. If this is not desirable, reliance needs to be placed on complex models which incorporate what is known about transformation. These models can require a considerable amount of information about chemical reaction times and media conditions. Transformation is a difficult step to complete, especially for organic molecules that react with many other substances.

The third step in exposure assessment is the determination of the ultimate fate of the hazardous material. Fate refers to the: (1) final environmental concentration, (2) geographical area exposed, and (3) duration of the exposure for the pollutant(s). The first activity in the fate component is to determine the estimated environmental concentration (EEC) of the chemical at its point of contact with receptors. Knowledge of the amount and volume of chemical being discharged, whether the discharge is point source, and the discharge rate are available from the step on source and must be integrated with information on migration and dilution, removal from original medium to alternate media, and chemical or biochemical transformations.

Two additional aspects of fate are the geographical area exposed and the duration of the exposure. Geographical area means the distribution of the EEC through space while duration means the distribution of the EEC through time. A small geographical area of a

few square meters presents a different problem from an area of many square kilometers. Likewise, duration is an important aspect of the risk assessment process because a one-year exposure could lead to greater environmental degradation than a one-day exposure at a greater concentration.

After the EEC for a pollutant(s) has its spatial and temporal boundaries defined, the fate data can be used as a guide for dose range in the effects assessment element. For example, mercury once transferred from its source and transformed to methyl mercury becomes dangerous to organisms at certain environmental concentrations.<sup>16</sup> Chromium undergoes valence changes and many organic pollutants are transformed as they move through the environment and become more or less toxic.<sup>4</sup> The fate of the pollutant provides clues about the nature, extent, and magnitude of the possible biological effects. But it is the next component—ecological and human effects assessment—where the fate data are used in this way.

### ECOLOGICAL EFFECTS ASSESSMENT

There are three basic steps necessary to evaluate ecological effects of uncontrolled hazardous waste sites: (1) environmental classification, (2) key receptor selection, and (3) dose-response relationship. Each step is completed in proper sequence. The completion of the effects evaluation will result in the inputs needed for the actual quantification of environmental risk of the pollutant(s) of concern. The following narrative defines the variables and discusses the approach for each step in the ecological effects evaluation process.

By knowing the geographical location and areal extent of effluents released from uncontrolled hazardous waste sites, the types of environments exposed can be identified. Within each environment the actual ecosystems (terrestrial and aquatic) affected can also be determined. Classifications for habitats are numerous and are available in the work of Odum.<sup>12,13</sup>

Once the geographical area which will be exposed has been classified into one or more of various types of environments, it is necessary to develop weights for these environments; this will facilitate the integration of risk (a step later in this integrated scheme). The weighting needs to be done from the human-welfare or value-to-man viewpoint. The value of collective ecological attributes of each affected environment is expressed on an appropriate scale. Attributes to be considered in the development of weights include not only agricultural productivity, recreational resources, and commercial fisheries, but also the ability of the system to assimilate and process wastes, protect threatened species, and act as a life-support system for man (e.g., oxygen generation by green plants). Weighting is best accomplished through a review of the specific component ecosystems of each environmental type and the values associated with each component system tallied and then summed.

The components of each environmental type which will be exposed must be identified. In contrast to human risk assessment, which deals with risk to the individual and starts at the population level and worked down to lower levels of organization (e.g., organs, tissues, and cells), ecological risk assessment is concerned with effects to whole populations or organisms and must start at the population level and work up to higher levels. Three basic components of ecological organization are recognized: populations, communities (multiple populations), and ecosystems (communities plus the nonliving environment and the processes such as nutrient cycling which bind them together into a functioning system).

The key receptors for the pollutant of interest must be carefully selected for each aquatic and terrestrial ecosystem. These receptors must be representative of the important components and processes at risk in each system and their importance must be scientifically defensible. Once key member population and communities and ecological processes at risk for each aquatic and terrestrial ecosystem are identified, appropriate indicators of effects to these key

receptors can be chosen. Indicators are used simply because it will likely be impossible to obtain data on all the key receptors within the time and cost constraints imposed by the risk assessment process. In addition, data collection techniques are standardized and validated for a relatively small number of receptors. The use of nonvalidated protocols and populations or processes lacking a good interpretive data base can seriously compromise ecological effects evaluation.

The third step in ecological effects assessment is the dose-response assessment. Dose-response assessment involves the measurement of the change in ecological effect(s) in relation to the change in concentration and duration of the stressor to which the population or process is exposed.

Two basic approaches to dose-response data collection are recognized. The first is the simultaneous approach where a full set of tests are implemented essentially simultaneously on the pollutant(s) of concern. This approach is thorough, usually provides highly reliable results, but is time consuming and expensive, often including redundancy among the test results. A second approach, called the phased or tiered approach, uses a sequence of testing activities rather than simultaneous implementation.<sup>8</sup>

In the phased approach, each subsequent phase is designed using the results of the preceding step. Generally, short-term acute exposures using single-species or process tests are employed at the first tier or phase. These inexpensive procedures can provide a coarse, quick, relative assessment of hazard.<sup>11</sup> The results are used in the design of the next phase of testing with emphasis placed on those indicators in the first phase which showed the highest level of hazard.

The higher levels of testing (Phase 2 and above) generally employ longer duration or chronic exposures and may use multi-species or process techniques. Data collection procedures have four key attributes: (1) type of endpoint, (2) conditions of exposure, (3) complexity of experimental measures, and (4) form of experimentation. The endpoint is the effect that is actually measured in the experiment. Commonly used endpoints include survivability or lethality, reproductive success, rates or products of chemical reactions, growth, and development time.<sup>3</sup>

The objective of dose-response experiment would be to determine how the endpoint changes with increasing concentration of the pollutant. Exposure conditions include both the means and length of exposure. The key receptors may be exposed via their food or through air- or water-borne pathways. They may receive a single dose or a continually renewed dose designed to maintain the concentration of the pollutant constant during the experiment. The duration of the test can be very short or extend to a partial or the full cycle. Multiple generations may also be used.<sup>15</sup>

The complexity of the experimental measure can range from a study of highly controlled single process or study to a highly complex multiple species and process (microcosm) test. The latter tends to be more indicative of real-world effects but is a more complicated test procedure.<sup>17</sup>

Closely related to complexity is the form of experimentation. Laboratory tests are highly controlled and have the best chance of giving unequivocal results, but they are less indicative of real-world conditions and effects than tests conducted in the field. Thus, it is clear that dose-response data collection for ecological effects can vary from laboratory exposure of a simple acute, static single species or process through complex, lengthy field tests. The overall technical approach or philosophy will determine just which procedures are selected and how they are used to define biological effects.

Another important aspect of dose-response assessment is the recovery potential of populations and processes after exposure steps. Populations able to recover rapidly after exposure to a particular stress are subject to less damage overall than populations which are slow to recover or never recover after a similar exposure. Recovery potential data for a population or process has not routinely been measured and no widely accepted protocols exist. Techniques need to be developed to indicate recovery potential.

## Human Effects Assessment

Human risk assessment models are much further developed than ecological risk assessment models. The subjects at risk—humans—are more valuable and important than nonhumans and, therefore, more attention has been given to the development of risk systems for human protection. Human risk assessment models rely on at least three basic types of extrapolations: (1) high-dose-to-low-dose, (2) species-to-species, and (3) acute-to-chronic-effect extrapolations.

The concept of interspecies extrapolation is implicit in both high-dose-to-low-dose and acute-to-chronic-effect extrapolation. The models are usually developed for estimating human risk from animal data; they can, in some instances, be applied to other populations in a general way. However, the concepts, but not the results of human and ecological effects and risk assessments, are comparable at present. The results could be made comparable through improvement of population models and the development of community and ecosystem level risk models. Because the thrust of this paper is on the nonhuman aspects of risk, no further treatment will be given to human effects assessment.

## QUANTIFICATION OF RISK

The third component in the overall risk assessment scheme is the synthesis of environmental fate information with effects data to obtain an overall assessment of risk. This process applies to both human as well as ecological risk assessment and can be broken into three basic steps: (1) exposure/effects adjustment, (2) integration of risk, and (3) relative risk evaluation. Each step successively integrates the data until a single measure results.

The development of the two risk estimates, one for human and the other for ecological, is done in step 1 and the first part of step 2. These two estimates are then combined in the last part of step 2 to give a single integrated risk value. The third and final step (comparative risk assessment) gives perspective to the work through relative comparisons among hazardous waste locations and control alternatives.

The objective of the exposure/effects adjustment step in the risk assessment scheme is to synthesize the dose-response data for each indicator with the environmental fate information. This estimate of the level of effect is modified by the duration of the exposure, the potential for recovery, and the area of the ecosystem or the number of humans actually exposed. The duration of the exposure is a function of the pattern and rate of release to the environment, the rate of movement along the pathways to the target ecosystems or human populations, and the retention of time.

Recovery is the ability of the receptor to either adapt to the level of exposure or return relatively quickly to pre-exposure conditions after cessation of exposure. Ecological populations or processes with short generation times or half-lives can recover more quickly than those with long generation times.<sup>12</sup> For example, planktonic algal populations subject to chemical stressors can often return to pre-exposure levels within days and weeks after the stress ceases. Rooted plants may take significantly longer to recover. A third modifier of the quantitative effect level derived from the dose-response curve is the area exposed. The larger the area of exposure, the greater the magnitude of effect, i.e., a larger proportion of the ecosystem or human population is affected.<sup>13</sup>

The integration of risk involves the synthesis of the individual receptor effect estimates, into a single risk value. The integrated ecological risk value is obtained by summing the risk values of each individual receptor. This sum is then multiplied by the importance value or weight assigned to that particular environmental type. The resulting weighted values are then summed to give the overall ecological risk assessment value for the pollutant and action of concern. The development of the human risk estimate involves a similar activity.

The final step in risk integration is the combining of the human and ecological risk values. This involves summing the two values with the ecological value being multiplied by a 0-1 weighting factor before the addition. This weighting factor is an estimate of the relative importance of ecological risk in reference to human risk. The output of this step of risk assessment is a single fully integrated estimate of risk associated with the action or pollutant of concern.

The relative risk evaluation step culminates the risk assessment scheme. Its objective is to develop overall risk assessment values which can be used directly in the decision-making process. It factors together the risk value and economic costs of each alternative action (including no action) associated with the control and cleanup of a hazardous waste site and permits the comparison of alternatives so the "best" one can be selected. This is, perhaps, the most difficult step in the risk assessment process and the one for which sound, widely acceptable approaches are lacking. However, efforts are underway to develop the formulas or algorithms to solve this step.

## CONCLUSIONS

Risk assessment of uncontrolled hazardous waste sites are incomplete without ecological considerations. Not only could some risk assessments be based totally on nonhuman health issues but results of ecological risk assessments could be used to differentiate between options where there are alternatives of equal or similar health risk. Concepts and techniques for ecological risk assessment lag behind concepts and techniques for human risk assessment. This is especially true for higher levels of biological organization (ecological communities and ecosystems) which are less conceptualized than the population level. The individual (expressed in terms of a population statistic) is the primary element of concern in human risk assessment whereas the population is the lowest level of concern in ecological risk assessment.

Both human and ecological risks have now been put together in a new logical scheme to aid in characterizing uncontrolled hazardous waste sites. This scheme recognizes three interrelated components: exposure assessment, effects assessment (which includes parallel human and ecological effects steps), and quantification of risk. The steps in each of these components has been identified and explained. The actual risk assessment component includes steps that integrate and compare risks to facilitate the decision-making process.

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# EXPOSURE-RESPONSE ANALYSIS FOR SETTING SITE RESTORATION CRITERIA

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## INTRODUCTION

As with most endeavors, the selection and development of remedial action alternatives for site restoration is most productive when targeted for specific environmental objectives. In general, the objective is to reduce associated risks to an acceptable level. The National Contingency Plan speaks of a balanced consideration of risks and cost to select appropriate levels of actions.

Ideally, one would eliminate all risks, but experience has shown that there is no zero risk site. Indeed, prudent observers have noted that risk minimization becomes exceedingly costly at low levels of residual primary risk and may in so doing increase secondary risks associated with producing the resources required for implementing greater degrees of reduction. When residual risk becomes indistinguishable with normal or background risk, the added costs (including the cost of secondary risks) can not be justified. Thus, remedial action assessment is best based on the evaluation of alternatives in the context of acceptable levels of residual risk. This approach is currently phrased in the vernacular as "How clean is clean enough?"

Resolution of the "How clean is clean" question is directed at two elements of the site mitigation process: 1) the designation of those areas within a site which must be addressed, and 2) the selection of mitigation alternatives capable of achieving designated levels of restoration. With respect to the former, one would have to designate a threshold level of contamination such that environmental media (waste, soil, sediments, etc.) containing hazardous residual at that level or greater would be subjected to restoration, while media containing less would be left undisturbed. Only those remedial action alternatives capable of bringing all environmental media below the designated thresholds would be considered for implementation.

## THE EXPOSURE-RESPONSE APPROACH

A method has been developed for the derivation of cleanup criteria using environmental risk assessment techniques in a mode designated as Exposure-Response analysis. This approach was taken recently in a study of the LaBounty Landfill at Charles City, Iowa. The methodology is described here followed by excerpts from the Iowa work to illustrate how the application is accomplished.

The most direct approach to setting restoration goals would be to use existing media criteria. However, no criteria presently exist for soils or sediments. For nearly all contaminants, there are no soil threshold limits defining when hazardous effects will begin to be evidenced. In part, this reflects the fact that there are no simple standard tests to which a contaminated soil can be subjected for designation as hazardous or nonhazardous.

Fortunately, there is still a relatively simple approach available for establishing criteria. For most contaminants, soil residuals are of concern because of the ultimate ability to contaminate the atmosphere (through volatilization or resuspension) and the hydrosphere (through leaching and runoff). Hence, for those con-

taminants, hazardous levels in soil can be defined as those which will sponsor hazardous levels in air or water.

Criteria and guidelines for ambient air and water have been suggested for a number of chemicals. By working backwards with minimal data on dilution potential and distribution coefficients, criteria can be established. Given these, one can determine the subset of alternatives which can meet objectives and the extent of restoration required.

This approach to establishing restoration goals, requires knowledge of three basic components:

- The air and/or water criteria which are not to be exceeded
- Intrinsic properties of the contaminants involved which will determine their fate and migration from source to receiving atmosphere/hydrosphere
- The algorithms required to account for soil, air, and water dynamics which will dictate the transport of the contaminants

The criteria level (RC) is derived very simply from the above inputs utilizing the relation:

$$RC = (S) \times (A) \times (D)$$

where

S = the standard or criteria for the receiving water or atmosphere (concentration)

A = the attenuation or loss of contaminant during transport defined in terms of the ratio of the chemical on the soil to that in the air or water at any given time—the distribution constant

D = the dilution factor during transport defined in terms of the ratio of the concentration at the source to the concentration in the receiving water or atmosphere

Dimensionally, the result RC is provided a concentration term in  $\mu\text{g/l}$  in the soil.

The text following this section is directed to the selection of restoration goals (threshold criteria) for the LaBounty Landfill in Charles City, Iowa. Preliminary studies have determined that the major migration route of concern is the generation of contaminated leachate with subsequent transport to the Cedar River. As a consequence, damage to human health and aquatic life are hazards of interest upon which restoration should be based. Possible interconnection of the upper and lower Cedar Valley aquifers raises concerns for potable wells located in the latter. More restrictive standards would be in order if development of the Upper Cedar River aquifer at the landfill site were contemplated in the future.

## PERTINENT STANDARDS

The LaBounty Landfill received a wide variety of materials including municipal refuse and pharmaceutical wastes from the Salsbury Laboratories. As a consequence, a number of discreet chemical compounds were disposed at the site and may ultimately escape into ground and surface waters. For the purpose of the cur-



rent study, however, attention is focused on the five constituents identified in Table 1 as major components of LaBounty waste. For the purposes of illustrating the Exposure-Response approach, details will be provided for the arsenic only. Results will then be given to establish criteria for all five contaminants.

**Table 1.**  
**Estimate of Major Components of LaBounty Waste<sup>a</sup>**

Chemical	Amount(kg)
Arsenic	2,750,000
O-Nitroaniline	680,000
Nitrobenzene	127,000
1,1,2-Trichloroethane	32,000
Phenol	12,300

Available data on time-dose relations for ingested arsenic are summarized in Fig. 1. The lowest detrimental concentrations reported relate to the potential for initiation of skin cancer in humans.

Much of the literature on arsenic poisoning stems from an incidence in Taiwan where contaminated water was consumed over an extended period. It is likely that this source of arsenic was supplemented by locally grown foods. Hence, extrapolation for designation of carcinogenic risk using a straight line, no threshold relation yields a very low value of 220 ng/l for the  $10^{-4}$  risk level. This is well below the primary drinking water standard of 50  $\mu\text{g/l}$  and the findings of a large-scale survey in Taiwan wherein popula-

tions consuming 1 to 17  $\mu\text{g/l}$  arsenic could not be found to evidence any cancer. Skin cancer appeared only in those inhabitants consuming water with 50 to 1820  $\mu\text{g/l}$  As.

Based on these contrasting values, it is believed that a criteria value of 10  $\mu\text{g/l}$  in Cedar River water should provide ample protection for human health and aquatic life. This is roughly a factor of 5 lower than the arsenic levels currently reported in the Cedar River under mean flow conditions.

Similar evaluations were made of toxicological data for the four organic contaminants found in the LaBounty Landfill. The selected receiving water standards are summarized in Table 2.

**Table 2.**  
**Selected Threshold Criteria in Receiving Waters**

Contaminant	Surface Waters ( $\mu\text{g/l}$ )	Ground Waters ( $\mu\text{g/l}$ )	Basis
Arsenic	10	10	human health
1,1,2-Trichloroethane	0.6	0.6	$10^{-6}$ cancer risk
O-Nitroaniline	10,000	100,000	aquatic life/human health
Phenol	300	300	organoleptic
Nitrobenzene	30	30	organoleptic

#### Notes to Figure 1

1. Estimated lethal dose<sup>21</sup> [70 to 180 mg] for 1 l/day in a 10 kg child, this equates to 70 mg/l, since arsenic has a half-life in the human body of 280 days<sup>24</sup> a simple model of the concentration of arsenic in the human body<sup>7</sup> yields a chronic lethal drinking level of  $AG = 70(\ln^2)/280 = 0.17 \text{ mg/l}$ . Thus, a consumption schedule for lethality would be

Days of Consumption	Concentration (mg/l)
1	70
2	3.5
$\infty$	0.17

2. Daily ingestion of 3 mg As for 2 to 3 weeks led to skin and nervous system disorders.<sup>8</sup> This equates to consumption of 3 mg/l water for the 10 kg child model.

3. Chronic exposure (assume >1 year) to <1 mg/l in water led to skin cancer, keratosis and hyperpigmentation.<sup>7</sup>

4. EPA estimates that chronic exposure to 220 ng/l of As will increase cancer risk at the  $10^{-4}$  level exposure.<sup>4</sup>

5. EPA estimates that chronic consumption of aquatic organisms from water with 175 ng/l As will raise the cancer risk at  $10^{-5}$ .<sup>4</sup>

6. EPA estimates a chronic limit for freshwater fish of 440  $\mu\text{g/l}$ .<sup>4</sup>

7. Primary drinking water standard for As is currently 0.05 mg/l.

8. Lowest reported level for chronic poisoning 0.21 mg/l.<sup>3</sup>

9. LC50 for daphnia 7.4 mg/l over 96 hr exposure  
LC50 for daphnia 2.85 mg/l over 21 days exposure.<sup>1</sup>

10. Reproductive impairment in Daphnia was 50% and 16% at 1400 and 520  $\mu\text{g/l}$  respectively.<sup>1</sup>

11. 96 hr LC50 values for bluegill, channel catfish and fathead minnows reported as 44.8, 18.1 and 15.1 mg/l respectively.<sup>4</sup>

12. 16 week exposure to 0.7 mg/l As resulted in 18% survival for formative bluegills.<sup>10</sup>

13. Residents using water with 50 to 1820  $\mu\text{g/l}$  As showed excessive cases of cancerous epithelial lesions.<sup>10</sup>

14. Residents using water with 1 to 7  $\mu\text{g/l}$  As had no cancer.<sup>10</sup>

15. Consumption of water with 80  $\mu\text{g/l}$  As yield cancerous lesions in 0.01% of population.<sup>22</sup>

#### INTRINSIC PROPERTIES

The migration of contaminants in the groundwater is largely a function of solubility, the affinity for the constituent of interest to associate with soil particles and degradation mechanisms. With respect to the former, the primary issue is the relation of solubility levels to pertinent criteria. If a contaminant's solubility is less than the criteria, no risk is posed in the way of leaching with subsequent contamination of receiving waters. On the other hand, if solubility exceeds criteria, the potential exists for leachate to bring receiving

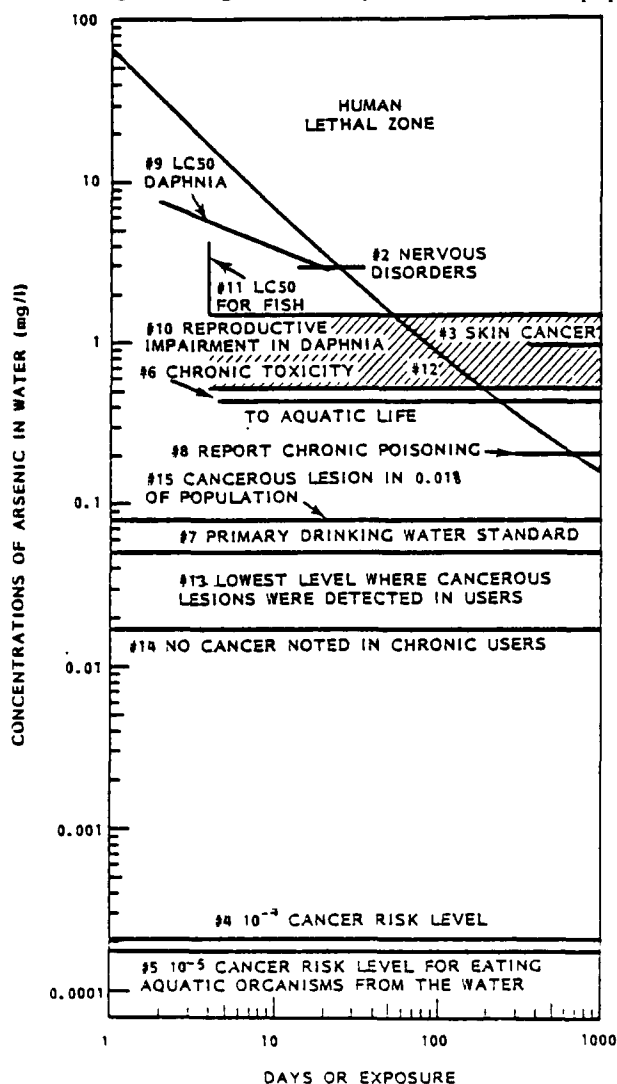


Figure 1.

Time-Dose Universe for Arsenic in Water

waters to unacceptable contaminant concentrations. Similarly, if the ratio of solubility to criteria is less than the dilution factor, solubility constraints will prevent the criteria from being exceeded in the receiving water.

The affinity contaminants have for soil affects their mobility by retarding transport. The more strongly a chemical is attracted to the soil, the more its transport is attenuated, and hence, the slower its migration is relative to the groundwater itself and the resultant equilibrium water concentration is lower. Retention on soil may be due to ion exchange or physical adsorption. If migration carries the contaminant into different geochemical environments, precipitation of less soluble salts may also occur. Soil retention mechanisms are often quantitatively described with a distribution coefficient,  $k_d$ , which is defined as the ratio of the concentration of the contaminant on the soil to its concentration in associated waters. For those organic contaminants whose attenuation results from sorption on organic matter in soil, the distribution coefficient is referred to as  $k_{oc}$ . The latter is a  $k_d$  adjusted to organic soil content. Hence,

$$k_{oc} = \frac{\mu\text{g adsorbed contaminant/g of soil organic carbon}}{\mu\text{g dissolved contaminant/g solution}}$$

Degradation mechanisms serve to reduce both soil and groundwater contaminant concentrations over time. They may result from hydrolysis, photolysis, biodegradation and volatilization. Groundwater conditions are typically such that only hydrolysis plays a major role in contaminant loss. The following review provides order of magnitude estimates for the pertinent intrinsic properties of arsenic.

Arsenic solubility is dependent on the form (valence state) and presence of other ions. In general, arsenic is soluble at 100 to 500 mg/l. This is well above the criteria level of 0.01 mg/l and therefore, solubility will not limit the ability of leachate to contaminate receiving waters.

Arsenic is one of the few anionic species that ties up in soils. Arsenic attenuation in soil is believed to be a result of adsorption on metal oxide species and coprecipitation. In Sharpsburg and Menfro soils, Hess and Blanchard<sup>14</sup> found a  $k_d$  for arsenic of 50 at solution concentrations  $\leq 0.3$  mg/l and 200 at solution concentrations 70.3 mg/l. The odd shape of the results when plotted as a Freundlich isotherm suggested that precipitation was the controlling mechanism and not monolayer adsorption.

In liner studies at the University of Arizona, Fuller<sup>9</sup> found approximate retardation factors of 5 to 10 in soil and 50 to 75 in soil with limestone. By definition, the retardation factor equates to the sum  $1 + 3(k_d)$ . Hence, these values correspond to  $k_d$  values of 2 to 25 depending on soil pH. Since Charles City is underlain by dolomite, it is not unreasonable to assume that the soil attenuation will lie midway between these values rather than at the low end. Therefore, a  $k_d$  value of 10 is reasonable for the purposes of determining where a soil is contaminated to the point of requiring mitigation.

No loss mechanisms are important for arsenic. In some circumstances, biological action can sponsor the production of arsine which will volatilize. However, in flowing groundwaters, bacteria are typically filtered out so that this mechanism is not likely to occur at Charles City.

From the above data and other assumptions, it is possible to derive the necessary parameters to predict movement of arsenic from the LaBounty Landfill site. A similar evaluation resulted in pertinent values for the four organic contaminants. The selected values are summarized in Table 3.

## TRANSPORT DYNAMICS

The final data required to set restoration objectives relates to the dynamics of the migration route. In the case of the LaBounty Landfill, the factors of importance will be the dilution factors encountered when affected groundwaters enter the Cedar River and when the affected groundwaters enter Upper Cedar Valley aquifer.

These dilution factors can be estimated from the water flux values employed in calibrating the groundwater model developed

**Table 3.**  
Intrinsic Properties Affecting the Fate and Migration of Contaminants at LaBounty Landfill

Contaminant	( $\sim$ ratio) Solubility Threshold Criteria	$K_d$	Half-life	Decay Mechanism
Arsenic	$10^4 - 10^5$	10	---	None
1,1,2-Trichloroethane	$10^6$	3.7	6 mo.	hydrolysis
O-Nitroaniline	$10^2$	1.5	long	biological
Phenol	$10^3$	0.17	long	biological
Nitrobenzene	$10^3$	1.7	long	biological

for the site. In particular, it was found that the flow through the waste area which generates the contaminant plume is 55.2 m<sup>3</sup>/day. The total aquifer flow in the region is 11,694 m<sup>3</sup>/day. Hence, aquifer dilution is  $11,692 \div 55.2$  or approximately 200. Similarly, low flow in the river (7 day, 10 year value) is 230,893 m<sup>3</sup>/day which yields a river dilution factor of  $230,893 \div 55.2$  or approximately  $\sim 4,000$ .

## CRITERIA FORMULATION

As noted previously, the pertinent criteria (RC) for a site is estimated from the relation:

$$RC = S \times A \times D$$

The necessary input values for each contaminant at LaBounty are summarized in Table 4 along with the calculated criteria. Several comments are appropriate:

**Table 4.**  
Input Values and Restoration Criteria for LaBounty Landfill

Contaminant	Standard-S ( $\mu\text{g/l}$ )	Attenuat'n Factor-A*	Dilution Factor-D	Soil Criteria RC-( $\mu\text{g/g}$ )
<b>Upper Cedar Valley Aquifer</b>				
Arsenic	10	10	200	20
1,1,2-Trichloroethane	0.6	3.7	200	0.4
O-Nitroaniline	10,000	1.5	200	3,000
Phenol	300	1	200	60
Nitrobenzene	30	1.7	200	10
<b>Cedar River</b>				
Arsenic	10	10	4,000	400
1,1,2-Trichloroethane	0.6	3.7	4,000	8
O-Nitroaniline	100,000	1.5	4,000	600,000
Phenol	300	1	4,000	1,200
Nitrobenzene	30	1.7	4,000	200

•The 7 day 10 yr low flow value may be conservative for use of chronic hazard values. Mean flow values (1.9 million m<sup>3</sup>/day) may be more appropriate. This would result in soil criteria roughly 10 times as high for the Cedar River.

•The dilution is proportional to the size of the contaminant plume source. As a consequence, the dilution factor goes up as source is removed. Hence, development of maximum criteria would require interactive consideration of reduced source term size as the criteria level is raised. The values provided here are order of magnitude only.

It is clear that this approach to setting criteria will be conservative. As noted above, partial reduction of the source term increases the dilution term and therefore would allow a smaller volume of more concentrated soils to remain without exceeding receiving water standards. This does not invalidate the approach, it merely suggests that if remedial action is going to be very expensive, more effort could be effectively employed in refining the criteria for the site through an interactive evaluation recalculating dilution

factors for each source term reduction until outflows do not exceed the receiving water standard.

From Table 4, it is readily apparent that contamination of the Cedar River will be the controlling concern in setting cleanup criteria. Since no good data are available on soil contamination contours, it is not possible to determine the extent of cleanup that would be required as a result of applying these criteria. In general, however, the contaminant plume extends under the landfill area to the river. Hence, in this application one need only address the area of the landfill itself. Indeed, as noted above, removal of the waste materials themselves will increase the dilution factor significantly. This, in turn, will reduce the amount of contaminated soil which must be removed. A few measurements of soil contamination levels downflow of the wastes would quickly identify the extent of the area to be addressed.

A cursory review of the criteria suggests that arsenic and trichloroethane will be the determining contaminants in setting restoration criteria. While these materials have the highest attenuation factors of the five contaminants, neither value is very large. As a consequence, the groundwater concentration profiles will yield a fairly accurate estimate of the zone of soil which will exceed the cleanup criteria. The solubility to toxicity ratio for O-nitroaniline is on the same order of magnitude as the aquifer dilution factor. It is an order of magnitude less than the river dilution factor. As a consequence it would appear that O-nitroaniline standards are not likely to be exceeded even if no remedial action is taken. However, caution is necessary here since there are few toxicological data available on this chemical. If the toxicity level is found to be much lower, the solubility ratio may exceed dilution.

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# PERSPECTIVES OF RISK ASSESSMENT FOR UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

To answer the prime question of risk assessments, "Is this risk acceptable?", requires that one first know the magnitude of risk that exists. Mathematically risk can be defined as a function of the probability of a negative consequence occurring and the value of that consequence. Therefore, the information required to estimate risk is the joint probability of a series of events leading to a consequence, the value of this consequence and the functional relationship defining risk. The concepts connected with the valuation of consequences will be covered in a later discussion. In this paper, the authors concentrate on the estimation of probabilities of occurrence and the definition of the functional relationship.

## BASICS

To understand the risk estimation process, one must first delve into some of the characteristics of risk. The first property of risk that one should note, is that it can be modeled as a chain or series of events. As indicated in Fig. 1, the events that occur in this path are hazard, outcome, exposure and consequence. An example of each type of event is provided in the diagram. One would normally expect a multiplicity of interconnected hazards, outcomes, etc., so one should properly think in terms of risk paths.

The second property that should be considered is that in modern technological risk problems, hazardous waste included, many of these events will be relatively rare occurrences. This means that a good base of historical statistical data on event occurrence frequencies is limited or nonexistent. This problem is further complicated by the final property which needs to be considered. Many of the elements of risk pathways, such as the specific toxic substance involved, are new and therefore unknown.

Event	Hazard	→	Outcome	→	Exposure	→	Consequence
Example	Tree struck by lightning		Tree falls		Man walking in woods		Injury to man

Figure 1.  
Pathway Concept

The probability of a consequence occurring is normally:

$$P(H \cdot O \cdot E \cdot C) = P(H) \cdot P(O/H) \cdot P(E/H \cdot O) \cdot P(C/H \cdot O \cdot E) \quad (1)$$

where:

- $P(H)$  = probability of a specific hazard  
 $P(O/H)$  = probability of an outcome given that a specific hazard has occurred  
 $P(E/H \cdot O)$  = probability of exposure given a hazard and outcome  
 $P(C/H \cdot O \cdot E)$  = probability of a specific consequence given an exposure, outcome and hazard

In the case of mutual independence this reduces to:

$$P(H \cdot O \cdot E \cdot C) = P(H) \cdot P(O) \cdot P(E) \cdot P(C) \quad (2)$$

Therefore, to determine the desired probability, requires that one know the conditional probabilities along a specific risk path or in the case of mutual independence the *a priori* probability of occurrence for each event. However, as indicated earlier, in many cases this will not be easy to accomplish since one will be dealing with events for which little or no historical data exist. Thus one needs a technique that will allow one to estimate those probabilities where historical data are lacking.

Nor is this the only difficulty to be encountered. How does one determine all the likely risk paths (or at least the significant ones) in an "acceptable manner"? Considering the potential sensitivity of the final risk estimate to the completeness of this information, answering this question becomes critical to the solution search.

To address these problems, special efforts involving both technical experts and community based citizen groups must be orchestrated. Four suggested actions seem to enjoy the widest acceptance: (1) use of a multidisciplinary team headed by a generalist and composed of knowledgeable personnel, (2) allowance for some type of peer review of the technical data base developed, (3) some mechanism for meaningful public involvement, and (4) a suitable analytical methodology.

Most of the remainder of the paper will be devoted to this "suitable analytical methodology". This methodology will need to possess the following capabilities:

1. Means to provide estimates of risk probability
2. Procedures to facilitate systematic thinking
3. Processes which allow for the incorporation of inputs from multiple individuals and disciplines
4. Easy to review

In short, what is required is a quantitative analysis method which is both structured and flexible and which imposes a reasonably stringent standard of documentation.

A continuum of methods, from totally informal undocumented intuition to very formal fault tree analysis, are possible. However, only the formal end of the scale has the potential to meet all the requirements listed above. In particular, fault tree analyses possess each of the capabilities mentioned. Fault trees allow one to logically break down a problem until one reaches a level at which one knows or can readily determine occurrence probabilities.

## RISK ACCEPTABILITY

Risk acceptability is concerned with the determination of what level of safety is required (or what level of risk can be allowed) by society for specific risk situations. The problems of risk acceptability can be summarized in two questions. The first is "How safe is safe enough?" The second question, "Acceptable to whom?" is not nearly so often heard as the first. There are no organized techniques to handle this problem. It is of course impossible to really answer the first question without first answering the second, but

often the answer to the second question is only implicitly stated if at all. Regretfully, the authors also will have to bypass the second question with the tacit understanding that the individual decision maker involved in hazardous waste management has a clear idea of who the "whom" is.

## RISK PERCEPTION

If every individual perceived the world around him the same way there would be no difficulty in assessing the acceptability of a particular risk situation. In the real world people often fail to perceive reality very clearly or in the same way. The risk problems of interest to the authors, are, in many cases, neither well established nor documented. They are often surrounded with a large degree of uncertainty resulting from such diverse causes as limited knowledge and restricted measurement capabilities. Compounding these limitations is the complexity of the problem, not just in terms of the multiplicity of risk pathways but also because risk does not exist by itself. It is only one of many problems which must be considered as simply one factor in a morass of benefits and costs, direct and indirect, that surround any public decision problem.

The intuitive and cognitive ability of the normal individual are simply swamped by this complexity, thereby forcing him to rely on simplified rules of thumb. These simplified information-straining and decision making rules often produce erroneous judgments. For instance, one such heuristic, judging the probability of a risk based on the ease with which instances can be brought to mind, can obviously lead to unjustified biases. This heuristic at least partially accounts for the media's ability to distort the public's perception of risk. Under these circumstances, it is not surprising that it is often difficult, if not impossible, to assess a risk's public acceptability. Often one simply does not even know what the general subjective perception of the risk is until after the fact.

An anatomy of human perception and its effect on choice behavior based on experimental evidence is beginning to be generalized in prospect theory.<sup>6</sup> Under this theory one can no longer use expected value (i.e., probability consequence) to describe the preference ordering of options. Instead, one must also incorporate functions which account for the differences in perception due to the problems framing (i.e., the observers conception of the problem, consequences, and contingencies). As a result instead of the familiar expected value formulation for risk one gets:

$$R = [\Pi(p)][v(c)] \quad (3)$$

where:

- $\Pi()$  = decision weight associated with probability of occurrence
- $v()$  = values associated with consequences
- $R$  = risk

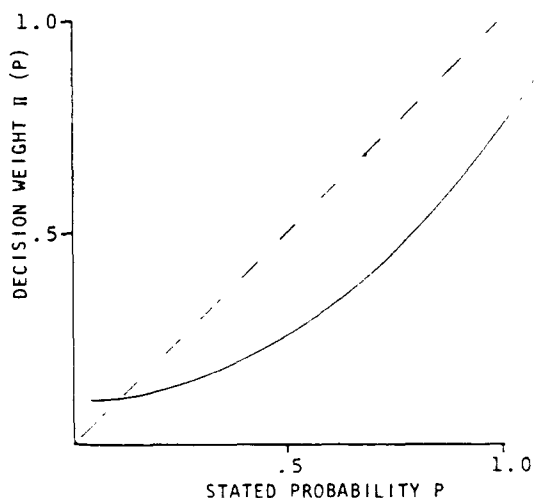


Figure 2.  
Hypothetical Probability Function\*

Hypothetical value and decision weight functions are depicted in Figs. 2 and 3. If  $\Pi$  and  $v$  were linear throughout, an individual's preference between choices would be independent of the problem's framing. However, due to the characteristic nonlinearities, different frames can lead to different choices even though the expected values of the options remain the same. Prospect theory is amendable to incorporation in multiattribute utility measurements, a topic which will be covered elsewhere.

Besides the theoretical and experimental work on prospect theory, a great deal has been done to determine inferred or intuitive factors in the development of perception. One of the most complete analyses, at least for the specific area of risk assessments, has been provided by Rowe.<sup>4</sup> His factors for transforming objective reality in to subjective perception are summarized in Table 1. A brief description of these factors follows:

Table 1.  
Objective to Subjective Transformation Factors\*

### Factors involving type of consequence:

- Voluntary or involuntary
- Discounting of time
- Identifiable or statistical risk taker
- Controllability

### Factors involving nature of consequence:

- Position in hierarchy of consequence
- Ordinary or catastrophic
- Natural or man originated

### Other factors:

- Magnitude of probability of occurrence
- Propensity for risk taking

- Voluntary or involuntary—perception appears to be markedly effected by whether the risk is incurred by choice or not. For instance, one normally expects a worker at a hazardous waste site to be much more tolerant of risk than the surrounding inhabitants.
- Discounting of time—events happening now tend to be valued higher than the same event sometime in the future. This obviously dovetails with the long held financial concept that a dollar today is worth more than the same dollar a year from now.
- Identifiable or statistical risk taker—whether a risk will be taken (or imposed) on individuals or groups with which we identify or just a "number in the crowd" affects one's perception. A classical example of this can be seen in the huge expenditures of money undertaken to rescue trapped miners who have become identifiable while begrudging support to routine safety budgets.

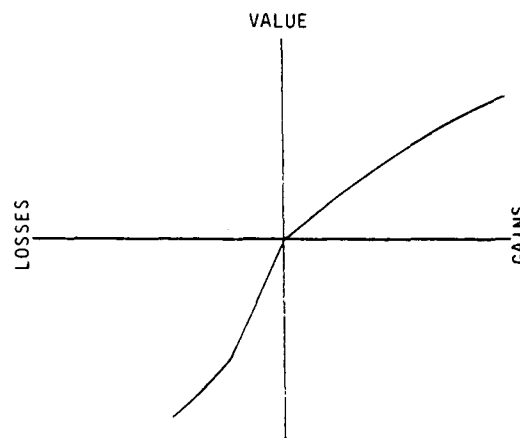


Figure 3.  
Hypothetical Value Function\*

- **Controllability**—people appear to accept much higher risk when they feel that the situation is well controlled such as when they are driving the car.
- **Position in hierarchy of consequences**—the wish to avoid a consequence depends heavily on the perceived undesirability, i.e. position in a desirable-undesirable hierarchy, of the consequence (see Table 2). As a result, one would normally expect the threshold for noticing risk to be much lower for fatality situations than ones involving risk to security.
- **Ordinary or catastrophic**—large numbers of fatalities, etc. in a single accident has a much more pronounced impact than the same number of fatalities spread over a number of small accidents. For example, a much higher risk tolerance is expressed by the public in the case of auto accidents (which are normally ordinary) than in commercial aviation accidents (which tend to be catastrophic).
- **Natural or man originated**—risk imposed by natural causes tends to be much more easily tolerated than man-made risks probably because there are few if any alternatives to accepting the natural risk.
- **Magnitude of probability of occurrence**—the perceptions of a consequence are nonlinearly influenced by the magnitude of the

probability of that consequence. This often results in very low probabilities being overstated and high probabilities understated.

- **Propensity for taking risk**—the inherent level of risk taking acceptable to an individual or group can reasonably be expected to vary. As a result we see instances such as the nuclear power controversy where equally rational groups have extremely divergent opinions on the acceptability of a risk activity.

It seems fairly obvious that one is dealing with a very complex human phenomenon. Further, if one accepts the factors listed (or a similar set), then it is necessary to reject the use of aggregated risk to make decisions. If one wishes to use subjective perceptions in one's assessments, then risk must be differentiated into classes which are commensurate with the difference between reality (or our best objective estimate of it) and these perceptions.

### TECHNIQUES FOR DETERMINING RISK ACCEPTABILITY

A number of possible techniques for addressing the question, "How safe is safe enough?" have been proposed. Three basic approaches can be readily identified. The first is the formal analysis approach. The principal methods included in this category are benefit/cost analysis and decision analysis. This approach relies heavily on formal logic and optimization principles.

The next technique is the comparative analysis approach. It is composed of three distinct methods: revealed preference, expressed preference and natural standards. In each case a more or less absolute acceptable risk limit is devised against which the estimated risk of an activity can be compared.

The last major category is professional judgment. This approach, of course, relies principally on the intuitive intelligence of the professional community. An in-depth comparison of each technique using five key characteristics, decision making criteria, locus of wisdom, principal assumptions, decision attributes possible and data requirements, is provided in Table 3.

Table 2.  
Consequence Hierarchy

Lowest Priority	Self-Actualization
	Egocentric
	Belonging/Love
	Security
	Exhaustable Resources
	Survival Factors
	Illness & Disability
Highest Priority	Death

Table 3.  
Comparison of Techniques

Technique	Decision Making Criteria	Locus of Wisdom	Principal Assumptions	Decision Attributes	Data Requirements Possible
<b>Formal Analysis</b>					
•Benefit/Cost Analysis	Economic optimization	Formalized intellectual processes	•Man is or should be a rational economic maximizer •Decisions should be purely objective	Anything which can be converted to money	•All significant economic events & consequences  •Accurate probabilities & magnitudes for each
•Decision Analysis	Utility optimization	Formalized intellectual processes	•Man is or should be a rational utility maximizer •Decisions should use decision makers value judgments	Anything; any number	•All significant events & consequence  •Accurate probabilities & magnitudes for each
<b>Comparative Analysis</b>					
•Revealed Preference	Preservation of historical balance	Societal decisions during recent past	•Past decisions were essentially optimal •Little or no change in circumstances	Risk only	•Current risk •Historical risk
•Expressed Preference	Current preference	Societal decisions now	•Public understands & has well articulated preferences	Risk only	•Current risk •Current preferences
•Natural Standards	Biological wisdom	Long term species survival	•The optimal level of exposure to pollutants is characteristic of conditions during species evolution	Risk only	•Current risk •Risk magnitudes during geologic time
<b>Professional Judgment</b>	Professional judgment	Intuitive intellectual processes	•Professionals understand & have well articulated preferences •Professionals always exercise free will	Anything but limited number	Almost anything

Each of these techniques has strengths and by themselves some serious weaknesses (Table 4). The formal analysis methods, especially decision analysis, provide structure, flexibility and the potential for easy and meaningful review. Benefit/cost analysis is seriously constrained, however, since any attribute which cannot readily be converted into economic terms is ignored. Both formal techniques suffer from the requirement for large amounts of detailed and reliable data and the inability to incorporate public subjective perceptions of risk into the formulation.

All the comparative analysis methodologies have the advantage of establishing "absolute" risk limits. This benefit, however, is offset by the fact that all three are only intended to address risk, they cannot handle the entire decision problem, i.e., the tradeoffs between risk and the other decision dimensions such as benefits. In addition, both revealed and expressed preference methods are subject to the limitations of society and its citizens.

Finally, professional judgment enjoys the benefit of being easily implemented. However, it is severely constrained by its limited review capabilities and potentially significant errors in judgment in the case of complex problems. Probably even more important is the apparent recent loss of public trust in professional judgments.

**Table 4.**  
**Technique Strengths and Weaknesses**

Technique	Strength	Weaknesses
<b>Formal Analysis</b>		
Benefit/Cost	<ul style="list-style-type: none"> <li>•Systematic</li> <li>•Ease of review</li> <li>•Handles all decision dimensions</li> </ul>	<ul style="list-style-type: none"> <li>•Discounts attributes which cannot be readily converted to economic terms</li> <li>•Large data requirements</li> <li>•Cannot handle subjective value judgments</li> </ul>
Decision Analysis	<ul style="list-style-type: none"> <li>•Systematic</li> <li>•Ease of review</li> <li>•Flexible</li> <li>•Handles all decision dimensions</li> <li>•Incorporates decision maker's judgment</li> <li>•Handles uncertainty well</li> </ul>	<ul style="list-style-type: none"> <li>•Large data requirements</li> <li>•Cannot handle public perceptions of risk</li> </ul>
<b>Comparative Analysis</b>		
Revealed Preference	<ul style="list-style-type: none"> <li>•Establishes absolute limits</li> <li>•Incorporates historical experience</li> </ul>	<ul style="list-style-type: none"> <li>•Past decisions often were not always optimal</li> <li>•Circumstances changing rapidly</li> <li>•Disaggregated historical baseline hard to establish</li> <li>•Does not address whole decision</li> <li>•Subject to inherent limitations of society and its citizens</li> </ul>
Expressed Preference	<ul style="list-style-type: none"> <li>•Establishes absolute limits</li> <li>•Allows for widespread public involvement</li> </ul>	<ul style="list-style-type: none"> <li>•Dependent on ability to get unbiased survey</li> <li>•Public does not always understand or have a preference</li> <li>•Does not address whole decision</li> <li>•Subject to inherent limitations of society and its citizens</li> </ul>
Natural Standard	<ul style="list-style-type: none"> <li>•Establishes absolute limits</li> <li>•Not subject to limitations of society</li> </ul>	<ul style="list-style-type: none"> <li>•Many of today's pollutants did not exist before</li> <li>•Does not address whole decision</li> <li>•Geological time baseline hard to establish</li> <li>•Does not allow for tradeoffs</li> </ul>
<b>Professional</b>	<ul style="list-style-type: none"> <li>•Handles all decision dimensions</li> <li>•Flexible</li> <li>•Easy to implement</li> <li>•Well established</li> </ul>	<ul style="list-style-type: none"> <li>•Hard to impossible to review</li> <li>•Bias due to employer</li> <li>•Stretched intuitive &amp; cognitive skills can lead to erroneous judgments</li> <li>•Professionals appear to be losing public support</li> </ul>

## A QUANTITATIVE REVEALED PREFERENCE METHOD

Of the techniques discussed, probably the two which have enjoyed the most recent exploration in a risk context are revealed preference and decision analysis. The remainder of this paper will deal with a quantitative methodology for determining risk acceptability based on revealed preference which is based on the work of Rowe.<sup>4</sup> Rowe's technique is composed of four principal parts:

- Devise an appropriate risk classification scheme
- Determine an absolute risk reference for each class in the scheme
- Using risk references as a base, calculate risk referents that act as the acceptability limits for specific situations
- Compare the estimated risk with the appropriate risk referent. If the estimated risk is within an order of magnitude of the referent then it can be considered acceptable.

The first two steps are intended to be completed only once, thereby creating an absolute reference base. The third step is repeated for each new activity and allows for the modification of the reference base to fit the situation specifics. As indicated in Table 5, these steps explicitly include all the objective to subjective transformation factors that were mentioned earlier except for one, the effect of the magnitude of probability of occurrence.

**Table 5.**  
**Transformation Factor Utilization in Risk Referents<sup>4</sup>**

### Factors involving type consequence:

- Voluntary or involuntary (1)
- Discounting of time (1)
- Identifiable or statistical risk taker (1)
- Controllability (2)

### Factors involving nature of consequence:

- Position in hierarchy of consequence (1)
- Ordinary or catastrophic (1)
- Natural or man originated (1)

### Other factors:

- Magnitude of probability of occurrence
- Propensity for risk taking (2)

(1) Explicitly included in determination of absolute risk reference

(2) Explicitly included in determination of risk referent

If risk assessments are to be useful, one cannot treat risk as an aggregate. One must break it into component parts commensurate with one's understanding of the factors that lead to subjective perception. The basic classification scheme advocated by Rowe is shown in Table 6. In conjunction with this scheme, four classes of consequence are delineated: (1) fatalities, (2) injuries and morbidity, (3) property damage, and (4) reduction in years of life expectancy. Additional consequence classes would be desirable in order to adequately cover the entire range of the consequence hierarchy (Table 2) but the data just do not exist to justify any other classes.

**Table 6.**  
**Classification of Absolute Risk<sup>4</sup>**

Classification	Voluntary	Regulated	Involuntary
Immediate statistical			
1. Natural			
a. Catastrophic			X
b. Ordinary			X
2. Man triggered			
a. Catastrophic	X		X
b. Ordinary	X	X	X
3. Man originated			
a. Catastrophic	X		X
b. Ordinary	X	X	X
Immediate identifiable (1)			
Delayed statistical (1)			
Delayed identifiable (1)			

(1) Same as immediate statistical



Once a classification scheme is adopted, an absolute risk reference must be established for each class. These are estimated directly from historic, societal risk data (Rowe selected reference 1 as his primary source for man-originated accidents) as revealed preferences. Where data do not exist for a specific class, estimates are based on an analogous set of risk classes for which data exist. The risk references determined by Rowe for immediate statistical accidents are shown in Table 7.

**Table 7.**  
**Summary of Risk References<sup>a</sup>**

Risk Classification	Class of Consequence			
	Fat/Yr	He/Yr	\$/Yr	Yr
Naturally occurring				
Catastrophic	1x10 <sup>-6</sup>	5x10 <sup>-6</sup>	0.02	3x10 <sup>-2</sup>
Ordinary	7x10 <sup>-5</sup>	4x10 <sup>-4</sup>	3	0.2
Man originated				
Catastrophic				
Involuntary	1x10 <sup>-7</sup>	5x10 <sup>-7</sup>	2x10 <sup>-2</sup>	3x10 <sup>-4</sup>
Voluntary	2x10 <sup>-6</sup>	2x10 <sup>-6</sup>	0.4	6x10 <sup>-3</sup>
Regulated voluntary	3x10 <sup>-5</sup>	3x10 <sup>-6</sup>	0.4	6x10 <sup>-2</sup>
Ordinary				
Involuntary	5x10 <sup>-6</sup>	3x10 <sup>-5</sup>	1	1x10 <sup>-2</sup>
Voluntary	6x10 <sup>-4</sup>	3x10 <sup>-1</sup>	200	1
Regulated voluntary	1x10 <sup>-4</sup>	6x10 <sup>-2</sup>	30	.1
Man triggered				
Catastrophic				
Involuntary	2x10 <sup>-7</sup>	1x10 <sup>-6</sup>	4x10 <sup>-2</sup>	6x10 <sup>-4</sup>
Voluntary	4x10 <sup>-6</sup>	4x10 <sup>-6</sup>	0.8	6x10 <sup>-3</sup>
Ordinary				
Involuntary	1x10 <sup>-5</sup>			3x10 <sup>-2</sup>
Voluntary	1x10 <sup>-3</sup>			2
Regulated voluntary	2x10 <sup>-4</sup>			0.2

Conversion of a risk reference into a risk referent requires four steps:

- Determine the appropriate risk proportionality factor, i.e., the fraction of existing societal risk (risk reference) that would be considered acceptable in a situation where there was a very favorable indirect benefit/cost balance, for both voluntary and involuntary risk. (F1)
- Determine a factor, the risk proportionality derating factor, which modifies the risk proportionality factor in those situations where the indirect benefit/cost balance is not as favorable as in the first step (F2)
- Determine the modification factor associated with the degree of risk controllability. (F3)
- Using the three factors determined above, calculate the risk referent:

$$\text{Risk referent} = \text{Risk reference} \times F1 \times F2 \times F3 \quad (4)$$

The first two factors address the inherent propensity of specific individuals/groups to take risks and incorporates the additional decision dimension of indirect benefits/costs. This acknowledges the tendency for people to accept a higher level of risk if the benefit to them more than offsets the imposed risk or to be increasingly risk adverse if it does not. All three of these factors are based on value judgments. The specific numbers in Table 8, risk proportionality and proportionality derating factor, and Table 9, controllability factor, are based on the "straw man" values originally posed by Rowe.

A brief explanation of Table 9 is probably in order. The overall controllability factor is the result of the multiplication of four sub-factors (F1 = C1 x C2 x C3 x C4). The four sub-factors are: (1) control approach (i.e., the type risk control management used), (2) degree of control (i.e., effectiveness of risk control), (3) state of implementation, and (4) basis for control effectiveness (i.e., whether

risk change calculations are related to an activity index, relative, or not, absolute).

### Example Problem

An example that may help illustrate this process concerns an aquifer in San Antonio, Texas. In this illustration, only ordinary fatalities of either the public or workers will be considered, since it is assumed that there is no possibility of a catastrophic accident and that fatalities are the only type risk impact.

Since both the risk reference for a given risk class and the risk proportionality factor are constants, the first factor one needs to determine is the proportionality derating factor. Even without a detailed indirect benefit/cost study it is possible to make a good estimate of what the public and workers are likely to perceive given a specific disposal site plan. For instance, if the plan (call it alternative 1) was to just dig a hole, dump in 55 gal drums of waste and cover them with dirt then one could expect that both the public and workers would perceive this as a much worse balance than another plan (call it alternative 2) which includes some advanced type of container design that incorporated a monitoring system and extensive precautions for worker protection.

**Table 8.**  
**Risk Proportionality and Risk Proportionality Derating Factors<sup>a</sup>**

Factor	Involuntary Risk	Regulated Voluntary
Proportionality factor	0.01	1.0
Derating factor		
Balance		
Favorable	1.0	1.0
Marginal favorable	0.1	0.2
Indecisive	0.01	0.1
Marginal unfavorable	0.001	0.02
Unfavorable	0.0001	0.01

**Table 9.**  
**Controllability Factor<sup>a</sup>**

Control Approach	Degree of Control	State of Implementatn.	Basis for Control Effectiveness
Systematic Control	Positive	Demonstrated	Absolute
1.0	1.0	1.0	1.0
Risk Mgt. System			
0.8			
Special design		Proposed	Relative
0.5		0.5	0.5
Inspec. & regulation	Level		
0.3	0.3		
No scheme	Uncontrolled	No action	None
0.1	0.1	---	---

**Table 10.**  
**Hypothetical Indirect Benefit/Cost Example**

Class	Alt.	Balance	Value
Involuntary (public)	1	Marginally unfavorable	0.001
	2	Marginally favorable	0.1
Regulated voluntary (worker)	1	Indecisive	0.1
	2	Favorable	1.0

**Table 11.**  
**Hypothetical Controllability Example**

Alt.	Control Approach	Degree of Control	State of Implement.	Basis for Effective.	Factor Value
1	0.1	0.1	---	---	0.01
2	0.5	0.3	0.5	0.5	0.0375

**Table 12.**  
**Risk Referent Calculation Summary**

Risk Classification	Reference	Proportion.	Alt.	Derate.	Control.	Reference
Involuntary, ordinary, fatal	5x10 <sup>-6</sup>	0.1	1	0.001	0.01	5x10 <sup>-12</sup>
			2	0.1	0.0375	2x10 <sup>-9</sup>
Regulated voluntary ordinary, fatal	1x10 <sup>-4</sup>	1.0	1	0.1	0.01	1x10 <sup>-7</sup>
			2	1.0	0.0375	4x10 <sup>-6</sup>

This hypothetical example is shown in Table 10. It is also fairly obvious that the controllability factor would be significantly different for each of these two alternatives (Table 11). All the risk

referent factors and the resulting risk referents are summarized in Table 12. These referents would be compared to risk estimates for each alternative and if the estimates were no more the one order of magnitude higher than the appropriate referent then the risk would be judged "acceptable".

As indicated before, this approach makes some heroic assumptions about the optimality of past risk acceptance decisions made in the market place. By itself, therefore, it may be of limited usefulness. However, when incorporated with another technique—the quantitative revealed preference method—it may serve the important task of eliminating totally unacceptable alternatives from consideration.

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# ABANDONED SITE RISK ASSESSMENT MODELING AND SENSITIVITY ANALYSIS

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## INTRODUCTION

In this paper, the author presents an objective calculational procedure (OCP) for evaluating site specific risks due to hazardous waste migration in the environment. The procedure is based on describing environmental pathways in terms of series and parallel diffusion and advection elements. Analogies with electric circuit theory then permit one to identify the controlling elements and to compute losses along a pathway. A simplified equation results for the risk presented by a particular chemical to a particular cohort group, that is a group of individuals exposed along a particular pathway.

The Hazard Ranking System (HRS) described in the National Contingency Plan also can be reduced to a single equation (for air, groundwater and surface water pathways) and hence comparisons with the OCP are possible if one assumes that the HRS also measures risk. Three observations can be made as a result of this comparison:

- The HRS attempts to express multiple viewpoints in terms of the relative importance of near term versus long range future risks as well as near field versus far field risks. The OCP can only express a single viewpoint consistent with the input assumptions and parameters.
- For two sections of a pathway through the environment in series for the OCP describes the one offering the most resistance (i.e., the most secure) as controlling. The HRS description is opposite, the least resistive or least secure portion contributes most to the final score.
- Sensitivity analysis reveals that the HRS final score is most sensitive to the least important scoring areas. For the OCP, a percentage change in toxicity, release rate or population density will produce the same percentage change in risk.

The principal conclusion to be drawn from the observations above is that the HRS embodies values other than degree of risk. The first observation, for example, can be interpreted as a willingness to sacrifice consistency in return for including multiple viewpoints as to what constitutes "risk." One can interpret the second observation that the HRS focuses on things that are "wrong" at a site in the sense of poor design or practice rather than things that are "right," irrespective of how these influence risk. The last observation can be attributed at least in part to the parameters in the HRS being arranged and combined based on user ease rather than strictly according to the logic of risk evaluation.

## AN OBJECTIVE CALCULATION PROCEDURE

One can assume risk to a human population to be defined by:

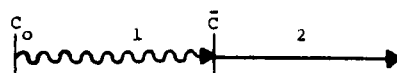
$$R = \sum_{\substack{\text{cohorts} \\ \text{chemicals}}} \beta \gamma P C_e \quad (1)$$

where  $\beta$  is the potency of the chemical in question,  $\gamma$  is a factor relating ambient concentrations to inhalation or ingestion rates,  $P$  is the population exposed and  $C_e$  is the exposure concentration level. One also defines a cohort group as individuals who share a common pathway of exposure. The remainder of this section is devoted to further development of  $C_e$ .

A diagram such as Fig. 1 illustrating the migration of chemicals through the environment can be viewed as diffusion and advection

processes in series and parallel arrangements. To estimate flux an electrical circuit analogy can be exploited to produce simplification of complex diagrams.

Assume a quasi-steady-state. It cannot be a true steady state because the ultimate source region (e.g., the buried wastes) must be diminishing or otherwise changing in character. Using the same notation as in Fig. 1, one then has for conservation of flux,  $F$ , in a series diffusion-advection process (e.g., diffusion of components from bulk waste interior into groundwater flow):



$$F = k_1 A_1 (C_o - \bar{C}) = v_2 A_2 \bar{C} \quad (2)$$

$k$  being the mass transfer coefficient,  $A$  the flux area,  $C$  the concentration and  $V$  the advection velocity. Eliminating  $\bar{C}$  gives:

$$F = K C_o \quad (3)$$

where

$$\frac{1}{K} = \frac{1}{k_1 A_1} + \frac{1}{v_2 A_2} \quad (4)$$

For a series diffusion process (e.g., diffusion through laminar surface water and air microlayers during chemical evaporation) the analogous expressions are:

$$F = k_1 A_1 (C_o - \bar{C}_1) = k_2 A_2 (\bar{C}_2 - C) \quad (5)$$

If  $C_1 = C_2$  and  $C \ll C_2$ , one obtains Equations 3 and 4 with  $V_2$  replaced by  $k_2$ . It will be appropriate to neglect  $C$  if there is an advective process beyond the second diffusive process with  $V$   $k_2$ .

If the boundary between regions is a liquid-gas phase change then:

$$\bar{C}_2 = \frac{H}{RT} \bar{C}_1 \quad (6)$$

where  $H$  is the Henry's Law constant,  $R$  is the gas constant and  $T$  is the temperature. In this case we obtain:

$$\frac{1}{K} = \frac{1}{k_1 A_1} + \frac{RT}{k_2 H A_2} \quad (7)$$

In summary, for processes in series by repeating these steps one always obtains a sum over terms of the form

$$\frac{1}{kA} \quad \frac{1}{VA} \quad \frac{RT}{kHA}$$

One term (the smallest) in this sum will generally dominate. If two terms are competitive, one makes an error of about a factor or two in making this assumption, three terms a factor of three, etc.

Thus, one may write:

$$F = C_o \min [k A, \frac{k H A}{RT}, V A] = C_o K_m A_m \quad (8)$$

where it must be remembered that  $K_m$  represents three different situations. Note that  $K_m A_m$  may refer to any location along the pathway and not just the ultimate source region where  $C = C_o$ .

Now parallel processes such as evaporation from a surface water body will be considered where the interest is in downstream surface

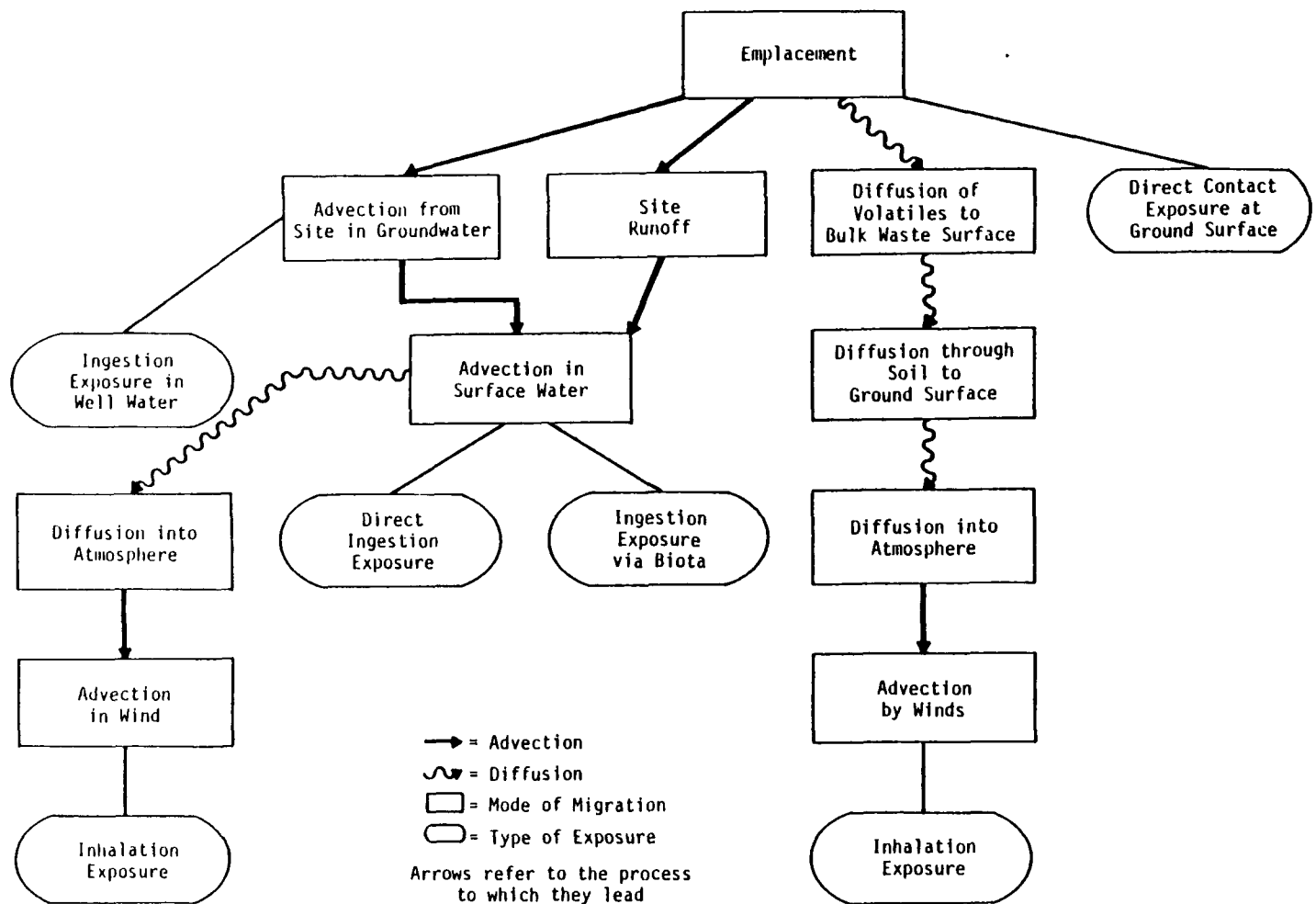
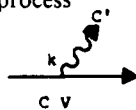


Figure 1.  
Sample diagram for migration of hazardous wastes in the environment.

water concentration. The process



produces a flux out of the main flow at rate  $k A C$  (assuming as before  $C' < C$ ). Suppose material in the main flow is contained in a layer of constant thickness  $L$ . Then:

$$F = k A C = -LA \frac{dC}{dt} \quad (9)$$

or

$$C = C_0 e^{-\mu t} \quad (10)$$

where

$$\mu = \frac{k}{L} \quad (11)$$

Other types of loss process, e.g., where  $L$  diminishes and  $C$  is constant or where there is a bifurcation in the flow can be modeled in similar fashion. Equation 8 can be changed to read:

$$F = C_0 K_m A_m e^{-\mu \tau} \quad (12)$$

where  $\tau$  is the duration of the loss period.

Human exposure occurs at the end diagrams of Fig. 1; the subscript  $e$  is used to denote this location. Then the flux is  $F = C_e V_e A_e$  and:

$$C_e = C_0 \frac{K_m}{V_e} \frac{A_m}{A_e} e^{-\mu \tau} \quad (13)$$

where  $V_e$  has been written instead of  $K_e$  since it appears that all important human exposure occurs in advection locations (groundwater, surface water and air flows).

The analysis procedure implied by Equation 8 requires one to estimate  $k$ ,  $H$  and  $V$  at various points along the flow.  $V$  is assumed to be part of the description of the problem and  $H$  is either tabulated or chemical properties to calculate it are in handbooks for many substances. The mass transfer coefficient  $k$  can be estimated from the sources shown in Table 1.

Finally, substituting Equation 13 in Equation 1, one obtains the equation for total risk over time  $t_1$ , the release lifetime or other suitable time horizon:

$$R_t = t_1 \sum_{\text{chemicals cohorts}} \beta \gamma \left( \frac{P}{A_e} \right) \left( \frac{C_0 K_m A_m}{V_e} \right) e^{-\mu \tau} \quad (14)$$

where the ratio  $\frac{P}{A_e}$  is the population density of the cohort group in the exposure area and  $(C_0 K_m A_m)$  is an effective emission rate.

Table 1.  
Estimated  $k$  Values

$k$ Value	Situation	Reference
$k_L$	liquid side of interface, lagoon	Mackay <sup>1</sup>
$k_L$	liquid side of interface, stream	Owens <i>et al.</i> <sup>2</sup>
$k_A$	air side of interface in earth's lower boundary layer	Sutton <sup>3</sup>
$k_S$	diffusion through soil for vapor transport	Farmer <sup>4</sup>

## CORRESPONDENCE WITH THE HAZARD RANKING SYSTEM

In the HRS "parameter" scores  $S_{RAP}$  are combined with multipliers  $M_{RAP}$  to form an "area" score  $S_{RA}$ . The area scores are then combined into "route" scores  $S_R$ . Finally, these are combined into an aggregate groundwater, surface water, air score  $S$ . Specifically:

$$S = .59 \sqrt{\sum_R S_R^2} \quad (15)$$

$$S_R = K_R \prod_A S_{RA} \quad (16)$$

where  $K_R$  is a constant for each route,  $\pi$  is the product operator and,

$$S_{RA} = \sum_P M_{RAP} S_{RAP} \quad (17)$$

or combining the above:

$$S = .59 \left[ \sum_R K_R^2 \left( \prod_A \sum_P M_{RAP} S_{RAP} \right)^2 \right]^{1/2} \quad (18)$$

While Equations 15 through 18 accurately express the form of the HRS, they do obscure the fact that an observed release produces an override of the route characteristics and containment areas. It is the parameters  $P$  whose scores are  $S_{RAP}$  that we wish to identify with the quantities used in Equation 19. This correspondence is shown for the groundwater route in Table 2. Similar tables can be constructed for the surface water and air routes and comments similar to those which follow would ensue.

Table 2.  
Correspondence Between Equation 14 (OCP) and  
Equation 18 (HRS) Parameters

HRS	OCP
R=1 Groundwater	
A=1 Observed release	$C_o K_m A_m$
A=2 Route characteristics	$K_m A_m$
P=1 Depth to aquifer of concern	
P=2 Net Precipitation	
P=3 Permeability	
A=3 Containment	$K_m A_m$
A=4 and A=5*	
A=6 Waste characteristics	
P=1 Physical state	$K_m$
P=2 Persistence	$\mu$
P=3 Toxicity/infectiousness	$\beta$
A=7 Hazardous waste quantity	$C_o K_m A_m t_1$
A=8 Targets	
P=1 Groundwater use	$\gamma$
P= Distance to nearest well downgradient	$A_e, \tau$
P=3 Population served by groundwater within 3-mile radius	$P$

\*These steps simply choose the larger score between A=1 and (A=2) x (A=3) for subsequent calculation.

There is no transformation which will map the HRS into the OCP or vice versa. Perhaps this is not surprising since parameters in the HRS appear to be arranged by topical area for use convenience. In any case, consider the parameters  $\mu$  (persistence),  $\beta$  (toxicity) and  $P$  (population exposed). In the HRS the scores combine in the form  $(M_\mu S_\mu + M_\beta S_\beta) S_P$ . In the OCP the parameters occur as the factor  $\beta P e^{-\mu\tau}$ . One transformation of Equation 14 is of particular interest. It is possible to generate a scoring system for a particular chemical and cohort group by taking the logarithm of  $R_t$ :

$$S_{R_t} = S_\beta + S_\gamma + S_P + S_W - S_V e^{-\mu\tau} \quad (19)$$

where  $S_\beta = \ln \beta$ , for example,  $P$  is population density and  $W$  is quantity of waste,  $t_1 C_o K_m A_m$ . Alternatively one can set  $t_1 = 1$  to consider risk per unit time and replace  $S_W$  by  $S_Q$ , where  $Q$  is the release rate ( $C_o K_m A_m$ ).

In fact the HRS Equation 18 is a combination of additive and multiplicative factors, a sort of hybrid between Equations 14 and 19.

## CONCLUSIONS

Examination of Equations 14 and 18 in light of Table 2 yields the following conclusions:

- The OCP makes no attempt to discount future risks although this could be done. Thus if there is a release the total risk is simply proportional to the amount of hazardous material involved ( $C_o K_m A_m t_1$ ). The HRS on the other hand "strikes a balance" by combining scores for both total amount of material and release rate ( $K_m A_m$ ) parameters. As a related issue, it is noted that for a linear no-threshold dose response only the factor  $e^{-\mu\tau}$  in Equation 19 can contain the risk within a limited area  $A_e$ . For a persistent chemical therefore the distances involved can become very large. Again, the HRS takes a middle course by scoring on the basis of persistence but (for groundwater) only including population within a 3-mile radius.
- In the absence of an observed release the HRS multiplies scores for containment and route characteristics. Thus the precise value of either scoring area is important no matter how large (or small) the score. The OCP on the other hand stresses the area with what amounts to the *smaller* score since containment and route characteristics are serial elements with the more resistive or secure one controlling. Put differently, the OCP tends to consider what is "right" about a site and the HRS what is "wrong" about a site.
- The particular structure of Equation 18 leads to an interesting result for the sensitivity of the HRS results to input scores. From Equations 15 through 18, one can compute the derivative  $\partial (S)^2 / \partial S_{RAP}$  which is a measure of the sensitivity of the final score to the parameter score  $S_{RAP}$ , since  $\Delta S_{RAP}$  may be taken as  $\pm 1$  (parameter scores only take integral values). Of course for the case of an observed release or not one must compute  $S^2$  (observed) -  $S^2$  (not observed).

$$\frac{\partial (S^2)}{\partial S_{RAP}} = .70 \frac{S_R^2 M_{RAP}}{S_{RA}} \quad (20)$$

The significance of  $S_{RA}$  occurring in the denominator of this result is that the final score is most sensitive to the least important area scores.

## ACKNOWLEDGEMENT

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# ASSESSING SOIL CONTAMINATION AT LOVE CANAL

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## INTRODUCTION

No chemical waste site has caused more controversy and concern than Love Canal. Located in the midst of a residential area, this permanent repository of large quantities of discarded industrial chemicals and chemical wastes has been a center of attention, locally and nationally, both for environmental groups interested in waste disposal policies and for individuals directly impacted by nearby waste sites. The Canal has also attracted the attention of many of the Nation's leading scientists concerned with the technical complexities of determining the impact of toxic chemicals on human health.

During the latter half of 1980, the USEPA carried out an intensive study of environmental contamination in the area near Love Canal. While several limited investigations of contamination in the area had been previously conducted by Federal and State agencies, none approached the scope or magnitude of this 1980 effort.

The geographical area of special concern during the study, namely, the Declaration Area, is shown in Fig. 1. This U-shaped area was defined by a Presidential state of emergency order on May 21, 1980, following the earlier evacuation of the two rings of houses adjacent to the Canal inside the U-shaped area which are referred to as Rings 1 and 2. Within the Declaration Area are approximately 700 residences, some occupied and some evacuated.

A cross-section of the Canal and the subsurface features in the immediate vicinity of the Canal are shown in Fig. 2. As discussed below, this subsurface profile provides important clues as to the containment capability of the terrain around the Canal.

The study included a hydrogeological investigation, involving groundwater pumping tests and geophysical investigations, and a monitoring program involving the collection and analysis of a large number of air, soil, sediment, water, and biota samples. The magnitude of the monitoring program which included analyses of more than 6000 environmental samples and about the same number of quality assurance samples, is illustrated in Table 1.

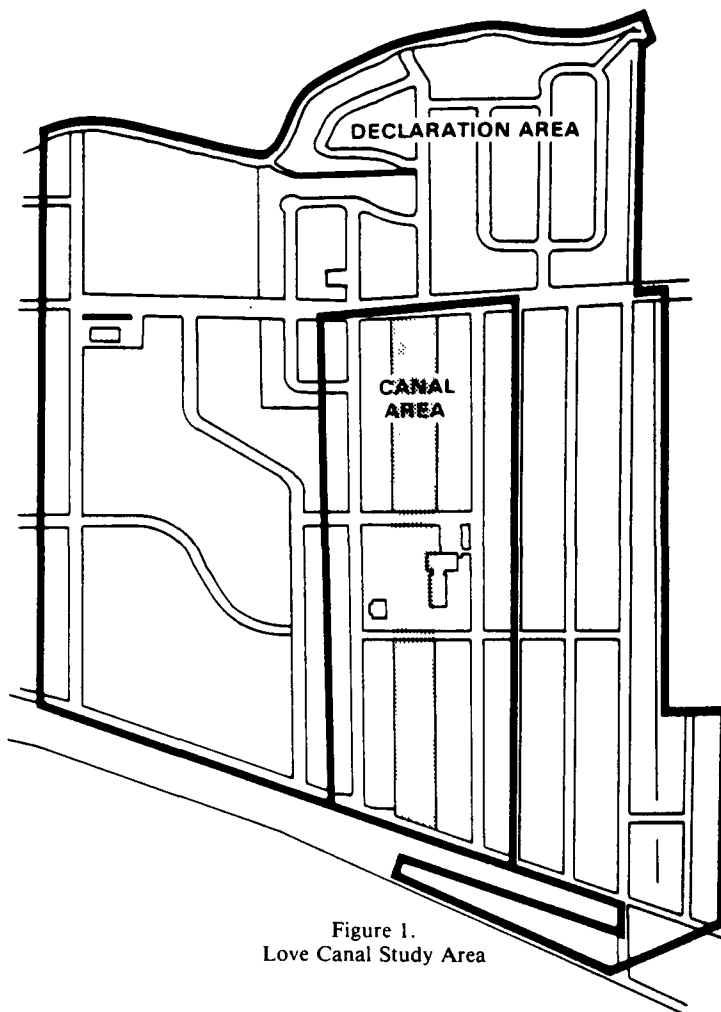


Figure 1.  
Love Canal Study Area

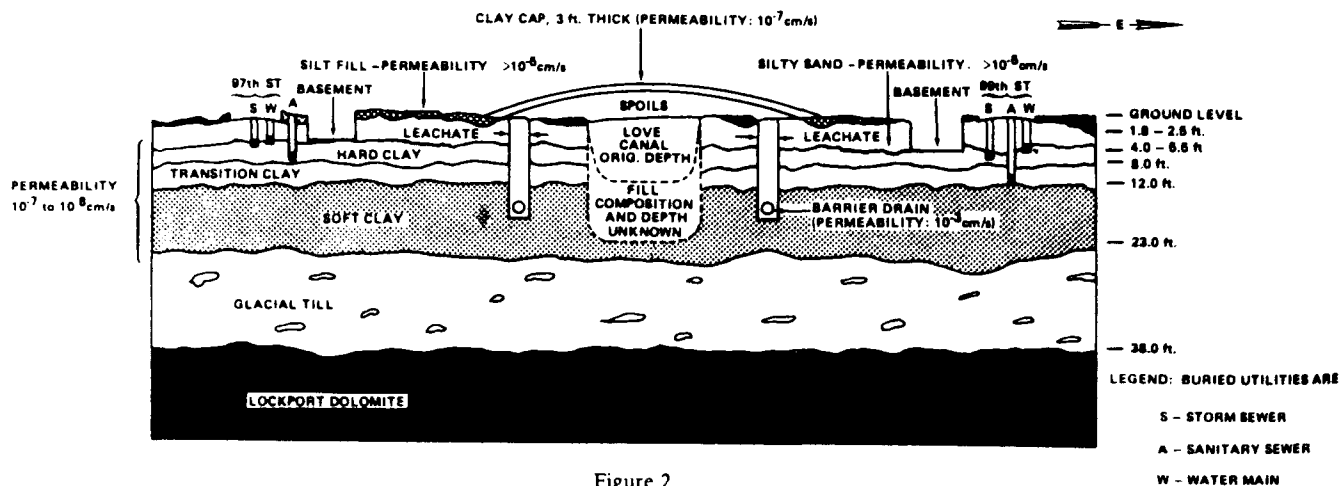


Figure 2.  
Vertical Profile of the Canal and Surrounding Area

**Table 1.**  
**Magnitude of the Love Canal Monitoring Program**  
**Sampling Areas**

	Declara- tion Area	Canal Area	Control Areas	Peripher- al Area	Total
<b>Water</b>					
Drinking	31	3	5	5	44
Ground:					
A shallow	49	19	11	---	79
B deep	29	13	15	---	57
Sanitary sewer	1	0	0	---	1
Storm sewer	22	3	1	2	28
Sump	33	13	1	7	54
Surface	4	---	5	10	19
<b>Soil</b>	112	24	9	28	171
<b>Sediment</b>					
Sanitary sewer	1	0	0	---	1
Storm sewer	18	4	1	1	24
Stream	4	---	5	9	18
Sump	---	3	---	---	3
<b>Air</b>					
Basement	9	1	0	---	10
Living	55	6	4	---	65
Outside	8	1	0	---	9
Transport study	---	---	---	5	5
Occupied/Unoccupied study	3	0	0	4	7
Sump/Basement-Air Study	0	9	0	---	9
<b>Biota</b>					
Crayfish	1	---	1	---	2
Dog hair	20	---	15	---	35
Maple leaves	14	6	11	---	31
Mice	5	2	2	---	9
Oatmeal	12	2	4	---	18
Potatoes	11	2	3	---	16
Worms	4	2	3	---	9

The field aspects of the program were, of necessity, confined to a three-month period. Therefore, there was no attempt to acquire and interpret preliminary field data to guide a more intensive effort. Such a two-phased approach is often desirable to help reduce monitoring costs through more deliberate selection of sampling sites. Also, the acquisition of data during different seasons was not possible. However, given the stable condition of the clay cap on the Canal and the sampling approach, it is unlikely that seasonal variations reflected in different patterns of surface runoff would significantly affect the monitoring results.

#### Study Objectives

The objectives of the overall study effort were:

- To determine the extent of environmental contamination in the Declaration Area attributable to Love Canal as of the Fall of 1980
- To assess the short-term and long-term implications of any detected groundwater contamination
- To assess the relative environmental quality of the Declaration Area
- To provide environmental data which could be used to determine the habitability of residences within the Declaration Area

A central consideration in achieving these objectives was an assessment of the chemical contamination of the soil in the area. Discussed below are the soil monitoring program that was carried out, the significance of data that were obtained from the program, and the relationship of the data to data obtained from the other study efforts.

#### Target and Non-Target Chemicals

About 150 chemicals including metals, pesticides, and industrial organic chemicals were selected as target chemicals for the soil, sediment, and water monitoring program. In making this selection, particular attention was given to chemicals that were identified in

**Table 2.**  
**Chemicals Disposed at Love Canal by Hooker Electrochemical Company (1942-1953)\***

Physical Type of Waste	State	Total Est. Quant. (Tons)	Container
Misc. acid chlorides other than benzoyl—includes acetyl, caprylyl, butyryl, nitro benzoyls	liquid & solid	400	drum
Thionyl chloride and misc. sul-ful/fchlorine compounds	liquid & solid	500	drum
Misc. chlorination—includes waxes, oils, naphthalenes, aniline	liquid & solid	1,000	drum
Dodecyl (Lauryl, Lorol) mercaptans (DDM), chlorides and misc. organic sulfur compounds	liquid & solid	2,400	drum
Trichlorophenol (TCP)	liquid & solid	200	drum
Benzoyl chlorides and benzo-trichlorides	liquid & solid	800	drum
Metal chlorides	solid	400	drum
Liquid disulfides (LDS/LDSN/BDS) and chlorotoluenes	liquid	700	drum
Hexachlorocyclohexane ( $\gamma$ -BHC/Lindane)	solid	6,900	drum & nonmetallic containers
Chlorobenzenes	liquid & solid	2,000	drum and nonmetallic containers
Benzylchlorides—includes benzyl chloride, benzyl alcohol, benzyl thiocyanate	solid	2,400	drum
Sodium sulfide/sulphydrates	solid	2,000	drum
Misc. 10% of above		2,000	
<b>Total</b>		<b>21,800</b>	

\*Interagency Task Force on Hazardous Wastes, Draft Report on Hazardous Waste Disposal in Erie and Niagara Counties, New York, March 1979. Hooker Electrochemical Company is now known as the Hooker Chemicals and Plastics Corporation.

previous monitoring efforts at Love Canal, were detected in chemical analyses of leachate from the Canal, and/or were known to have been deposited in the Canal (Table 2). Also, consideration was given to selecting chemicals of special toxicological concern (e.g. radionuclides, dioxin) and chemicals with a range of physical/chemical properties, such as solubilities and partition coefficients, that might influence their rates of environmental migration.

In addition to the target compounds, the analytical laboratories were required to identify up to 20 additional organic chemicals present in each sample if the chromatogram of the sample indicated the presence of such non-target chemicals. This requirement was to help insure that if other organic chemicals from whatever sources were present in the Declaration Area, they would be detected.

#### Sampling Strategy

The soil sampling program was based on both random and directed sampling. Random sampling was carried out on the basis of a grid, with grid squares measuring 440 ft on each side, throughout the Declaration Area. In the absence of reliable preliminary sampling data, it was not possible to develop a statistical basis for determining the optimum size of the grid squares. Therefore, the dimension of 440 ft was selected taking into account the constituency of the soil, the pattern of man-induced disturbances of the soil and of possible pollutant pathways through soil, soil sampling experience at other locations, and budgetary limitations. In retrospect, the data that were acquired confirmed that from a statistical viewpoint, the size of the grid squares was reasonable.



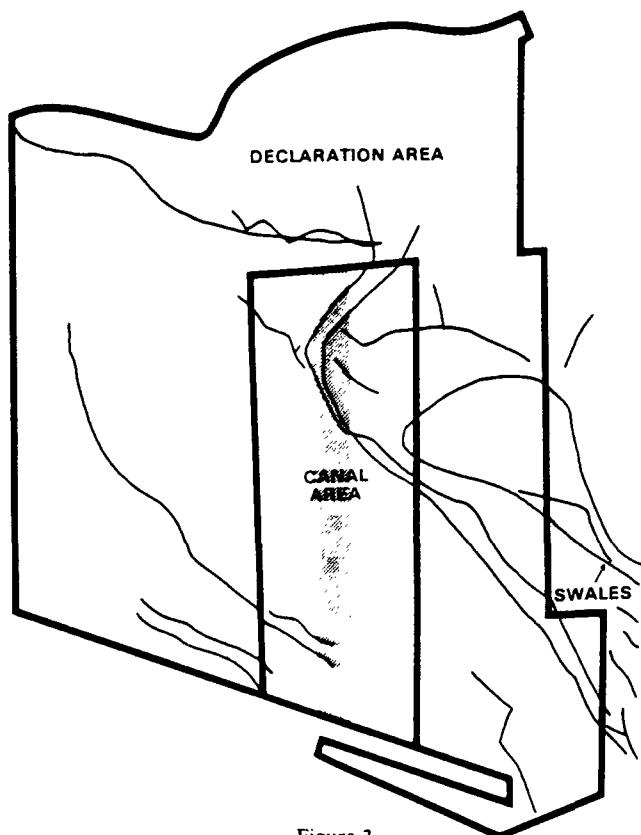


Figure 3.  
Swales in the Love Canal Area

Directed sampling was carried out:

- Along swales, or geological depressions which over the years had been filled in and which were suspected of providing surface runoff pathways for pollutant migration (Fig. 3)
- In areas associated with wet basements which were believed to be areas of more heavily contaminated soil
- In a known sand lens near the Canal which might have provided a preferential pathway for chemical migration

To provide a basis for statistical comparisons, samples were taken in three areas: (1) in the area immediately adjacent to the Canal, (2) in the Declaration Area, and (3) in several control areas one to two miles from the Canal. Also, a few soil samples were taken at "base" sites throughout the Declaration Area where multimedia sampling was conducted in efforts to clarify possible transport pathways (Fig. 4).

Special soil sampling efforts were undertaken in the search for possible problems related to dioxin and radionuclides. These activities revealed no indication of dioxin contamination in the soil nor radiation levels above world-wide background and are not discussed further.

#### Sampling Techniques

The basic soil sampling scheme at each site is shown in Fig. 5. Five cores, 6 ft long and 1.375 in. in diameter, were composited at the site and subsequently analyzed for semi-volatile organic chemicals, including pesticides, and for metals. Two additional cores were taken at each site and immediately sealed for analysis for volatile organic chemicals. The sampling equipment was carefully cleaned between samples to avoid contamination, and a number of field blanks were analyzed as a further precaution to insure that contaminants due to sampling procedures were not misidentified as pollutants in the soil.

A coring depth of 6 ft was selected since this depth included most of the more permeable soil layers in the area although the area was generally characterized by a predominance of relatively impermeable clays. A shallower depth might have provided a better

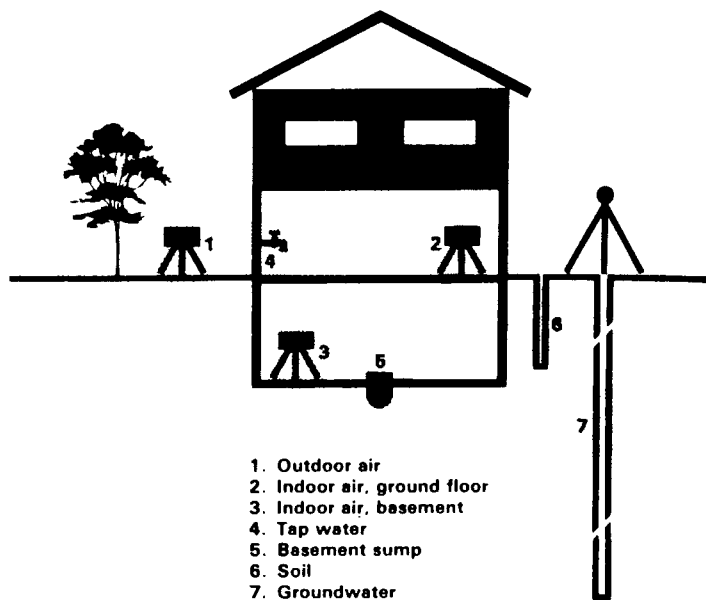
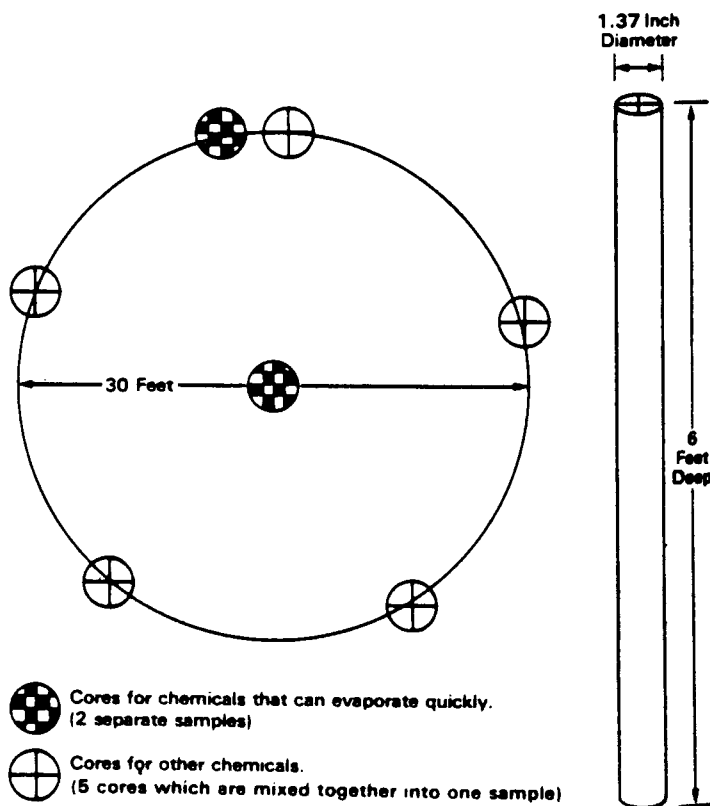


Figure 4.  
Multimedia Monitoring at Base Sites

picture of contamination due to surface water runoff in the area in recent years while greater depths conceivably might have provided better correlations between the shallow groundwater aquifer and soil contamination. Budget and time constraints prohibited multi-depth sampling, and composite sampling of the top six feet of soil was considered a reasonable compromise in determining possible pollution migration patterns as well as the pollution saturation of the area as one indicator of future habitability of the area. Had



- Cores for chemicals that can evaporate quickly. (2 separate samples)
- Cores for other chemicals. (5 cores which are mixed together into one sample)

Figure 5.  
Soil Sampling Scheme

preliminary sampling at different depths been possible, a statistical basis for determining the most appropriate depth might have been developed. In any event the soil data obtained was generally consistent with data acquired by the State of New York which collected soil samples using a trenching technique.

## ANALYTICAL METHODS

### Selecting the Methods

The selection of appropriate methods for the analysis of soil and sediment samples was one of the important challenges of the Love Canal program. Over the years, USEPA has had experience in the analysis of soil samples for most of the pesticides and metals of interest, and this experience was reflected in the analytical methods that were chosen as indicated in Figs. 6 and 7. On the other hand, prior to 1980 neither USEPA nor the scientific community as a whole had much experience in analyzing soil samples for the other organic compounds of interest, and no analytical methods had been evaluated in interlaboratory comparative studies.

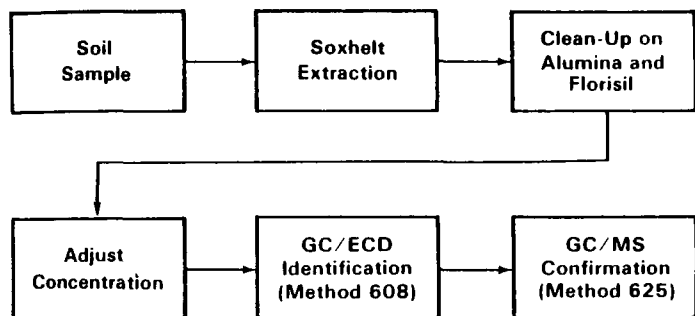


Figure 6.  
Method for Pesticide Analysis

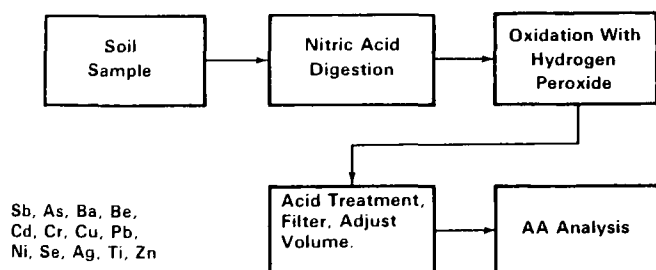


Figure 7.  
Method for Analysis of Metals

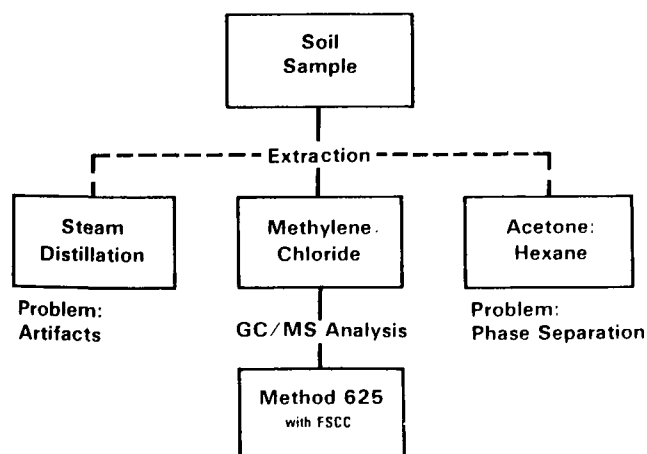


Figure 8.  
Candidate Methods for Extraction of Semi-Volatile Organics from Soil

The three candidate procedures that were considered for extracting semi-volatile chemicals from soil are shown in Fig. 8. Two contractor laboratories were selected for a quick evaluation of these procedures. These laboratories prepared extractions using each of the approaches from a limited number of triplicate samples. Analyses of the samples indicated that the steam distillation technique resulted in the formation of chemicals that were not originally present. Also, these analyses indicated that the acetone/hexane technique resulted in phase separations that impeded analysis. Therefore, the extraction technique using methylene chloride which did not exhibit comparable problems was selected as the most appropriate.

For analyzing the extracts the gas chromatography/mass spectrometry method that had been successfully used by USEPA in programs under the Clean Water Act (Method 625) was selected. However, one very significant modification of the method was introduced, namely, the use of fused silica capillary columns in lieu of packed columns. This technology had only recently become available and had demonstrated excellent results during USEPA evaluations. It reduced considerably the time and costs of analyses. Three other modifications of Method 625 were the use of a high speed mechanical stirrer, centrifuging to separate phases, and optional gel permeation chromatography procedures for heavily contaminated samples.

With regard to analyses for volatile organic compounds, USEPA's proposed Method 624 developed for the water program was used. Minor modifications of the method included placing a mixture of soil and reagent water in a vial and purging as in Method 624, but heating the mixture to 55°C during the purge to facilitate rapid equilibration of analyses between the sorbed and liquid phases.

### Quality Assurance/Quality Control Procedures

This aspect of the program was designed to insure that the field collection teams and the analytical laboratories performed at the highest scientific level possible, that all data included in the data base met minimum acceptance criteria, and that the variability of the data was set forth. Among the key elements of the approach were requirements for:

- Sample collection, preservation, and holding times
- On-site sample system audits and personnel performance audits
- Analytical methods, calibrations, and control chart usage
- External analytical quality assurance programs, including the use of EPA performance evaluation and quality control samples
- Internal analytical quality assurance programs, including reference compounds, method blanks, laboratory control standards, laboratory duplicates, and surrogate compound spikes
- The collection and analysis of replicate field samples and field blanks
- Splitting field samples between laboratories

The procedures worked. They uncovered deficiencies during the program and provided opportunities to correct the deficiencies. For example, prompt review of the data indicated that one of the laboratories had improperly analyzed 70 samples. The data that had been reported were rejected, and the activities of this laboratory were halted until the problems were corrected. In another case, laboratory contamination was identified through the quality assurance program, and correction factors were applied to the data.

### Data Review and Validation

In addition to the data review carried out by the USEPA contractor managing the overall program, USEPA specialists also reviewed all data. Each data point was individually "validated" by USEPA prior to acceptance into the data base. The validation process asked four aspects:

- Were the recoveries of the surrogate chemicals introduced into each soil sample within acceptable limits?

- Were the recoveries of laboratory control standards within an acceptable range?
- Were the holding times of samples prior to analysis within acceptable limits?
- Were there adequate adjustments in the reported data in response to indications of background contamination in the field or reagent blanks that were analyzed?

Only data which met these criteria were "validated" and entered into the data base.

The variability of the data attributable to the inherent variations in the analytical procedures was of special interest. It was recognized at the outset of the program that in applying state-of-the-art methods to an operational monitoring program for the first time without the benefit of interlaboratory comparative studies, there would be considerable uncertainty in this area.

Initially, precision and accuracy of the analytical data were to be based on the results of analyses of duplicate samples. However, the number of positive finding was so small that this approach was not feasible. Therefore, attention was directed to the performance of the laboratories in analyzing standard reference materials provided by the National Bureau of Standards. Unfortunately, soil or sediment reference materials for many of the chemicals of interest were not available, and rigorous precision and accuracy determinations were not possible. Nevertheless, using the limited information that was developed, rough estimates were made of the variability of the inorganics data attributable to the extraction and analytical procedures and were 15 to 30% and for the organic data were factors of 2 to 3.

Also of interest were the method detection limits, particularly for organic chemicals, since most of the data points were "below detectable." The recovery data for the sediment reference materials that were available and for the surrogate spikes together with a review of the performance of the analytical laboratories using aqueous samples provided important insights in this regard. The best estimates were that the instrument detection levels determined on a daily basis by each laboratory using laboratory control standards in an aqueous form were of the same order of magnitude as the detection capability of the methods employed to extract and measure the same chemicals from a soil matrix. These instrument detection limits were in the 10-20 ppb range for most organic chemicals.

## FINDINGS OF THE SOIL MONITORING PROGRAM

### Presentation of the Data

The findings were presented in several formats to ease the interpretation process. One approach (Table 3), was to compare statistically the extent of contamination in the Canal, Declaration Area, and Control Areas on a pollutant-by-pollutant basis. A second approach (Table 4), was to compare statistically the concentration levels of the few contaminants that were found in the three areas. Another approach was to present in tabular form data on the number of positive and trace findings in ten subareas of the Declaration Area. The final, and in many respects the most interesting, approach was to plot individual data points for selected chemicals on a map of the area and then to examine carefully the maps, individually and collectively, for possible pollution gradients or other patterns. Two examples of such maps are shown in Figs. 9 and 10.

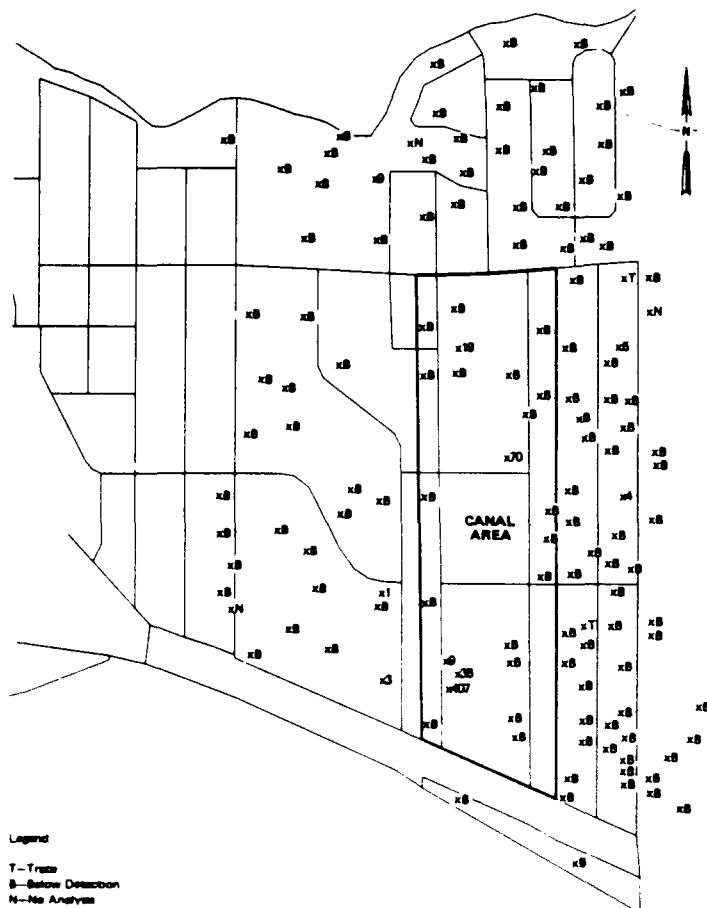


Figure 9.  
Soil Sampling Results (ppb), Lindane

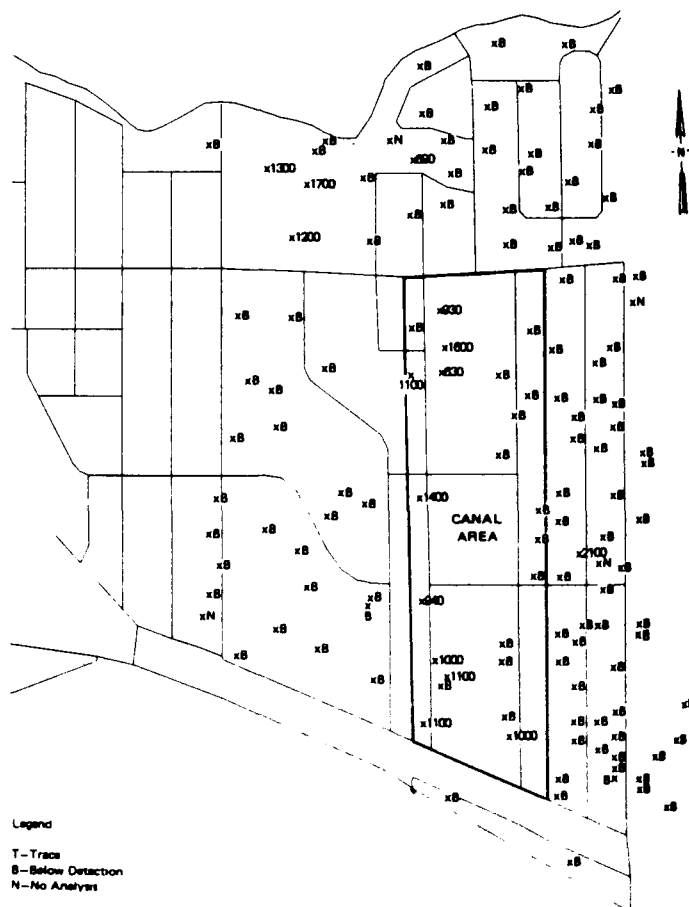


Figure 10.  
Soil Sampling Results (ppb), Cadmium

**Table 3.**  
**Significant Differences Observed in Extent of**  
**Soil Contamination at Love Canal**

Compound/Element	Percent Detect (No. of Samples)			Comparison*								
	Decl.	Control	Canal	Canal Decl.	Decl. Control							
Phenanthrene	23.8 (105)	44.4 (9)	39.1 (23)	No ( $\alpha =$ 0.108)	No	DDT	5.5 (109)	0.0 (9)	21.7 (23)	Yes	No	
$\alpha$ -BHC	8.3 (109)	0.0 (9)	26.1 (23)	Yes	No	1,1-Dichloroethene	2.3 (213)	0.0 (17)	17.8 (45)	Yes	No	
$\delta$ -BHC	10.1 (109)	0.0 (9)	39.1 (23)	Yes	* No	Chloroform	19.2 (213)	41.2 (17)	42.2 (45)	Yes	No	
$\gamma$ -BHC (Lindane)	6.4 (109)	0.0 (9)	21.7 (23)	Yes	No	3-Chlorotoluene	0.0 (213)	0.0 (17)	4.4 (45)	Yes	No	
Heptachlor epoxide	0.9 (109)	0.0 (9)	8.7 (23)	Yes	No	Chlorobenzene	1.4 (212)	0.0 (17)	6.7 (45)	Yes	No	
Endrin	9.2 (109)	0.0 (9)	26.1 (23)	Yes	No	Cadmium	4.6	0.0	39.1	Yes	No	

\*Comparisons are based on a one-tailed difference of proportions test ( $\alpha = 0.10$ ), using Fisher's exact test, for the areas indicated, and in the order presented.

### Contamination Patterns

In general, the few patterns of soil contamination that were observed, suggested that contaminants had migrated from the former Canal to the immediate vicinity of certain Ring 1 residences. These included residences that were suspected of having been sub-

jected to the overland flow of contaminants from the landfill prior to emplacement of the clay cap over the Canal and residences that had been constructed in the vicinity of more permeable soil pathways. In particular, soil contamination was prevalent at soil sampling sites located closest to the known sand lens and located at the former major swale that crossed Love Canal.

**Table 4.**  
**Significant Differences in Levels of Soil Concentration**

SUBSTANCE	PERCENT OF SAMPLES ABOVE DETECTION LIMIT/ STD. DEVIATION OF % / (NUMBER OF SAMPLES)			DIFFERENCE IN PERCENT OF SAMPLES ABOVE DETECTION LIMIT (PROBABILITY VALUE)			MEDIAN CONCENTRATION AND 90TH PERCENTILE			DIFFERENCE IN MEDIAN CONCENTRATIONS (PROBABILITY VALUE)		
	CONTROL	CANAL	DEC.	CANAL - CONTROL	DEC. - CONTROL	CANAL - DEC.	CONTROL	CANAL	DEC.	CANAL - CONTROL	DEC. - CONTROL	CANAL - DEC.
LEAD	100.0 0.0 ( 9 )	91.3 5.9 ( 23 )	98.1 1.3 ( 108 )	-9 (1.000)	-2 (1.000)	-7 (0.983)	19000 22000	13000 31000	22000 57000	-6000 (0.943)	3000 (0.017)	-9000 (0.999)
NICKEL	100.0 0.0 ( 9 )	100.0 0.0 ( 23 )	100.0 0.0 ( 108 )	0 (1.000)	0 (1.000)	0 (1.000)	20000 30000	20000 26000	22000 29000	0 (0.589)	2000 (0.639)	-2000 (0.971)
MERCURY	100.0 0.0 ( 9 )	69.6 9.6 ( 23 )	92.5 2.5 ( 107 )	-30 (1.000)	-7 (1.000)	-23 (0.999)	34 62	31 2300	35 85	-3 (0.783)	1 (0.522)	-4 (0.968)
SILVER	0.0 0.0 ( 6 )	52.2 10.4 ( 23 )	61.7 4.7 ( 107 )	52 (0.026)	62 (0.004)	-10 (0.859)	B B	560 1100	860 1600	. ( . )	. ( . )	-300 (0.988)
THALLIUM	0.0 0.0 ( 9 )	4.5 4.4 ( 22 )	3.7 1.8 ( 108 )	5 (0.710)	4 (0.723)	1 (0.611)	B B	B B	B B	. ( . )	. ( . )	. ( . )
ZINC	88.9 10.5 ( 9 )	100.0 0.0 ( 23 )	100.0 0.0 ( 108 )	11 (0.281)	11 (0.077)	0 (1.000)	63000 92000	58000 74000	64000 112000	-5000 (0.996)	1000 (0.511)	-6000 (0.965)
ALPHA-BHC	0.0 0.0 ( 9 )	26.1 9.2 ( 23 )	8.3 2.6 ( 109 )	26 (0.111)	8 (0.477)	18 (0.025)	B B	B 38	B B	. ( . )	. ( . )	. ( . )
BETA-BHC	0.0 0.0 ( 9 )	21.7 8.6 ( 23 )	13.8 3.3 ( 109 )	22 (0.167)	14 (0.281)	8 (0.249)	B B	B 143	B 7	. ( . )	. ( . )	. ( . )
GAMMA-BHC	0.0 0.0 ( 9 )	21.7 8.6 ( 23 )	6.4 2.3 ( 109 )	22 (0.167)	6 (0.565)	15 (0.035)	B B	B 36	B B	. ( . )	. ( . )	. ( . )
DELTA-BHC	0.0 0.0 ( 9 )	39.1 10.2 ( 23 )	10.1 2.9 ( 109 )	39 (0.029)	10 (0.401)	29 (0.002)	B B	B 80	B T	. ( . )	. ( . )	. ( . )

However, there was no indication that contaminants had migrated into the Declaration Area. Gradients or other patterns which could relate contaminants to the Canal were not present. While a few relatively high values of inorganic chemicals were reported in the Declaration Area, they appeared to be clearly anomalies surrounded by lower values which were generally "below detectable" values. No evidence of Love Canal-related contamination that had migrated preferentially through former swales into the Declaration Area was found, nor were residences with wet basements found to have a higher degree of contamination than "dry" residences.

#### Comparison with Control Areas

Neither the extent of soil contamination nor the concentration levels observed in the Declaration Area were statistically different than the extent or levels of contamination in the Control Areas. The presence of a number of heavy metals in both Areas, such as mercury, zinc, copper, and lead, was consistent with findings in soils in many other parts of the country. Similarly, the occasional occurrence in soil of pesticide contaminants associated with household applications is not unusual in many residential areas.

#### Consistency with Other Aspects of the Study

The findings of the individual media monitoring efforts were generally consistent and mutually reinforcing. Specifically, the findings of the shallow aquifer and sump monitoring efforts were consistent with the soil findings. Each indicated probable contamination within Rings 1 and 2 directly attributable to the Canal within the Declaration Area. Within Rings 1 and 2 the highest values for the individual media tended to be centered at the same residences which were located along suspected pathways through permeable soils.

Similarly, the findings of the hydrogeology program demonstrated that there is little potential for migration from the Canal into the Declaration Area. Specifically, the geological investigations indicated that the extensive clay deposits with very low permeability throughout the area offer little opportunity for pollutant movement through soil. Also, the shallow aquifer meanders very slowly with little opportunity for distant transport of pollutants. There is no evidence that this aquifer is hydraulically connected with the bedrock aquifer which does move with somewhat greater speeds. Finally, man-made barriers such as electrical and sewer conduits and road foundations effectively block lateral migration of pollutants through the shallow aquifer or soil.

#### CONCLUSIONS

The soil monitoring data clearly support the principal conclusions of the overall study, namely, contamination which had migrated from the Canal into residential areas was confined to localized portions of the area within Rings 1 and 2. There was no evidence that the soil in the Declaration Area contained pollutants

which had migrated from the Canal. In addition, it is unlikely that undetected contamination exists in the Declaration Area above the detection levels, because the target compounds and many of the sampling sites were intentionally selected to maximize the probability of detection of both individual pollutant points and migration patterns.

The soil data are consistent with the information obtained from the hydrogeological program and the groundwater monitoring effort. This information indicates that given the subsurface structure of the area and continued effective operation of the existing barrier drain system around the Canal the lateral migration of contaminants through the overburden will not occur in the near term and there is little likelihood of lateral or vertical migration over the long term.

The anomalous data points of relatively high values found in the Declaration Area cannot be explained by migration from the Canal. According to local residents there were cases of soil from the Canal being used as fill in earlier years, and this might explain some of the anomalies. Also, habits of individual consumers in using household chemicals and in maintaining their residences are known to result in different types of contamination.

Finally, with regard to the environmental quality of the Declaration Area, the soil is no more contaminated than the soil in the Control Areas. This level of contamination which is in large measure attributable to naturally occurring chemicals is probably little different than contamination levels in many other industrialized areas of the country.

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# USES AND LIMITATIONS OF RISK ASSESSMENTS IN DECISION-MAKING ON HAZARDOUS WASTE SITES

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## INTRODUCTION

Many decisions on the management or cleanup of hazardous waste sites require a more or less explicit balancing of costs against risks. For example, the decision as to whether or not to clean up an uncontrolled hazardous waste site that is leaking involves weighing the costs of cleanup against the risks resulting from continued leakage. The decision to site a new facility in one place rather than another involves weighing the relative costs of the two sites against their relative risks. The decision by an operator to seek insurance coverage for a site involves weighing the risks posed by the site against the cost of premiums and loss control programs. Although these and other decisions are subject to governmental regulations and permits, the regulations themselves are established by a process that involves at least some modicum of cost-benefit analysis. Almost every aspect of operating a hazardous waste site, from selecting the site through design, permitting, construction, insurance, operation, public relations, and closure, to remedial cleanup action and settlement of liability claims, requires some attempt—formal or informal—to assess risks.

Risk assessment for toxic chemicals is a fairly well-established scientific procedure which requires comparison of the degree of exposure of individual persons to a toxic chemical with the exposure levels known to cause toxic effects. The degree of exposure is calculated from knowledge of the distribution of the chemical in the environment, which is derived from dispersion models, from monitoring data, or from some combination of the two. Toxicity information is derived, where possible, from human experience, but more frequently is obtained from experimental studies in laboratory animals. The exposure and toxicity data are combined with information on the size of the exposed population to yield overall estimates of the number of people likely to be affected, and the nature and severity of the effects.

Risk assessments for toxic chemicals are almost always difficult to conduct and give uncertain results, among other things because exposure is usually variable and poorly characterized, and because toxicity information is difficult to extrapolate from animals to humans. The problems are much greater for hazardous wastes, for several reasons. First, the wastes are often poorly characterized chemically, especially when they result from disposal in the "bad old days" of the past. Even when the chemicals present in the wastes are reasonably well known, they are usually present as complex and variable mixtures, which makes it very difficult to assess either exposure or toxicity. In uncontrolled landfills, for example, where wastes are leaking into subsoil and groundwater, the variability of underground media makes it very difficult to calculate rates of dispersion, and the variability of underground concentrations makes it difficult to measure rates of dispersion without elaborate and expensive monitoring programs. The toxicity of mixtures is very rarely measured, and is difficult to assess theoretically because so little is known about interactions and synergisms. And without knowledge of the rate of dispersion, even the size of the population at risk is difficult to estimate reliably.

## QUALITATIVE RISK ASSESSMENT

For these reasons, risk assessments for hazardous waste sites are frequently made only in a qualitative way. A typical qualitative risk assessment involves a number of steps:

- An engineering survey of the site, including an assessment of the propensity for scheduled and unscheduled releases;
- An inventory of the materials stored or disposed of at the site;
- An assessment of geological, hydrogeological and meteorological data, to assess the propensity for transport of materials away from the site;
- A monitoring program for groundwater, air, and other media, to measure the ambient concentrations of chemicals being transported away from the site;
- A survey of the distribution of the human population and other sensitive targets subject to exposure;
- A review of the toxicity of each of the major components of the material subject to release;
- Finally, an assessment of potential risks resulting from the exposure, including characterization of the uncertainty in this assessment.

Unless a very detailed monitoring program is carried out, it is rarely possible for such an assessment to be quantitatively reliable. In many cases, the risk assessor has to settle for much less—often a ranking or scoring procedure for factors controlling inherent hazard, release, environmental transport, and population at risk. At best, such a procedure can yield a ranking of risk on a qualitative or semi-quantitative scale; for example, on a scale from 1-10, or from "low" to "high". This is sufficient for many purposes—e.g., for priority setting, for permitting, or for decisions on loss control programs or insurance.

## QUANTITATIVE RISK ASSESSMENT

There are at least three situations, however, in which semi-quantitative assessment of risks is not sufficient, and the risk assessor is forced to venture into the risky area of quantitative assessment. These three areas will be the subject of the remainder of this paper.

### Defining Boundaries of Areas of Habitability

Once contamination has been identified as posing a significant hazard to local residents, the decision-maker is faced with an immediate problem: how is the boundary to be drawn between areas of habitability and uninhabitability? Clearly, the places where hazardous exposures have been identified are uninhabitable: if immediate cleanup cannot be effected, the inhabitants must be evacuated. Clearly, areas far enough from the site are habitable. But how is the boundary to be determined? By definition, it corresponds to the margin between acceptable and unacceptable risk. This margin is difficult to determine in the best of circumstances, but in circumstances of multi-chemical contamination the difficulty is compounded by the lack of information about both exposure and toxicity. Initial decisions on evacuation usually have to be taken at short notice, under conditions of public pressure or panic. However, subsequent decisions may not be much easier, as experience at Love Canal illustrates. Although the U.S. Environmental Protection Agency spent over \$5 million on an extensive multi-media monitoring program to document its finding that the "Declaration Area" was habitable after remedial work at the disposal site, this finding was vigorously disputed by other interested parties. It is noteworthy that this decision was not based on a formal assessment of risks, or exposures, or even of transport of

chemicals away from the site. Indeed, EPA's report suggests that the data were not sufficient to make quantitative assessments, despite the scope and expense of the monitoring program.

### **Establishing the Limits of Cleanup**

Once a decision is made to clean up a site, the issue immediately arises as to the extent of cleanup. Although a large fraction of the hazardous materials at a site may be concentrated, some are usually widely dispersed, and the marginal cost per unit of material removed usually rises steeply as the cleanup progresses. For rational allocation of resources, the marginal costs of cleanup should not increase much beyond the marginal value of the reduction in risk thereby achieved.

To implement this economic efficiency criterion, however, requires fairly precise calculation of the marginal reduction in risk, not to mention agreement on how to express the value of risk reduction in dollars. Calculation of marginal risk reductions requires numerical estimates of risk for each degree of cleanup, which in turn requires precise estimates of exposure and toxicity as a function of exposure. A classic illustration is provided by the contamination of the Hudson River with PCBs. Despite fairly detailed information on exposure and on the toxicity of PCBs, cost-risk calculations did not command sufficient acceptance to serve as the basis for public policy decisions. EPA has still to make final decisions on the degree of cleanup required for PCB spills, despite the immediate importance of such decisions for many affected parties.

### **Award of Damages in Personal Injury Suits**

In the event that material leaking from hazardous waste sites actually leads to injury to individuals, their final recourse is to seek redress through the courts. The award of compensatory damages is a third area in which quantitative risk assessment should play an important role. Except in cases where exposure has led to short-

term injury, clearly attributable to a hazardous waste site, the establishment of liability and the assessment of damages require the proof of risk (i.e., probability of injury). This involves the same process of estimation of exposure and toxicity that has proved difficult in other contexts. Although some personal injury cases have been settled out of court after presentation of scientific evidence about the magnitude of risk, I know of none which has gone to trial and has been resolved on the basis of such evidence.

### **SUMMARY**

Enough has been said to illustrate the limitations of risk assessment in resolving critical issues involving hazardous waste sites. Although quantitative risk assessment is theoretically essential for certain types of decision-making, in practice it is rarely, if ever, used for these purposes. One practical problem is that quantitative risk assessment requires a degree of comprehensiveness in monitoring and toxicity testing that is usually prohibitively expensive. But even where comprehensive data have been obtained, they have either not been used for risk assessment (as in the case of Love Canal) or the risk assessments have not been used in decision-making (as in the case of the Hudson River). In these and other cases, perceptions about the uncertainties in quantitative risk assessments have led to their results being discounted, so that public policy decisions were based on more traditional, more subjective weighing of the information.

All the effort is not wasted, however. At the least, the experience gained from these attempts to make quantitative risk assessments contributes significantly to their practitioners' ability to make the reasonable scientific judgments involved in qualitative and semi-quantitative risk assessments. With sufficient knowledge and experience, these assessments can be reliable and useful tools in decision-making for most hazardous waste issues. It is important, however, to recognize the limitations of risk assessments, and to understand that quantitative calculations of risk are only justified if unusually extensive information is available.



# MULTIATTRIBUTE DECISION-MAKING IMBEDDED WITH RISK ASSESSMENT FOR UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Many modern technology related societal problems, especially those involving risks to human health and safety are becoming more complex and uncertain. Large amounts of data and multiple conflicting objectives require the incorporation of subjective judgments. In case the adversary positions (i.e., a politicized conflict) exist, it usually becomes a problem so politically volatile that a decision maker must rely on more than just intuition. The problem area of sludge and compost utilization is just such a situation. It calls for a systematic technique which would allow decision makers to adequately address the complex issues involved and develop viable solutions based on both objective analysis and subjective adjustments.

Decision analysis that incorporates a multiattribute utility function is an apparent, effective tool for this type of problem since it is highly flexible, incorporates methods to handle uncertainty, and multiple objectives and is also a well developed technique. However, it is not without faults. The most glaring, as pointed out by Rose,<sup>3</sup> is its inability to properly treat the subjective nature of risk. Thus, an integrated method incorporating multiattribute decision analysis with a quantitative risk assessment technique is needed to handle such problems as sludge and compost utilization. The basic steps entailed in such a unified approach include:

- Construct a decision tree for the specific situation
- Complete a detailed risk analysis
  - Determine the objective risk of each decision branch
  - Determine the appropriate risk referents
  - Use an objective risk versus risk referent comparison to determine if a decision branch requires modification or should be eliminated from consideration
- Conduct a sensitivity analysis of the risk comparison in order to determine which branches are only "marginally" acceptable
- Complete the multiattribute decision analysis with the pruned tree
- Conduct a sensitivity analysis of the "solution"

In the remainder of this paper, the authors explore this integrated technique in more detail.

## DECISION TREE CONSTRUCTION

The organization and construction of a decision tree is essentially the first task in the decision making process. In general the following steps should be utilized to construct a tree:

- Generate an objective hierarchy which terminates in the attributes (which includes risks) and attribute measurements (a possible hierarchy for hazardous waste problems is shown in Fig. 1)
- Determine the viable courses of action available
- Determine the possible chance events (i.e., failure events, outcomes etc.) resulting from a decision

- Arrange the decision options and resulting chance events in chronological order (a generalized structure for problems which largely involve risk is shown in Fig. 2)
- Evaluate the specific probabilities for each chance event
- Evaluate the magnitude of each attribute

A number of key areas in this process require a more detailed explanation. First, it is necessary to take a closer look at the meaning of "viable courses of action". The term implies that some pre-decision tree criteria are used to eliminate "nonviable" alternatives from entering into the decision making process. In the hazardous waste area, the principal criterion to serve this purpose is implementation time. The discovery of an uncontrolled dump site for highly toxic substances would in all political reality require initial positive action which took a minimum time to implement. The number of viable options would probably be small. In the case of planning a new controlled disposal/storage site, this constraint would probably be greatly reduced, allowing a much wider scope of options to be considered.

A closer look is also required in the area of event space. A quick glance at Table 2 would cause some to think that what is being discussed is one "success" event and a few (one or more) "failure" event(s). This is of course far from the truth in anything but the most simplistic cases.

In most "real-life" type problems the failure event shown corresponds to the top event of an appropriate fault tree. A fault tree is another type of analytical tree which allows one to depict the

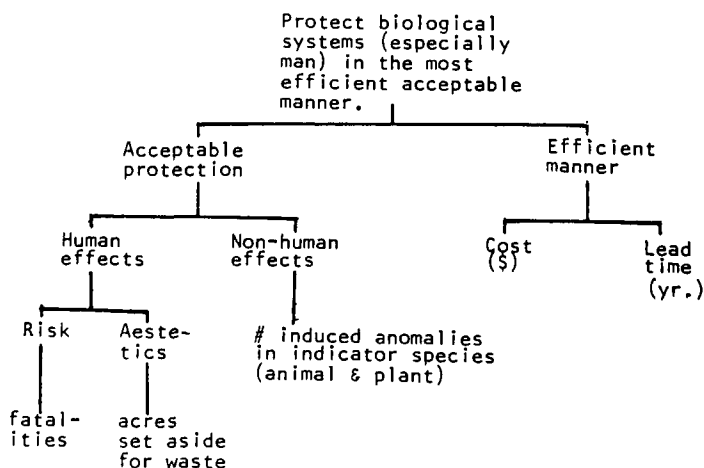


Figure 1.  
Sludge & Compost Utilization Objective Hierarchy

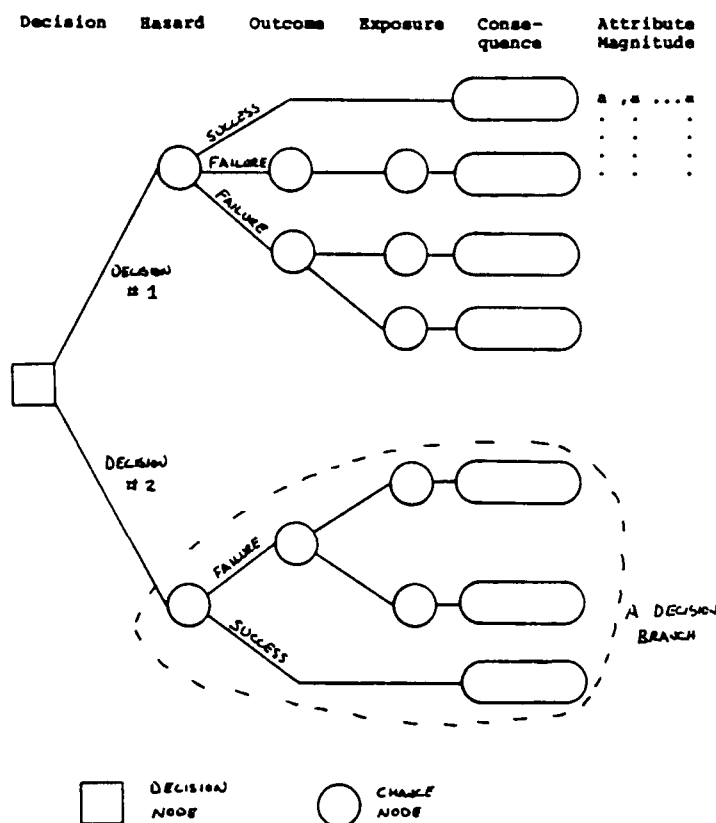


Figure 2.  
Generalized Decision Tree Structure

Table 1.  
Possible Risk Classification Scheme<sup>2</sup>

Risk Description	Class of Consequence		
	Fatalities	Morbidity	Property Damage
<b>Immediate</b>			
Catastrophic			
Involuntary	X	X	X
Regulated Voluntary	X	X	X
Ordinary			
Involuntary	X	X	X
Regulated Voluntary	X	X	X
<b>Delayed</b>			
Catastrophic			
Involuntary	X	X	X
Regulated Voluntary	X	X	X
Ordinary			
Involuntary	X	X	X
Regulated Voluntary	X	X	X

Table 2.  
Objective to Subjective Factors Summary<sup>2</sup>

#### Factors involving type of consequence

- Voluntary or involuntary (1)
- Discounting of time (2)
- Controlability (2)

#### Factors involving nature of consequence

- Position in hierarchy of consequences (1)
- Ordinary or catastrophic (1)
- Natural or man originated (1)

#### Other factors

- Magnitude of probability of occurrence
- Propensity for risk taking (2)

(1) Explicitly included in determination of absolute risk references

(2) Explicitly included in determination of risk referent

logical interrelationships between basic events that lead to an undesired event (i.e., the failure event). Using fault trees, Boolean algebra and various statistical techniques,<sup>6</sup> it is possible to determine failure event probabilities. In many cases the probabilities determined are only order of magnitude estimates. The success events shown in Fig. 2 represent the summation of all possible success events for a specific decision path. In practical terms the probability of this success is equal to one less the sum of all the computed failure event probabilities for the decision path.

This discussion leads right into the next area of decision tree construction which requires elaboration, the significant potential inaccuracies in both probability and attribute assessments. As indicated in the prior paragraph, even when "objective" methods are used the information obtained may be only order of magnitude. When value judgments are involved, which is often the case in these assessments, then even more inaccuracies can be expected. In fact, the level of accuracy can often be so low that a single "correct" answer cannot be determined. This does not negate the value of using quantitative techniques but should caution one to refrain from making unjustifiable claims of accuracy. Because of this, it is almost as important to obtain variance information about assessments as it is to know their location. This variance information especially becomes important in the subsequent step of sensitivity analysis.

### RISK ANALYSIS

As indicated by Rowe,<sup>3</sup> risk cannot be meaningfully analyzed in an aggregate; it must be differentiated into appropriate classes. A possible classification scheme for hazardous waste problems is provided in Table 1. After agreeing on an appropriate scheme, the objective (modeled) magnitude of risk of each class on each decision tree must be determined. In general this would be formulated in the following manner for each decision branch when a decision tree format is used:

$$Ro(A_i) = \sum (P_{c,j}) (a_{ij}) / ET \quad (1)$$

where:

- j a specific path in a decision branch
- $P_{c,j}$  conditional probability along path j
- $A_i$  a specific risk class
- $a_{ij}$  the consequence magnitude of risk  $A_i$  on path j (i.e., number of fatalities, etc.)
- E total population exposed to risk  $A_i$
- T time in years

(Note: This provides a measure of risk which is commensurate with the manner of data presentation used by Rowe.)

The next step is to determine appropriate risk referents. The purpose of a risk referent is to serve as the measure of risk acceptability (incorporating subjective perspectives). Rowe has proposed a methodology of calculating risk referents which is composed of two steps:

- Using historical data as a base, absolute risk references are determined for each risk class
- These absolute references are modified to fit the specific situation being analyzed producing risk referents

A clearer understanding of the details of this process can be gained by examining Table 2. In this table, the primary factors mentioned by Rowe as effecting the subjective (i.e., public) perception of risk are summarized and the step in which they are explicitly included in the calculation of risk referents is indicated. Rowe's assessment of the accuracy of this method indicated potential variances in excess of one order of magnitude. The area of prospect theory<sup>7</sup> provides a formalized explanation of the psychological rationale behind the determination of risk referents and provides some hope for future refinement of this process. At present, however, this is only a hope.

The final phase of the risk analysis can now be accomplished. This is nothing more complicated than a comparison of a decision branch's risk (for each class of risk) with the appropriate risk

referent. If the risk does not exceed the referent by more than one order of magnitude then the risk is considered publicly acceptable. This order of magnitude comparison is used due to the inherent inaccuracies in the risk information used. If this criterion cannot be met then the choice remains to either modify the decision branch (which will probably effect some or all of the non-risk attributes being considered such as cost) or to eliminate that branch. One of the modification steps involves, when the difference between objective and subjective risk is large, the education of the public as to the "actual" risk. In many cases, this may be a difficult, costly and time consuming path but in some cases it may be the only option other than complete abandonment of a project.

### MULTIATTRIBUTE DECISION ANALYSIS

This process can be broken into two principal parts:

- The development of a multiattribute utility function
- The calculation of expected utilities

The first is by far the more complicated procedure. It basically involves the assessment of attribute independence and then the development of appropriate mathematical formulations which allow the analyst to combine the utility function. A simplified summary of the independence assumptions and resulting formulations in multiattribute utility theory is provided in Table 3. The concept of preferential independence involves attributes under the condition of certainty while utility independence is specifically concerned with uncertainty. This process is developed according to the decision makers' perspective of the attributes not according to some set standard rules. Some general observations about the independence perceptions likely to be held by most decision makers in hazardous waste problems seems in order, though. First, the risk attributes normally will be both preferential and utility independent of the other attributes. Second, each risk attribute would normally be both preferential and utility independent of each other.

The second part of the process, the calculation of expected utilities, is basically just a mechanical process of "averaging out" and "folding back". Averaging out involves nothing more than the computation of  $\Sigma \text{PcU}$  (U-utility magnitude) for a decision node. Folding back entails the elimination of the less desirable paths at a decision node. Unlike most of the other aspects of the integrated analytical procedure, this portion of the process is purely "objective".

Table 3.  
Summary of Multiattribute Utility Theory<sup>1</sup>

#### Independence Definitions:

Preferential Independence (PI)—attribute X is PI of attribute Y if preference for consequences  $(x, y^2)$  with  $y^2$  held fixed do not depend on the amount of  $y^2$

Utility Independence (UI)—attribute X is UI of attribute Y if preference for lotteries on  $x, y^2$  with  $y^2$  fixed do not depend on the amount of  $y^2$

Additive Independence (AI)—attribute X and Y are AI preferences for lotteries  $(x, y)$  depend only on the marginal probability distributions on x and y

#### Utility Formulations:

If  $X_i \text{ UI } \bar{X}_i, i = 1, 2, \dots, n$  then

$$u(x) = \Sigma k_i u_i(x) + k_{ij} U_i(x_i) u_j(x_j) + \dots + k_{1 \dots n} u_1(x_1) \dots u_n(x_n)$$

If  $X, X_i \text{ PI } \bar{X}_{i,j}, i = 2, 3, \dots, n$  and  $X_1 \text{ UI } \bar{X}_1$ , then either

$$1) (1 + ku(x) = \Pi (1 + k k_i u_i(x_i)) \text{ or}$$

$$2) u(x) = \Sigma k_i u_i(x_i)$$

If  $X_i \text{ AI } \bar{X}_i, i = 1, 2, \dots, n$  then

$$u(x) = \Sigma k_i u_i(x_i)$$

### SENSITIVITY ANALYSIS

Sensitivity analysis is used at two points in this integrated procedure: (1) after the risk analysis, and (2) after completing the decision analysis. A sensible question at this point is what is sensitivity analysis and why is it necessary? Sensitivity analysis is a post-solution technique, intended to indicate how much trust can be placed in solutions, when one knows that all or most of the parameter values (probabilities, attribute assessments etc.) are not certain.

A significant level of inaccuracy is inherent in the type of problems being confronted here. Therefore, sensitivity analysis has a very important part to play in this analysis. Using this technique after risk analysis allows one to ascertain if any of the "acceptable" decision branches is really only marginally so. One would have a great deal of doubt if one of these marginally acceptable branches was the solution or a part of the solution chosen during decision analysis. In that case, one would probably be inclined to look at the problem with even greater intensity.

The same type of function is provided by the sensitivity analysis conducted after decision analysis. Sensitivity analysis does not have any rigid rules about what specific techniques to use. Within the context of the problems being addressed, there are two possibilities. The first is simply to change the value of selected parameters and see if the "solution" arrived at differs. A more useful approach involves the substitution of variables for selected parameters (normally one at a time), then solving the decision problem in terms of the variable. By changing the variable, one can graphically depict the effect it has on the desirability of each possible decision. This allows one to quickly determine which parameters are really significant and therefore require close attention.

### APPLICATION

In order to illustrate the use of the integrated methodology, the case study of Denny Farm 1<sup>1</sup> will be utilized. In this case an uncontrolled chemical dump site containing TCDD along with other substances was discovered in Missouri. The problem posed is how best to eliminate the health risk at and around this site. Four viable alternatives were suggested: (1) leave the site as is, (2) install and maintain a groundwater monitoring system, (3) excavate the dump and restore in a controlled manner on site, and (4) excavate the site and transport liquids and residues via truck to Syntex, an approved hazardous waste storage site. Since joint probabilities for each chance path have been delineated in the study, the simplified decision tree shown in Fig. 3 is used. Due to the lack of information provided by the study, only four attributes can be used: two classes of human risk, fatalities and morbidity, cost and lead time. The division of human impacts between fatalities and morbidity is made possible by assuming that 1.0% of all possible harmful human exposures determined in the study will result in fatalities. In reality, this assumption would have to be verified and revised as necessary.

The next step is to proceed with a risk analysis. The risk data provided by the study are summarized in Table 4. In order to use these data, it is necessary to express them in terms commensurate with the risk referents that will be calculated. This requires that a time duration in years for long term risk be established and that estimates of the total population exposed be determined. For the purposes of this paper, the long term risk duration is assumed to be evenly distributed over a span of 30 years.

Estimates of the total exposed population were calculated using data provided in the study. In some, but not all cases, this could be reasonably assumed to be equal to the maximum exposed numbers derived in the study. The objective risk was then calculated using the equation provided in the "Risk Analysis" section of this paper. These risk estimates are summarized in Table 7.

With objective risk determined, the next step was to calculate risk referents. This was accomplished using the procedure outlined by Rowe.<sup>3</sup> In order to do this some reasonable assumptions about the public's and worker's perception of the indirect gain-loss balance and the controllability of each alternative had to be made. These assumptions are shown in Table 5. A summary of the factors

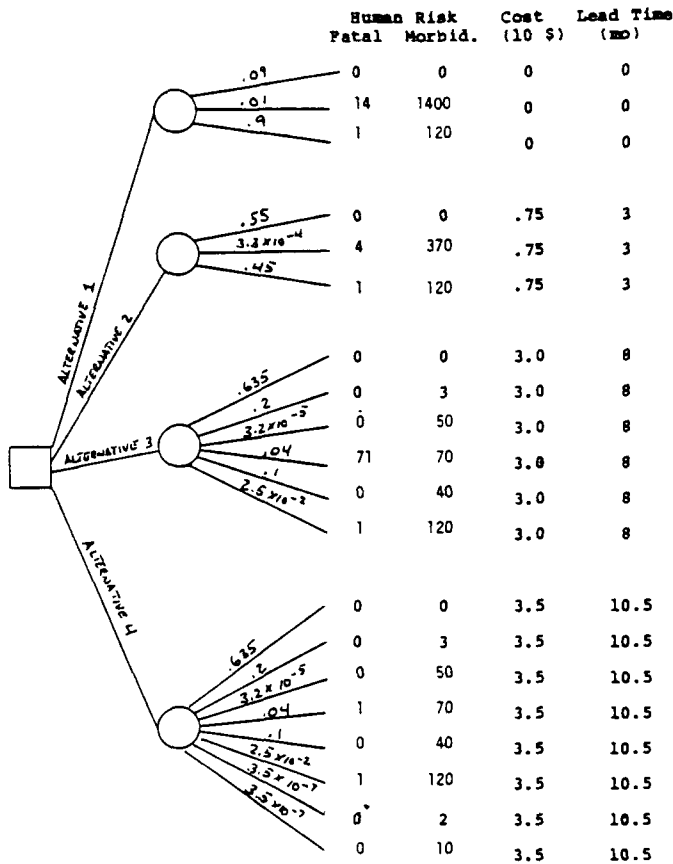


Figure 3.  
Initial Decision Tree

Table 4.  
Denney Farm Risk Data Summary

Alternative	Joint Probability (Term)	Invol. Fatal	Invol. Morb.	Reg. Fatal.	Vol. Morb.
1. Leave buried	0.01 (long)	14	1400	---	---
	0.9 (long)	1	120	---	---
2. Install & maintain a groundwater monitoring system	$3.3 \times 10^{-4}$ (long)	4	370	---	---
	0.45 (long)	1	120	---	---
3. Excavate & store material on site	0.2 (short)	---	---	---	3
	$3.2 \times 10^{-5}$ (short)	1	50	---	---
	0.04 (long)	0	70	---	---
	0.1 (short)	---	---	0.04	40
4. Excavate & transport liquids and residues via truck to Syntex	$2.5 \times 10^{-2}$	1	120	---	---
	same as 3 plus:	---	---	---	2
	$3.5 \times 10^{-7}$ (short)	0	10	---	---

used in the risk referent calculation is shown in Table 6. A comparison of objective risk and risk referents is provided in Table 7. A quick glance at this comparison indicates that none of the proposed alternatives is "acceptable" to the public and that alternatives 3 and 4 are only marginally "acceptable" to the workers in terms of fatalities.

Table 5.  
Risk Referent Assumptions

#### Indirect gain-loss balance:

Class	Alt	Balance	Value
Involuntary (public)	1	Marginally unfavorable	0.001
	2	Indecisive	0.01
	3	Marginally favorable	0.1
	4	Favorable	1.0
Regulated Voluntary (workers)	3/4	Favorable	1.0

#### Controlability:

Alt	Control Approach	Degree of Control	State of Implement.	Basis of Effect.
1	0.1	0.1	---	---
2	0.3	0.3	0.5	0.5
3/4	1.0	1.0	1.0	---

Table 6.  
Risk Referent Calculation Factors

Risk Classification	Risk Ref.	Risk Prop Fac.	Proportion. Derating Factor	Control. Factor
Involuntary, catastrophic, fatal	$1 \times 10^{-7}$	0.1	Alt 1 0.001	Alt 1 0.01
			Alt 2 0.01	Alt 2 0.015
Involuntary, ordinary, fatal	$5 \times 10^{-6}$	0.1	Alt 1 0.001	Alt 1 0.01
			Alt 2 0.01	Alt 2 0.015
			Alt 3 0.1	3/4 1.0
			Alt 4 1.0	Alt 4
Involuntary, catastrophic, health effect	$5 \times 10^{-7}$	0.1	Alt 1 0.001	Alt 1 0.01
			Alt 2 0.01	Alt 2 0.015
Involuntary, ordinary, health effect	$3 \times 10^{-5}$	0.1	Alt 1 0.001	Alt 1 0.01
			Alt 2 0.01	Alt 2 0.015
			Alt 3 0.1	3/4 1.0
			Alt 4 1.0	---
Regulated voluntary, ordinary, fatal	$1 \times 10^{-4}$	1.0	1.0	1.0
Regulated voluntary,	$6 \times 10^{-2}$	1.0	1.0	1.0

Note: All risks are treated as immediate

Table 7.  
Risk Comparison

Alt	Risk Classification	Objective Risk	Risk Referent
1	Involuntary, catastrophic, fatal	$3.3 \times 10^{-6}$	$1.0 \times 10^{-13}$
	Involuntary, ordinary, fatal	$3.0 \times 10^{-4}$	$5.0 \times 10^{-12}$
	Involuntary, catastrophic, health	$3.0 \times 10^{-4}$	$5.0 \times 10^{-12}$
	Involuntary, ordinary, health	$2.7 \times 10^{-2}$	$3.0 \times 10^{-11}$
2	Involuntary, catastrophic, fatal	$1.1 \times 10^{-7}$	$1.5 \times 10^{-12}$
	Involuntary, ordinary, fatal	$1.5 \times 10^{-4}$	$7.5 \times 10^{-11}$
	Involuntary, catastrophic, health	$9.9 \times 10^{-6}$	$7.5 \times 10^{-12}$
	Involuntary, ordinary, health	$1.3 \times 10^{-2}$	$4.5 \times 10^{-10}$
3	Involuntary, ordinary, fatal	$1.7 \times 10^{-5}$	$5.0 \times 10^{-7}$
	Involuntary, ordinary, health	$1.5 \times 10^{-3}$	$3.0 \times 10^{-7}$
	Reg. voluntary, ordinary, fatal	$3.2 \times 10^{-4}$	$1.0 \times 10^{-3}$
	Reg. voluntary, ordinary, health	$3.3 \times 10^{-2}$	$6.0 \times 10^{-2}$
4	Involuntary, ordinary, fatal	$2.5 \times 10^{-7}$	$5.0 \times 10^{-7}$
	Involuntary, ordinary, health	$1.5 \times 10^{-3}$	$3.0 \times 10^{-7}$
	Reg. voluntary, ordinary, fatal	$3.2 \times 10^{-4}$	$1.0 \times 10^{-3}$
	Reg. voluntary, ordinary, health	$3.3 \times 10^{-2}$	$6.0 \times 10^{-2}$
4 Mod	Involuntary, ordinary, fatal	$4.1 \times 10^{-8}$	$5.0 \times 10^{-7}$
	Involuntary, ordinary, health	$1.7 \times 10^{-7}$	$3.0 \times 10^{-7}$
	Reg. voluntary, ordinary, fatal	$3.2 \times 10^{-4}$	$1.0 \times 10^{-3}$
	Reg. voluntary, ordinary, health	$3.3 \times 10^{-2}$	$6.0 \times 10^{-2}$

**Table 8.**  
**Sensitivity Analysis**

Alt	Risk Classification	Objective Risk Range	Risk Referent Range
1	Involuntary, catastrophic, fatal	$8.4 \times 10^{-6}$ - $7.5 \times 10^{-5}$	$1.0 \times 10^{-14}$ - $1.0 \times 10^{-12}$
	Involuntary, ordinary, fatal	$7.5 \times 10^{-5}$ - $5.0 \times 10^{-3}$	$5.0 \times 10^{-13}$ - $5.0 \times 10^{-11}$
	Involuntary, catastrophic, health	$7.5 \times 10^{-5}$ - $5.0 \times 10^{-4}$	$5.0 \times 10^{-14}$ - $5.0 \times 10^{-12}$
	Involuntary, ordinary, health	$7.6 \times 10^{-4}$ - $3.3 \times 10^{-12}$	$3.0 \times 10^{-12}$ - $3.0 \times 10^{-10}$
3	Involuntary, ordinary, fatal	$4.5 \times 10^{-6}$ - $4.0 \times 10^{-4}$	$5.0 \times 10^{-9}$ - $5.0 \times 10^{-6}$
	Involuntary, ordinary health	$3.9 \times 10^{-4}$ - $2.8 \times 10^{-3}$	$3.0 \times 10^{-8}$ - $3.0 \times 10^{-6}$
	Reg. voluntary, ordinary, fatal	$7.9 \times 10^{-5}$ - $5.2 \times 10^{-3}$	$1.0 \times 10^{-5}$ - $1.0 \times 10^{-2}$
	Reg. voluntary, ordinary, health	$8.3 \times 10^{-3}$ - $7.5 \times 10^{-2}$	$6.0 \times 10^{-3}$ - .06
3 Mod	Involuntary, ordinary, fatal	$1.0 \times 10^{-8}$ - $9.0 \times 10^{-5}$	Same as 3
	Involuntary, ordinary, health	$9.0 \times 10^{-8}$ - $8.0 \times 10^{-5}$	
	Reg. voluntary, ordinary, fatal	Same as 3	
	Reg. voluntary, ordinary, health		

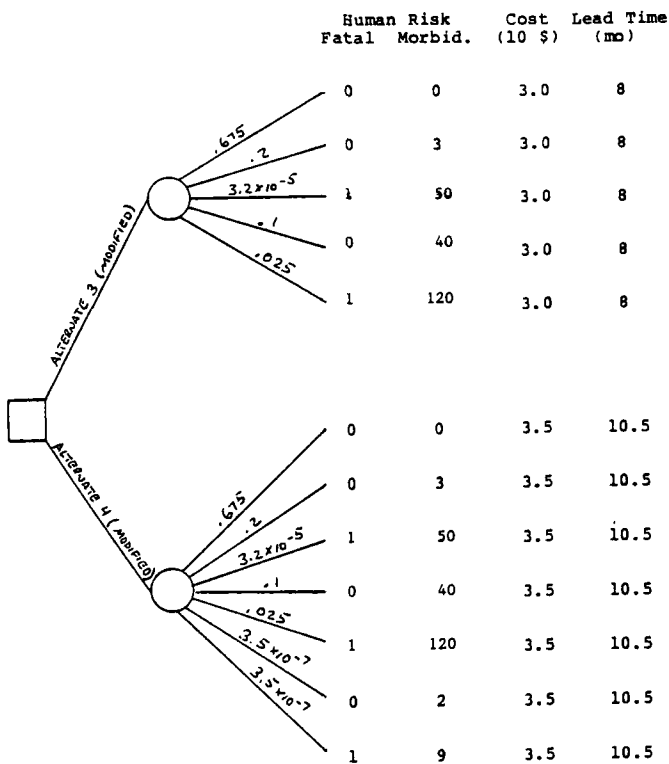


Figure 4.  
Revised Decision Tree

Unfortunately, no information was provided in the study to enable a sensitivity analysis. Illustrating this procedure will require that some reasonable variance information be postulated. It will be assumed that:

1. The parameters used in the decision tree, joint probabilities and attribute magnitudes, can vary by 50% within the limits imposed by the exposed population size and the maximum possible probability of 1.0.
2. The risk referents can vary by one order of magnitude.

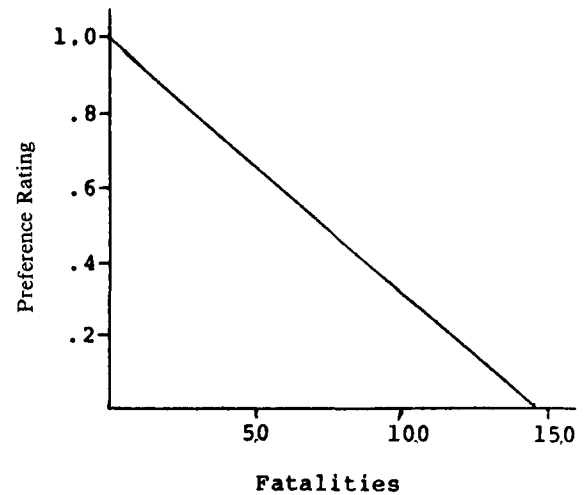


Figure 5.  
Fatalities Utility Function

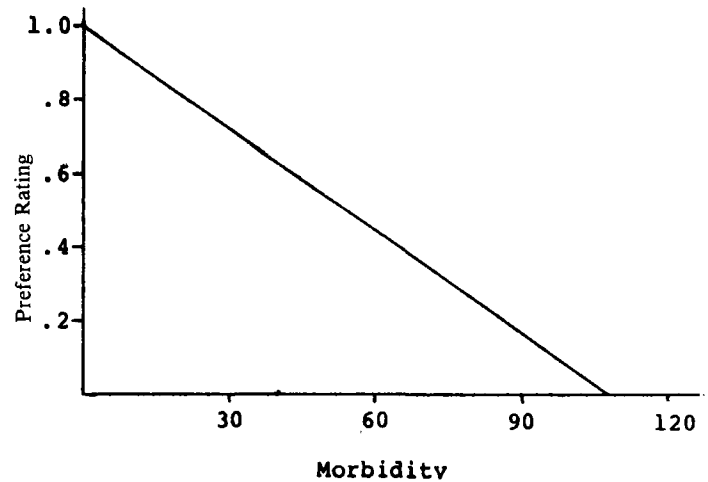


Figure 6.  
Morbidity Utility Function

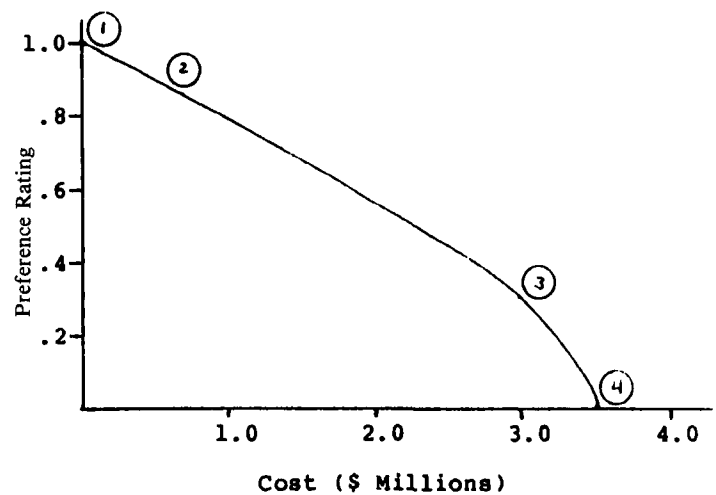


Figure 7.  
Cost Utility Function

Using these assumptions, the information in Table 8 was calculated. The data show the full range of variance in both objective risk estimates and risk referents which could be possible. This provides a sound basis for assessing which alternatives have a realistic chance of being acceptable.

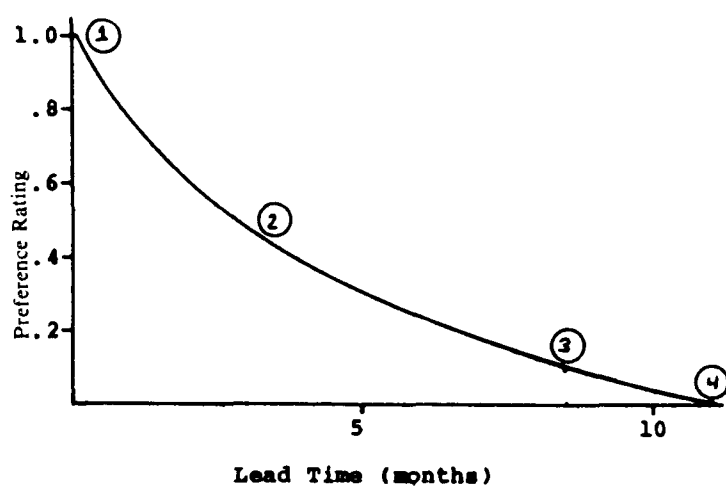


Figure 8.  
Lead Time Utility Function

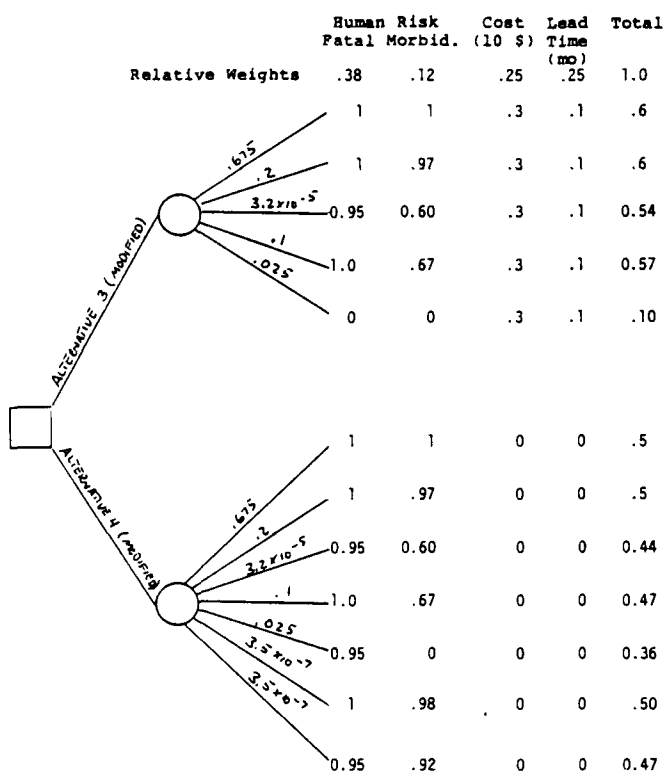


Figure 9.  
Problem Solution

At this point it is fairly clear that alternatives 1 and 2 will, under no foreseeable circumstances, approach an acceptable level of risk so they can be eliminated. It appears potentially feasible and worthwhile to modify alternatives 3 and 4 by eliminating the risk to the public of significant release of residual TCDD after excavation, by either eliminating most of this residual during the cleanup or by some form of encapsulation. This modification will of course cause both the cost and lead time of each alternative to be increased. No other risk modifications seem realistic with the information given. As indicated in Tables 7 and 8, with the suggested modification alternatives 3 and 4 would become acceptable. This suggests that it is time to seriously consider the modified approach or assemble some other alternatives. Possible other approaches would need to include means to either mitigate or eliminate the public exposure

due to tornados and contaminated workers. Since no in-depth information is provided, assumptions that alternatives No. 3 and 4, as modified above, are the best that can be developed for further analysis. In real life this is possibly an outcome that could materialize, in which case the public must be informed in detail.

With the risk assessment completed as above, a revised decision tree including only alternatives 3 and 4 (modified) is needed for further analysis. Such a tree is illustrated in Fig. 4. However completion of the formal analysis required utility functions for each individual attribute and a multiattribute utility function. The utility functions used for each attribute are diagrammed in Figs. 5 to 8. Figs. 5 and 6, fatalities and morbidity, provide an example of risk neutral functions while Fig. 7, costs, is slightly risk prone and Fig. 8, lead time, is risk averse. These functions would be a direct result of the perceptions of the decision maker for the problem. The original cost and lead time for the modified version of alternatives 3 and 4 are being used. Due to the similarity of the two options and the likelihood that the changes would be relatively minimal, this should not create any deviations for the resolution of data. In order to combine the four separate utility values for different attributes into a single utility value, a multiattribute utility function is required. As in the case of the individual utility functions, this multiattribute utility function is directly related to the perceptions of the decision maker in question. For the purposes of this paper the use of an additive function seems reasonable due to the general observations mentioned previously and the small relative difference between the two alternatives being considered.

Finally, expected utility for each path is calculated using the mechanics of decision analysis to arrive at a "solution". The decision tree with all calculated values is diagrammed in Fig. 9. Alternative 3 (modified) is obviously preferable to 4 (modified) in this particular case. Since both alternatives are so similar it is unlikely that sensitivity analysis would indicate any significant different choice within any reasonable limits.

## CONCLUSIONS

The proposed method provides a quantitative tool that is systematic but flexible, is capable of handling uncertainty, multiple conflicting objectives and the subjective judgments of decision makers, and addresses the highly subjective nature of public risk perception. With the prudent use of a "viable option" criteria and risk assessment, the number of options that must be fully considered can be effectively limited. On the other hand, this approach will help pinpoint requirements for considering a wider scope of alternatives when necessary.

The process is obviously powerful and, also, appropriate for use with multiattribute problems. Given the potential complexities inherent in sludge and compost utilization the use of this technique appears justified. This method of problem solving does not try to eliminate the subjective judgments, but does provide the judgments an opportunity of being scrutinized. It is the authors' attempt to bring together a set of powerful tools and apply them to the site management of uncontrolled hazardous wastes. More refinement and improvement will still be required to enable the application of this method to larger scale problems.

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# U.S. ARMY CORPS OF ENGINEERS ROLE IN REMEDIAL RESPONSE

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## INTRODUCTION

The USEPA under Executive Order 12316 was assigned primary responsibility for implementation of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (i.e., CERCLA or Superfund). The Superfund program consists of two parts: (1) emergency response (removal action) to hazardous substance spills and uncontrolled sites, and (2) remedial response to cleanup problem sites. Remedial response consists of the following four major activity phases:

- Investigation of the problem
- Feasibility study to select the most effective and cost efficient cleanup alternative
- Final design of cleanup action
- Implementation (construction) and related tasks

States may elect to manage and direct all or part of the remedial response activities, otherwise, EPA will take the lead. In either case, the state in which the site is located will be required to provide 10% or 50% cost-sharing.

The Army Corps of Engineers Agrees to Support USEPA in the Management of Superfund Work.

The USEPA and the Army Corps of Engineers signed an inter-agency agreement on February 3, 1982. Under the agreement,

upon USEPA request, the Corps of Engineers will manage design and construction contracts and provide technical assistance to USEPA in support of remedial cleanup of hazardous waste sites.

USEPA has a three-tiered process that will determine the extent of Corps assistance under Suprefund. Under this process, USEPA will: (1) determine whether a private entity is liable for cleanup and approach that entity to perform the necessary tasks; if that does not develop, then (2) determine whether the state can/will do the cleanup; if not, then (3) determine that Federal cleanup is appropriate and request that the Corps undertake design and construction.

## CORPS RESPONSIBILITIES UNDER THE INTERAGENCY AGREEMENT

The Corps of Engineers primary responsibilities under the inter-agency agreement are as follows:

**Serve as contract manager for design and construction**

- Review Designs
- Monitor Construction
- Provide Technical Assistance to EPA
- Review State Plans upon EPA Request

## Superfund Site Management Plan

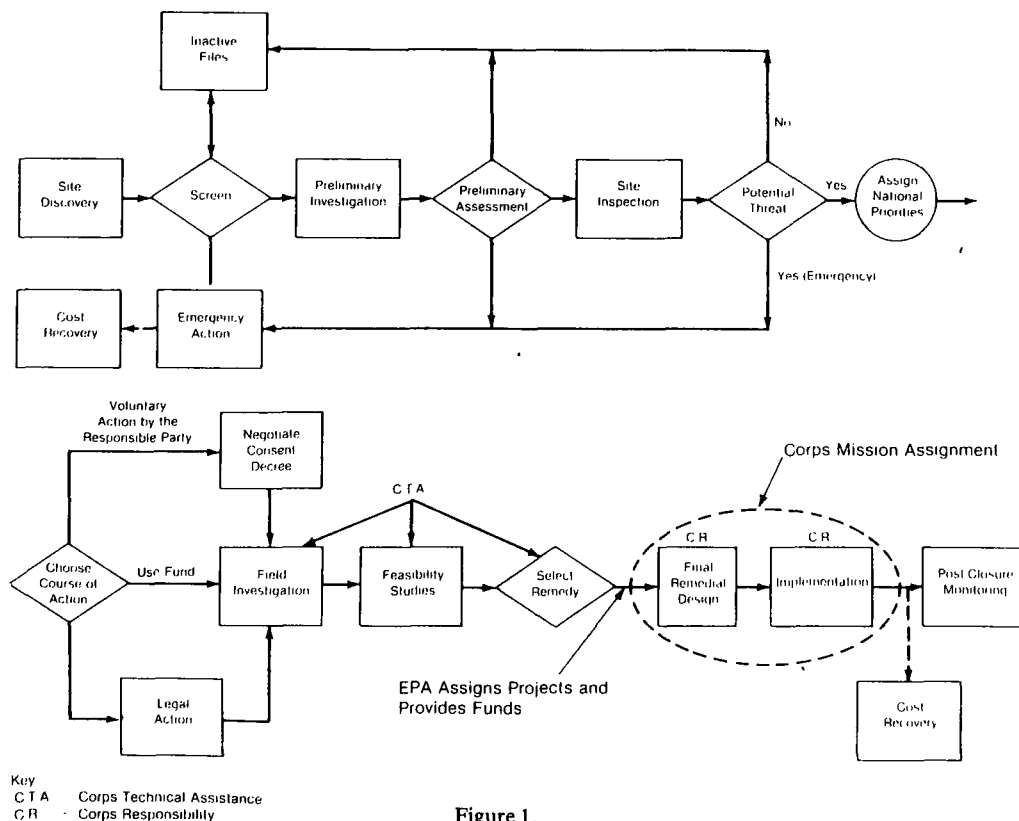


Figure 1.  
Superfund Site Management Plan



At sites where USEPA has primary responsibility for cleanup (Federal lead), the Corps will contract out and manage actual design and construction work, once a remedial concept is approved by USEPA and the Corps (Fig. 1). Overall program guidance, policy, and funding for Corps support will originate with USEPA.

The Corps will provide technical assistance to USEPA, as needed, during the remedial investigation and feasibility study phases. This assistance will be of necessary scope to assure that the proposed remedial action selected by USEPA can be engineered and constructed. The Corps will also assist USEPA in the review of projects undertaken by the states as to their suitability for bidding and construction. In any case, USEPA will not assign a remedial action to the Corps for management if the Corps determines that the action is not reasonable to design, construct, operate, and maintain.

#### ACTIVITIES OF OTHERS

USEPA, the states, local interests, or others will be responsible for the following:

- Establishing Priorities
- Selecting Sites
- Cost Recovery
- Public Involvement
- State Assurances
- Maintenance
- Cost Sharing
- Disposal Sites
- Environmental Impact Statements
- Obtaining Permits
- Legal Determinations
- Obtaining Real Estate Rights

#### CORPS OPERATING PRINCIPLES

The Corps of Engineers, in executing its EPA Superfund assignment, has adopted the following operating principles:

##### Be Responsive to USEPA's Program Needs

- Timely Response
- Single Point of Contact Concept
- Support USEPA's Cost Recovery Program

**Provide Highest Technical Competence in Engineering and Construction; Provide Assertive Technical Assistance**  
**Adopt Highest Standards in Safety and Health Aspects**  
**Provide Cost Control**

- Cost-Effective Solutions, Design, Construction
- Implement as Many Sites as Possible with Available USEPA Funds

##### Support EPA's Community Relations

- Promote Public Confidence in Corps and USEPA

##### Streamline Corps Management Structure

- Design Center-Centralized Engineering Resource
- Construction Managed by Lead Districts Along State Lines
- Maximum use of Private Sector

#### THE CORPS MANAGEMENT STRUCTURE

The Corps will utilize its existing nationwide decentralized management structure, integrating its Superfund responsibilities into the existing program. The Chief of Engineers designated the Director of Civil Works to perform executive direction and management activities in a similar manner to the Corps traditional civil works missions, except for the absence of a direct interface with the Office of Management and Budget, and the Congress, on budget and authorization activities. The Office of the Chief of Engineers (OCE) interfaces with EPA in determining Superfund issues, policy, funding, priorities, research needs and national program direction within the interagency agreement. OCE will assign projects to Corps division engineers, provide field guidance, perform

program management activities, conduct Washington-level program reviews and coordination, and provide design and construction oversight. The Chief, Engineering Division, OCE has been assigned programmatic responsibility by the Director of Civil Works.

#### Project Management and Program Coordination

The Chief, Engineering Division, OCE, is the Corps national program manager. The project management and program coordination function is assigned by state and will be based on the location of the hazardous waste site in relation to the state-lead district assignment (Table 1). The Division Engineers, through their staff designees, are regional Corps program managers responsible for overall project and program management, providing a project manager for each hazardous waste site designated by USEPA.

#### Design Review

Nationwide, the Missouri River Division (MRD) Engineer has been assigned the responsibility for the contracting, review, and coordination of project design. All actual design will be performed by private architect-engineer firms contracted by the Kansas City and Omaha Districts within MRD. MRD will coordinate the design contracting, resolve design problems, verify design cost estimates, coordinate the design review, and approve the designs. A flow diagram depicting how the engineering and design activity would normally function is shown in Fig. 2. The "con-

### Usual Process

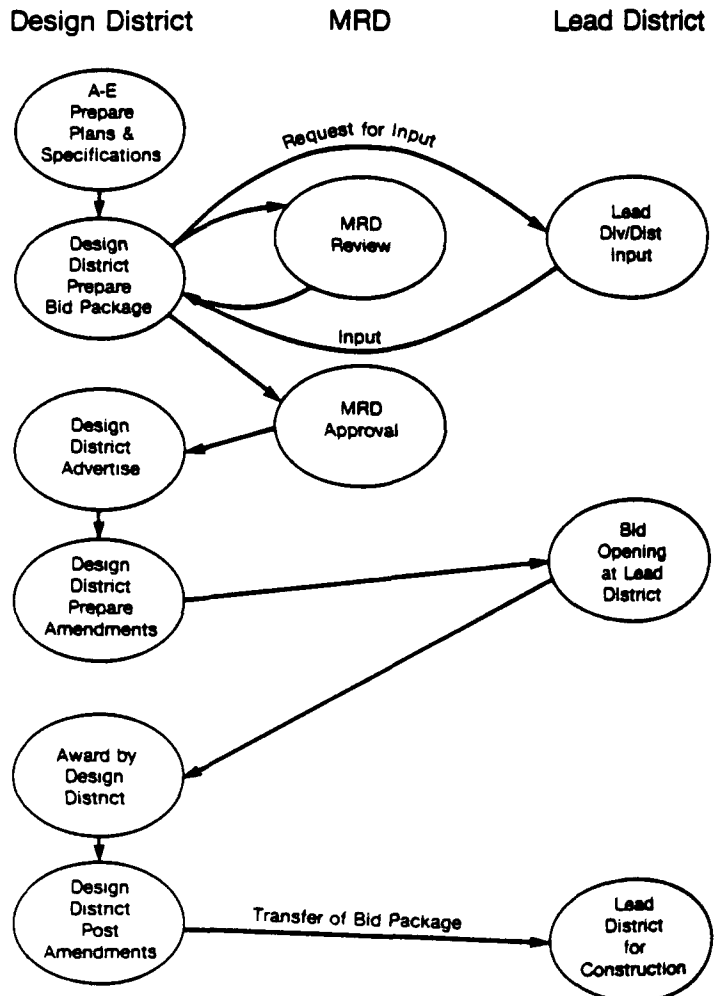


Figure 2.  
Design Review

structing” or lead district will coordinate design management activities with MRD (see Table 1). MRD will prepare construction bid packages for competitive award to private industry contractors. All division engineers will perform regional coordination within their respective EPA Superfund boundaries.

**Table 1**  
**USEPA Superfund Project Management and Construction Responsibilities**

Corps Division	States	Corps Lead District	USEPA Region
New England	ME	New England	I
	VT	New England	I
	MA	New England	I
	NH	New England	I
	RI	New England	I
	CN	New England	I
North Atlantic	NY	New York	II
	NJ	New York	II
	PA	Baltimore	III
	DL	Baltimore	III
	MD	Baltimore	III
	VA	Norfolk	III
	DC	Baltimore	III
Ohio River	WV	Huntington	III
	KY	Louisville	IV
	TN	Nashville	IV
	IN	Louisville	V
	OH	Huntington	V
South Atlantic	VI	Jacksonville	II
	PR	Jacksonville	II
	NC	Wilmington	IV
	SC	Charleston	IV
	AL	Mobile	IV
	GA	Savannah	IV
Lower Mississippi Valley	FL	Jacksonville	IV
	MS	Vicksburg	IV
LA	LA	New Orleans	VI
North Central	MN	St. Paul	V
	WI	St. Paul	V
	MI	Detroit	V
	IL	Chicago	V
Southwestern	NM	Albuquerque	VI
	TX	Ft. Worth	VI
	OK	Tulsa	VI
	AR	Little Rock	VI
Missouri	NE	Kansas City	VII
	IA	Kansas City	VII
	MO	Kansas City	VII
	KS	Kansas City	VII
	MT	Omaha	VIII
	ND	Omaha	VIII
	SD	Omaha	VIII
	WY	Omaha	VIII
	CO	Omaha	VIII
South Pacific	NV	Los Angeles	IX
	AZ	Los Angeles	IX
	CA	Sacramento	IX
	UT	Sacramento	VIII
North Pacific	WA	Seattle	X
	OR	Portland	X
	ID	Walla Walla	X
	AK	Alaska	X
Pacific Ocean	Amer	Pacific Ocean	IX
	Samoa	Pacific Ocean	IX
	Guam	Pacific Ocean	IX
	HI	Pacific Ocean	IX

## Construction Management

The implementation or construction activity will be fully integrated into the existing construction management structure at Corps districts, divisions, and at the Office of the Chief of Engineers. Lead districts will be responsible for the construction management phase (see Table 1 for state breakout.) The “constructing” district will execute contracts let by competitive bid to private industry and will provide contract administration and construction management activities, including financial management and reporting activities. The “constructing” district engineer, or his designee(s), will have contracting officer authority, using bid packages prepared by MRD. The construction effort will be managed by the lead district, which will turn over the completed project to the respective USEPA regional office.

## Simplified USEPA-Corps Activity Breakdown

Figure 3 is a simplified remedial response activity flow diagram that shows the activity interface between USEPA and the Corps.

## Other Corps Responsibilities

The Corps will be responsible for developing a site safety plan based on information contained in the remedial investigation and feasibility study. The plan will cover the health and safety of personnel involved in site design and remedial actions, as well as populations in the immediate site area. Implementation of the plan will be shared between USEPA and the Corps. Corps responsibility will be limited to design and remedial action personnel, and USEPA will coordinate all actions relating to off-site populations. In addition to development of the site safety plan, the Corps will be responsible for environmental monitoring during the design and construction phases; preparation of site operation and maintenance manuals; facility start-up; operator training; and assisting USEPA in the implementation of community relations plans.

## DESIGN AND CONSTRUCTION CONTRACTING

### Design

Architect-engineer firms and construction contractors can get information on upcoming work by:

- Keeping their current DA Form 254's on file with MRD and the Kansas City and Omaha districts for design, and with the geographic lead district for construction.
- Watching *Commerce Business Daily* announcements
- Keeping in contact with the geographic lead district procurement office

### Construction

In addition to the above, each District Engineer maintains a list of prospective construction bidders who have expressed interest in specified types of procurement that may occur within his assigned geographic area. Annually, in February, each division engineer publishes, for distribution to the construction industry and suppliers, a schedule of major construction procedures expected to be advertised for bids over a 20-month period.

## PROCUREMENT PROCEDURES

- The Corps will use its standard contracting and procurement procedures
- Small business set asides will be in accordance with the criteria set forth in the Federal Procurement Regulations at EPR 1-1-706-5(a).

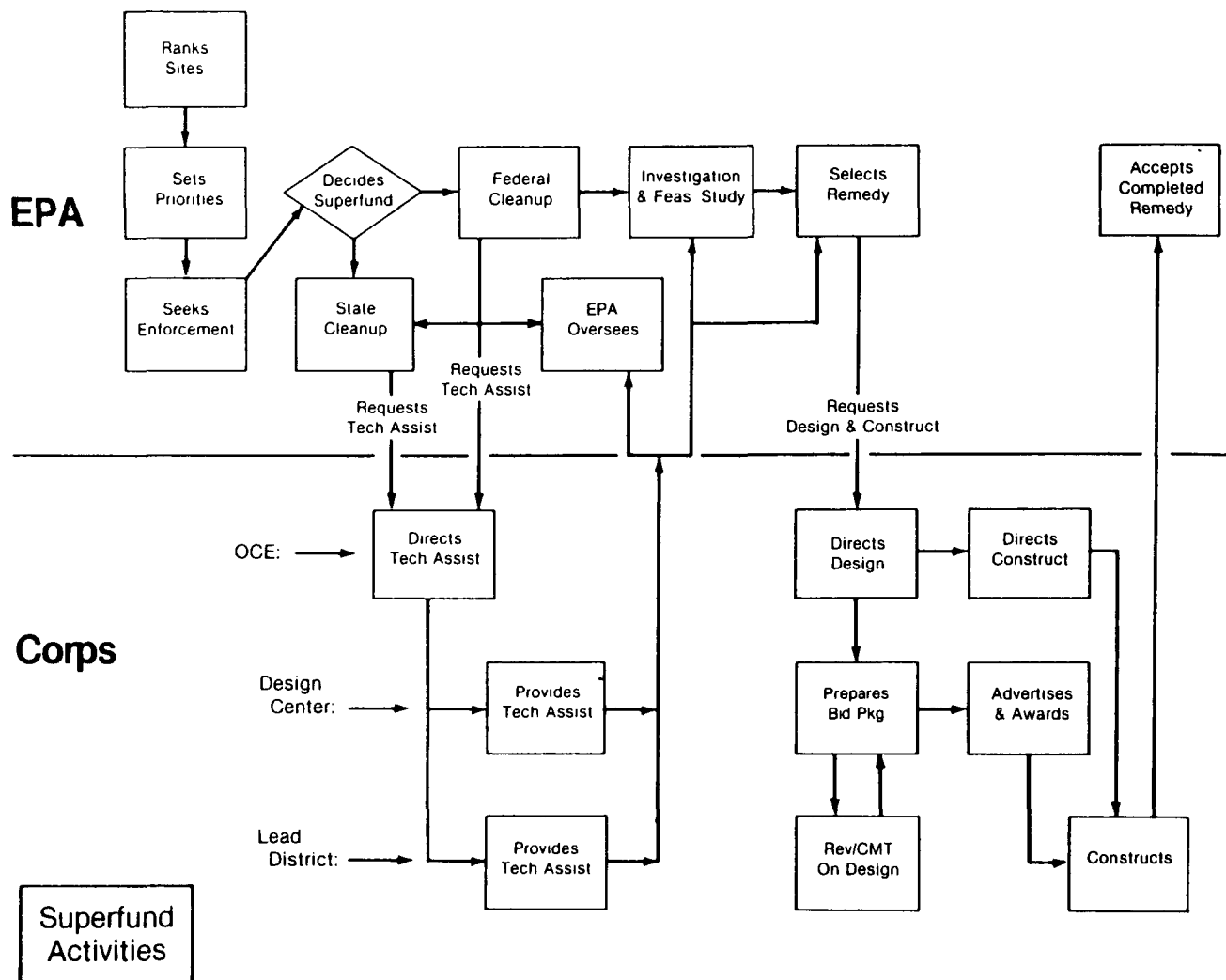


Figure 3.  
Remedial Response Activity Flow Diagram

# STATE PARTICIPATION UNDER SUPERFUND

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## INTRODUCTION

Effective hazardous materials cleanup requires a strong partnership between the USEPA, private parties, and the States. The strength of that coalition has been developing in recent years, and promises to continue to grow stronger. This paper focuses on the developing relationship between USEPA and the States, with primary attention to the joint participation of States and USEPA in taking remedial action at uncontrolled hazardous waste sites to date under the Superfund program.

## A PARTNERSHIP UNDER SUPERFUND

A strong partnership has developed between the States and USEPA over the first two years of the Superfund program. On the projects that have been initiated at 58 sites in 29 States across the country, USEPA and the States have assumed joint roles for the management of site activities and for decision-making. As the program has matured, the States have shown an increasing desire to take the lead role in managing the response actions at their sites.

### Mechanisms of Participation

Planning and executing the cleanup of a hazardous waste site is both technically and administratively complex. CERCLA and the National Contingency Plan specify a number of determinations and assurances that must be made before work can begin. They also specify a number of procedures and requirements that must be followed while carrying out preparatory planning and remedial actions. In addition, other Federal laws and regulations place requirements on either the State or USEPA, depending upon which has the lead role for the project.

Because of these requirements, it is imperative that there be a clear delineation of the responsibilities of all parties. The two documents that are being used to define USEPA and State roles are the cooperative agreement and the State Superfund contract. The cooperative agreement is used when the State takes the lead role, while the State Superfund contract is used when USEPA leads the effort. The responsibilities of the States and USEPA under the two instruments are summarized in Fig. 1, and the following sections provide more details.

### Cooperative Agreements

When the State desires the lead management role for remedial planning and implementation at a site, the State must submit an application for a cooperative agreement. A cooperative agreement is much like a grant, in that money is transferred from USEPA to the State. A key distinction, however, is that there is more substantial USEPA involvement in a cooperative agreement than under a grant.

The cooperative agreement application contains the State's work plan, schedule, project budget, and the assurances required by CERCLA. The work plan and schedule set forth specific details on how and in what time frame the State will accomplish the remedial action. The budget shows the expected cost of each major activity.

It is also broken down by categories such as personnel, travel, contractual services, and equipment. The assurances that are required by section 104(c)(3) of CERCLA are that the State will share in the cost of the action; that approved capacity is available for any necessary off-site treatment, storage, or disposal, and that the State will assume responsibility for all future maintenance of the response action. The application also documents how the State will comply with other applicable Federal laws and regulations.

USEPA reviews the application upon receipt, and drafts special conditions to the award for those aspects that are not adequately addressed in the application. An offer of award is then made by USEPA.

When the State signs the offer, USEPA sets up a letter of credit account in the amount of the award. The State may draw down from its account to meet its expenses. Using funds in the letter of credit, the State may procure contractors' services to conduct the work called for or use in-house resources. The costs of State personnel that are working on site activities are also included. It is the State's responsibility to see that the activities specified in the work plan are carried out according to schedule and within budget.

Even though the State has the lead role under a cooperative agreement, USEPA also has responsibilities. The Agency's main responsibilities are to monitor the State's progress throughout the project and, in accordance with section 104(c)(2) and (4) of CERCLA, to select the appropriate remedial action to be taken at the site, after consultation with the State.

### State Superfund Contracts

When USEPA takes the lead for a project, the work is done by a USEPA contractor or through the Corps of Engineers. Consequently, there is no transfer of funds from USEPA to the State, as

RESPONSIBILITIES	COOPERATIVE AGREEMENT		SUPERFUND CONTRACT	
	EPA	STATE	EPA	STATE
1. APPOINT PROJECT OFFICER TO COORDINATE AND LEAD ACTIVITIES		•	•	
2. HANDLE ALL CONTRACTUAL MATTERS RELATING TO THE PROJECT		•	•	
3. DEVELOP SCOPE OF WORK INCLUDING COST ESTIMATES AND SCHEDULES	•	•	•	•
4. OVERSEE AND DIRECT ALL PROJECT WORK		•	•	
5. REVIEW AND COMMENT ON WORK PLAN AND COST AND TIME ESTIMATES	•			•
6. DEVELOP AND IMPLEMENT COMMUNITY RELATIONS PLAN		•	•	
7. PREPARE AND SUBMIT REPORTS ON PROGRESS AND EXPENDITURES		•		
8. MAKE STATUTORY REQUIRED ASSURANCES		•		•
9. PREPARE SITE SAFETY PLAN		•	•	
10. ASSURE SAMPLING AND ANALYSIS QUALITY		•	•	

Figure 1.  
Major Responsibilities of States and EPA under  
Superfund Contracts and Cooperative Agreements

there is with a cooperative agreement. However, with a USEPA-led project, as with a State-led project, there is a requirement that the State make the CERCLA 104(c)(3) assurances that are discussed above. The mechanism the State uses to make those assurances must be a formal legal document; thus a non-procurement contract between USEPA and the State—the State Superfund contract—is used.

The scope of work for the activities to be performed is, like the assurances, a major element of the State Superfund contract. The scope of work is prepared by USEPA, and along with the remainder of the State Superfund contract, it is reviewed by the State. The contract is signed by USEPA and the State when both agree to the terms.

If remedial planning activities—that is, a remedial investigation or feasibility study—are to be done, a USEPA contractor performs the required work. The contractor reports its findings to USEPA, and USEPA in turn reviews the information with the State. By contrast, for remedial design or remedial construction projects, USEPA transfers funds to the Corps of Engineers through an Interagency Agreement. The Corps of Engineers then contracts for and supervises the work.

Throughout the project, USEPA involves the State in major decisions that must be made. Foremost among these is the determination of the appropriate remedial action. USEPA is required by section 104(c)(2) of CERCLA to consult with the State before making this decision. There is also a substantial involvement of the State in reviewing contractor bids, contract documents, project work plans, and progress reports.

#### Record of State Participation

To date, States have shown a keen interest in participating under Superfund. A total of 41 States have sites on the Interim Priority List of 160 sites, and as of the end of Fiscal Year 1982 (Sept. 30, 1982), 29 States had initiated some kind of Superfund remedial activity. The lack of remedial action at the remaining 12, however, should not be construed as a lack of State involvement. In some cases, the State's site(s) had been cleaned up using emergency funds, and no further remedial action was necessary. In other cases, there was active negotiation for private party cleanup taking place between USEPA of the State and the responsible party. In still others, the responsible party was cleaning or had cleaned the site.

States have also demonstrated an increasing desire to lead remedial actions. The data in Table 1 shows that in Fiscal Year 1982, over 44% of the remedial projects that were initiated were State led, up from 27% in the first year of implementation. Furthermore, State led projects represented approximately 67% of the money obligated for remedial projects in Fiscal Year 1982, up from 42% in Fiscal Year 1981.

There are a number of reasons for a State to decide to have USEPA take the lead. In many cases, it is a question of timing. USEPA's contracts already have been negotiated, and therefore, USEPA led projects can begin shortly after the State Superfund contract is signed. Conversely, with State led projects, the State must go through the full procurement process to hire contractors, a process which may take from two to three months. In other cases, States have not had sufficient staff to take the lead role for all of their sites. They have chosen to have USEPA take the lead on some sites, while they take the lead on others.

**Table 1.**  
**Superfund Obligations for Remedial Actions**

Source of \$	State Led	Subtotal (\$)	EPA Led	Subtotal (\$)	Total Projects	Total (\$)
RCRA Projects	8	1,760,605	17	4,391,000	25	6,151,605
Other Projects	0	0	4	540,000	4	540,000
SF/FY 81 Projects	1	2,305,600	3	726,000	4	3,031,600
Total FY 81 Sites	9*		18*		26*	
SF/FY 82 Projects	30	34,021,740	38	17,098,140	68	51,119,880
Total FY 82 Sites	29*		20*		46*	
SF/Subtotal Projects	31	36,327,340	41	17,824,140	72	54,151,480
Grand Total	39	38,087,945	62	22,755,140	101	60,843,085
No. of States	20*		18*		29*	

\*Not additive. Some have both EPA-led and State-led projects.

As States and USEPA work together under Superfund, more and more projects will be initiated, and greater sums of monies will be expended. As shown in Table 1, in Fiscal Year 1981, using Resource Conservation and Recovery Act (RCRA), Clean Water Act, and Superfund monies, the States and USEPA initiated 33 projects at 26 sites. The total amount obligated was almost \$10 million for a site average of approximately \$370,000. By contrast, the total number of projects initiated in Fiscal Year 1982 doubled with 68 projects begun at 46 sites. Total funds obligated were over \$51 million, and the average obligation per site in the second year of Superfund implementation was over \$1.1 million, three times that of the first year.

The average obligation per site increased because the type of project being initiated at many of the sites was changing. Most of the projects initiated in Fiscal Year 1981 were planning projects—which are relatively low cost. In Fiscal Year 1982, a number of the planning activities that were initiated in Fiscal Year 1981 and earlier (those initiated by the States using their own funds) were completed, and more costly remedial actions were begun.

#### CONCLUSIONS

USEPA and the States have worked together for almost two years on Superfund activities. The record of those two years shows that the total number of actions undertaken has increased from the first to the second year. Furthermore, State involvement in those activities has also increased.

In the future, a larger number of sites will be eligible for Superfund attention. The Interim Priority List, the National list of priority sites for Superfund attention, was expanded on July 23, 1982, from 115 sites to 160 sites. The National Priority List of 400 sites will be announced in the fall of 1982. An increasing number of States will gain experience with Superfund activities through working with USEPA. This increased experience will be reflected in a greater number of State staff capable of managing future Superfund activities. It is expected that, as a result of the working relationship that has been established in the past two fiscal years, the partnership between USEPA and the States will continue to grow in Fiscal Years 1983 and 1984.

# FEDERAL/STATE COOPERATION ON SUPERFUND: IS IT WORKING?

GAIL TAPSCOTT

State Regulation Report, Business Publishers, Inc.  
Silver Spring, Maryland

## INTRODUCTION

This attempt to assess the success of the Federal/State partnership in implementing the Comprehensive Environmental Compensation and Liability Act of 1980 focuses on problems and successes in both policy formulation and practical application. The information presented is based on telephone or in personal interviews with major figures involved in this implementation process at the federal level (both headquarters and regional personnel) and at the state level. In addition, major documents published in the *Federal Register* or otherwise made available by the Environmental Protection Agency have been reviewed. Also several major speeches or pieces of testimony by key Administration figures that relate to the state role in CERCLA implementation have been examined.

Persons interviewed were assured that they would not be quoted directly and that all conclusions drawn would be based on a broad survey of opinions. All the interpretations and conclusions in the paper are those of the author and are based on an evaluation of general trends found in interviews with persons representing a broad spectrum of views.

## HISTORICAL FRAMEWORK

CERCLA popularly known as Superfund was designed to provide a coherent federal response to the growing problems caused by abandoned hazardous waste sites.

As it was developed during the waning days of the 96th Congress, CERCLA was conceived of primarily as a federally operated program. General thinking among the drafters of the legislation seemed to be that states were lacking both the financial and technical ability to adequately address the problem.

After Superfund became law and the USEPA began implementation, it rapidly became clear that state governments were not anxious to relinquish complete control of hazardous waste cleanup within their borders.

State interest in playing an active role in both policy development and practical implementation of Superfund was given a big boost by the commitment of a new Republican Administration to return as much regulatory power as possible to the states. Under the Reagan Administration banner of "new Federalism", state officials sought and quickly found a hearing in USEPA.

In what many observers said was an effort to anticipate the desires of the new Administration, Walter Barber, acting administrator of USEPA during the transition period, moved to set up a dialogue with states. In Mar. of 1981, Barber, working jointly with the National Governors' Association (NGA), the National Conference of State Legislators (NCSL), the National Association of Counties (NACo), the National Association of Attorneys General (NAAG) and the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) formed an ad hoc committee to advise USEPA's Superfund Task Force.

The *ad hoc* advisory group met on two occasions—Mar. 6 and Apr. 14 and 15—with members of USEPA's Superfund Task Force, headed by Gary Dietrich of the Office of Solid Waste. Purpose of the first meeting was to delineate state concerns, while the Apr. meeting was designed to seek state input and reaction to a preliminary draft of a Superfund Strategy prepared by USEPA staffers.

The *ad hoc* committee prepared a detailed response to the draft strategy in which it said in part, "the inevitable conclusion is that

the program for implementing superfund should be in every way possible delegated to units of state government."

State officials urged Congress to repeal Section 114 of Superfund, dealing with preemption of state funds. On the compensable costs issue, states urged that, contrary to strategy's intent, direct costs for state personnel working on a site should be compensable on grounds this would not only be cost-effective but would also provide an incentive for states to develop and expand their own response.

States expressed concern about the strategy's proposal for an annual site prioritization process, taking the position that this approach could jeopardize the continuation of cleanup programs. On the issue of selection of prime and subcontractors, the states expressed strong support for being allowed to choose their own subcontractors.

Although a final Superfund Strategy was never publicly released, USEPA officials insisted that the *ad hoc* committee position paper joined other USEPA-prepared documents on Administrator Anne Gorsuch's desk as she began on the job of administering the agency. Agency officials seemed to feel that the view expressed in the draft agency strategy and the state dissenting paper made their point. They noted that early drafts of headquarters guidance to USEPA regional offices reflected a desire on USEPA's part to create a real partnership with states.

Although the *ad hoc* advisory committee was originally conceived as a potential ongoing advisory committee, this has not turned out to be the case. However, the staff of the Natural Resources and Environment Section of the NGA sees itself as playing at least a monitoring role *vis-a-vis* the federal government as Superfund implementation continues.

Concurrent with but distinct from the *ad hoc* committee, a State Task Force on Superfund composed of hazardous waste regulatory officials was created under the umbrella of the Association of State and Territorial Solid Waste Management Officials. The ASTSWMO Task Force headed first by Don Lazarchick of Pennsylvania and now by Dale Wikre of Minnesota participated in some meetings with USEPA to review preliminary drafts of the agency policy statements on Superfund Cooperative Agreements with states. Task force members provided comments on the draft and although some state officials found fault with the final document, they did not provide official comments on the final package.

In addition, at the ASTSWMO meeting in Utah on Sept. 1-3, 1981, the Task Force set itself several additional tasks in the area of monitoring Superfund implementation. The group made plans to file detailed comments on the National Contingency Plan proposal. Indeed when the NCP was proposed in Mar. 1982, the group as a whole as well as individual states provided in depth and somewhat critical comments on the proposal. With the final promulgation of the NCP in June 1982, many states continued to express their distress with several aspects of the plan which will be detailed in a later section of this paper.

The Task Force also agreed to monitor the activities of the other federal agencies involved in Superfund implementation, such as the U.S. Coast Guard and the Treasury Department to see that they are conducting themselves according to the spirit of the law.

In addition, the group expressed interest in monitoring the first few Cooperative Agreements with states reached under Superfund for such items as apportionment of leadership and consistency of policy among USEPA regions and to see how USEPA addresses

the "how-clean-is-clean?" issue on a case-by-case basis.

The Task Force is an ongoing group but it has not been very active since its group effort to file comments on the C/A Guidance Package and the NCP in April. The Task Force is set to meet on Sept. 10 and 12 before the National Solid Waste Management Association meeting in Salt Lake City. At that time Wikre said he will poll Task Force members and other state officials to get a better feel for a state consensus of how Superfund implementation is evolving.

#### MECHANISMS FOR STATE LIAISON

In order to facilitate a dialogue with the states, USEPA's organizational structure for the Office of Emergency and Remedial Response includes a branch devoted entirely to state and regional coordination. Although the existence of such a unit does suggest a commitment to state involvement, the number of people actually working on state issues at the headquarters level is limited to less than 10 full time professional persons out of approximately 90 people in the headquarters office.

The major division with state liaison responsibility is the Hazardous Site Control Division. Major functions of the division are: (1) policy guidance, technical studies, contracts and program management regarding uncontrolled hazardous waste sites, (2) discovery and assessment, remedial containment and control activities at sites, and (3) state liaison and coordination.

The formal organization of the division includes three branches: Discovery and Investigation Branch, Remedial Action Branch, and State and Regional Coordination Branch.

RCs branch is broken down into two sections. One section is State Programs and the other is the Remedial Implementation Section. To facilitate direct contact with the USEPA regional offices and to provide for an organized distribution of labor, the country has been divided into three zones, each with a Zone Manager reporting to a Section Head.

As currently organized under the severely limited staffing constraints, Zone I consists of Regions I, II and IV. Zone II covers Regions III and V, and Zone III contains Regions VI through X.

The State Programs Section is responsible for providing guidance to the regional offices on how to conduct Cooperative Agreements (C/As) with states on remedial actions. The section is also in charge of major technical review of each state application for a C/A. The C/A application goes to the regular USEPA Grants Administration Office where the formal award takes place. However, the bulk of the evaluation process will be in the Superfund Office.

The Remedial Implementation Section provides input in the development and later the implementation of the NCP. It will address the state role in the NCP and give guidance to states on their eventual part in the plan's operation.

The Emergency Response Division in OERR is also vitally connected to the state's interest. This group coordinates the National Response Team (NRT) and its Regional Response Teams (RRT) which often work closely with state emergency personnel in the case of spills, fires and explosions. When USEPA goes forward with current plans to develop a generic state C/A on Emergency Response action under Superfund, the C/As will be administered under this office.

At the regional level, the early stages of Superfund implementation were conducted largely on an *ad hoc* basis. By early summer of 1981, each regional office had on person known as a Superfund coordinator designated as the person to interact with both states and headquarters. Some of the more sophisticated regions like Region II have a staff of several people working exclusively on Superfund activities. In other regions like Region VIII such activities are carried out by persons who have many other duties.

In the wake of a Sept. 15, 1981 directive from USEPA Administrator Anne Gorsuch, regional handling of Superfund and related issues became more uniform. Regional offices choose between two organizational formats, both of which created greater consolidation of activities regarding Superfund, the Resources Conservation and Recovery Act and permits issuance and monitoring.

The major line of communication between USEPA state liaison staffers at headquarters and regional Superfund personnel takes the form of regional guidances which set down general parameters for dealing with the states.

A final version of the USEPA Guidance on Cooperative Agreements under CERCLA was made available on Mar. 11, 1982 at the same time the proposed National Contingency Plan was unveiled.

This version differs in some substantial ways from earlier public drafts and has given rise to many state objections that will be discussed in a later section of this paper.

The final C/A guidance notes four areas that are of particular importance to federal/state relations. The first is the requirement that federal remedial actions should be undertaken only after consultation with the affected party. Agreements between a state and USEPA are documented in either a C/A or a Superfund State contract.

The second provision related to assurances that the affected states must provide prior to any remedial action. The state must assure that it will: (1) assure operation and maintenance costs for all remedial and removal measures that are implemented, (2) provide for a facility for off-site disposal if necessary, and (3) share in the costs of the remedial action.

The third and fourth provision for coordinating state and federal actions related to the granting of a credit to an affected state for costs expended or obligated at a remedial site between Jan. 1, 1978 and Dec. 11, 1980. The credit is used as part of the states share of costs for federally funded response at the site.

According to the final guidance a C/A will be used when a state is expected to take the lead in remedial work and funds are actually transferred to the state. A Superfund State Contract will be used when USEPA is taking the lead.

On the state assurances issue, with regard to O & M costs, the guidance says the state must make a firm commitment to assure this responsibility. To satisfy this requirement the state must: (1) identify the organizational unit responsible for administering O & M ACTIVITY, (2) identify the state financial mechanisms for funding O & M and (3) identify milestones for assuming responsibility.

In probably the most controversial change from the earlier draft, the final guidance notes under the cost sharing provision that at privately owned sites, states must share 10% of both remedial planning (investigation, feasibility studies and design) and remedial implementation.

If the state credit is not sufficient to satisfy the state's share of the costs, either state funds will be used simultaneously with federal funds under a C/A or payment terms will be negotiated in a state contract.

Prior to remedial design activity, the state must either through a C/A or a new or amended state contract, make a firm commitment to provide funding for remedial implementation. A state may satisfy this assurance by (1) authorizing the reduction of a state credit to cover its share of costs, or (2) identifying current available funds earmarked for remedial implementation or (3) submitting a plan with milestones for obtaining necessary funds.

The final guidance notes that state credits must be documented on a site specific basis for state out-of-pocket non-federal eligible response costs between Jan. 1, 1978 and Dec. 11, 1980.

For USEPA-led remedial action where there is no state credit or the credit is not sufficient to cover state costs, payment terms will be negotiated between USEPA and the state and documented in the state contract.

For state-led remedial actions where there is no state credit or the credit is not sufficient to cover state costs, the C/A will cover only USEPA's share of the costs. USEPA will provide the award amount to the state through a letter of credit. States are required to match federal funds as work progresses.

On the controversial issue of how state trust funds may be preempted by federal Superfund, the final guidance explains that USEPA has determined that Section 114(c) of CERCLA does not apply to state funds which are used for the following purposes: to



finance the administrative costs of a state fund, to finance the purchase or preposition of hazardous substance response equipment and other preparations for responding to releases within a state, to finance the cleanup of petroleum discharges, to pay the required state contribution to cleanup actions financed by the CERCLA Trust Fund, to compensate claims to the cost of restoration and replacement of any natural resources damaged or destroyed by a release of a hazardous substance, to advance funds to remove or remedy releases of hazardous substances eligible to be financed by the Hazardous Substances Response fund if a Cooperative Agreement or Contract has been issued by the USEPA, and to compensate damage claims and to remove or remedy releases of hazardous substances eligible to be financed by the fund but for which no federal reimbursement is provided.

#### MAJOR CURRENT STATE PROBLEMS WITH SUPERFUND

The picture *vis-a-vis* major state problems with Superfund implementation has already changed several times during the less than two years that the Act has been law.

Starting with initial state euphoria that they were going to be able to have a more active part in Superfund planning than has historically been the case in other environmental law development, the situation then went into a phase where most state officials indicated the view that USEPA was moving much too slowly and husbanding the fund so closely that only a "trickle" of money was getting actually transferred to the states to deal with individual problem sites.

During the middle phase, the National Governors Association at its Feb. 1982 meeting in Washington, D.C. voted on a Superfund resolution through its Committee on Energy and the Environment. The resolution stated that in view of the absence of program guidelines and cleanup standards, the national program appeared to be stalled. It noted that states had also been reluctant to take action.

NGA urged USEPA to issue as soon as possible a national cleanup plan which would incorporate the following features: frequent consultation between NGA and USEPA on all aspects of Superfund implementation; inclusion of each state's first priority site in the National Priority List, rapid delegation of cleanup responsibility to willing capable states for remedial action and emergency response, annual appropriation request from the Administration to Congress to provide financial assistance to states for preparation of a national waste site inventory, federal payment of 100% of site investigations, feasibility and design costs for remedial actions; state payment 10% of construction costs and remedial action sites (or 50% if publicly owned during the time of dumping), management of remedial action and emergency response by willing and capable states, including selection and supervision of contractors and subcontractors, state payment of 100% of the operation and maintenance costs to remedial action sites with Superfund paying the balance for the life of the fund, close coordination between the Department of Justice and USEPA attorneys and their state counterparts in enforcement and litigation efforts.

Clearly the NGA position is in almost direct opposition to many of the positions set out in the final C/A package as well as to some of the provisions of the final NCP.

Regulatory officials who deal with the nitty gritty aspects of working with the USEPA regions share many of the governors' concerns and have also developed other problems with USEPA's state policies.

A 1980 General Accounting Office report called "Federal-State-Environmental Programs—The State Perspective" delineated four major problems that seemed to crop up in the implementation phase of most federal environmental programs requiring state participation. General problems fell in these categories: (1) delayed and inflexible regulations, (2) excessive USEPA control over state programs, (3) inability to fill state vacancies, and (4) delayed and uncertain federal funding.

This next section of the paper will attempt to look at how problems with Superfund at the state and regional level fall into these

categories.

Delays have plagued the Superfund program much as they have most other environmental programs. The first three major initiatives whose delay caused distress for states were the site notification list, the interim priority list, and the revised National Contingency Plan.

Many states had hoped to wait for the site notification list which is a compilation of known sites around the country before submitting preferred sites for the interim priority site list that appeared in late Oct. 1981. The states were very upset about the delay in the interim site list primarily because they were under great pressure to get on with cleaning up problem sites but felt they could not do so until they were assured the site would appear on the list and qualify for Superfund credit.

Once the interim list was out, states developed an even greater concern about what they saw as the potential delays that would be forthcoming in developing the 400 site National Priority List. State officials expressed great distress about the amount of information USEPA wanted on each site before it would even consider it for inclusion on the list. They noted that in many cases they would have to spend a great deal of money to even evaluate a site sufficiently to give it a score on the Hazard Ranking Model. States were also concerned about what they saw as the inflexibility of USEPA in wanting to make sure that there were detailed assurances as to the level of participation the states will promise on each site nominated for the 400 list.

In reality at least part of the state fears have proved to be an overreaction. Talks with state officials in early Sept. revealed that most of them have been able to gather the necessary data for hazard ranking more easily than thought. Many states attended USEPA-sponsored technical workshops on how to use the system and other states took a great deal of advantage of the technical expertise offered by USEPA in the form of its Field Investigation Teams.

A USEPA headquarters official observed that there were many different levels of participation in the scoring process by states but said most states took at least some type of role. Several state people remarked that although the ranking system was not entirely to their liking it had worked out better than they had expected. Headquarters spokesmen insisted that USEPA is keeping to the schedule it set itself in the June 20 Guidance for establishing the National Priorities List and will possibly announce the list by sometime in Oct. At any rate, as of early Sept. most of the ranking had been completed and was in USEPA's hands.

States were also distressed about the EPA delays in getting out the NCP. State Officials were afraid to spend much money until they had a clear idea of just what kind of role they would be playing under the new NCP. After reviewing the final NCP many state spokesmen indicated that they think it has a reasonable role for state and local governments. They are still concerned, however, that the NCP does not take a clearcut position on the "how-clean-is-clean?" issue. There is widespread state concern that USEPA may come in and do a "quick and dirty" job of cleanup and leave the huge longterm operation and maintenance costs to the states.

Several states that are geared up for emergency response-type activities were unhappy that USEPA had not moved more quickly to involve states in emergency response actions. They feel that states are in the best positions to determine what constitutes an emergency within their borders. Many regional officials think in contrast that the regional office is in the best position to assess what constitutes an emergency that qualifies for Superfund action. USEPA officials note that a C/A for emergency Response has been prepared under contract to Booz Allen and Hamilton and that a pilot program is underway to test the program in Region VI.

USEPA Assistant Administrator for Superfund, Rita Lavelle, noted in an Aug. 6 speech that one of the major issues that arose during the revision of the NCP was the development of the state's role in emergency response. She noted that the final plan encourages state involvement and delineates state roles in emergency re-

sponse actions. Lavelle noted that these roles include working with on-site coordinators in determining the appropriate extent of remedy and participation in Regional Response Teams. Also included is a receipt notification of releases. A new section indicates how a state may get into cooperative agreements or contracts for response actions pursuant to CERCLA.

Although Superfund does not operate under the massive and detailed regulations that states often complain about, the states were initially very disturbed about what they saw as inflexibility and inequality in the original Mitre Model for the initial ranking of sites.

Largely in response to state concerns and also at the behest of an Office of Technology Assessment study, the model was changed significantly and finally emerged as the Hazard Ranking System set down in the June 20 Guidance for development of priority sites. Although still not sure the system is the best possible method to rank sites according to the real level of danger they pose, most states admit the system is the best thing available at the moment.

Excessive USEPA control over state programs was a complaint in some states but not in others. A number of state officials indicated that the headquarters guidance on cooperative agreements has proved helpful and that their negotiations with regional officials were working well. A typical turnaround time on a C/A from the start of serious negotiations to USEPA headquarters sign off has tended to be around two months. Part of the reason that some states have few complaints about USEPA control is that due to the site-by-site nature of Superfund, the states and USEPA negotiate each C/A and Superfund contract individually and the precise federal/state duties and responsibilities are spelled out in detail. Some early concern about the possibility of USEPA exercising too much domination over the contracting process seems to have abated somewhat but problems will probably arise in situations where USEPA is taking the lead under state contracts. Several state officials expressed resentment of the fact that EPA-negotiated contracts often run higher costs than state-negotiated contracts. They said that it was only natural that states would resent having to pay their 10% of costs they felt were excessive to start with.

Although most states originally had expressed considerable skepticism about the major role that USEPA had carved out for the Corps of Engineers under Superfund, things don't seem to be as inflexible as the states may have originally feared. In all situations where the state is taking the lead on a site under a C/A they are being allowed the flexibility to choose their own contractors. A USEPA spokesman said that in the event that a state wanted to use the corps for the construction phase of a remedial action they could probably do so even though they are forbidden to negotiate directly with any USEPA contractors. In all USEPA situations, the Corps will be in charge of the construction phase of the work and will determine what contractors will handle the work. Many state officials anticipate some problems with the Corps as work at state Superfund contract sites moves into the construction phase.

Inability to fill state vacancies is proving to be a problem in Superfund implementation just as in other programs. In many states, already overworked staffs are being asked to handle Superfund activities in addition to trying to shoulder responsibilities for state hazardous waste programs under the Resource Conservation and Recovery Act. In several states such as New Jersey, New York and Pennsylvania, some of the same people are also involved in writing the technical criteria for siting disposal facilities. Many of the less industrialized states also have limited expertise in emergency response and tend to rely heavily on Regional Response Teams to address emergencies. Several states have also had major personnel changes in the last year and many are currently understaffed.

Probably the most serious state concerns about the way Superfund implementation is unfolding revolve around the funding issue. Although states have expressed some general concerns about how long it takes EPA to approve allocations to the states, the even bigger concern revolves around how the states themselves are going to meet the financial burden imposed on them under USEPA's

interpretation of the law *vis-a-vis* the state financial role.

Two major changes that became apparent last Mar. in the way USEPA is interpreting Superfund have resulted in what might almost be termed "paranoia" on the part of the states that they will wind up paying the lion's share of the final construction costs on sites not to mention the potentially vast burden of long term operations and maintenance costs. As discussed earlier, USEPA will not negotiate with a state unless it can provide certain assurances regarding the long term operation and maintenance costs. Many states see the current USEPA position that the states must take virtually total responsibility for O & M as both a policy reversal and a betrayal.

Several state officials expressed the fear that under this policy USEPA might choose to fund a lot of projects that involve minimal front end remedial work but will require complex and expensive long term monitoring of groundwater, surface water and air.

Of almost equal concern to states is USEPA's decision to require states to pay 10% of all the costs involved in remedial planning including preliminary feasibility and design studies. Although states have more or less reconciled themselves to this policy they are still predicting dire consequences down the pike as a result of the decision.

Shortly after the decision was made public, Dale Wikre, who heads the Minnesota hazardous waste program and also chairs an ASTWMO task force on Superfund, said that the timing issue presented by this unexpected requirement was almost as crucial as the money involved. He noted that given the legislative constraints in many states with regard to obtaining matching money, there will be long delays before even the preliminary work can start.

Although USEPA officials feel they have given the states a lot of flexibility in how they can provide assurances for their share of funds, Wikre expressed skepticism about whether most state legislators or governors will buy the package. He said that in some ways what states are being asked to do is tantamount to writing a blank check.

Noting that 1985, when Superfund sunsets, is not that far away, Wikre said the delays that could result from the 10% of everything requirement could last until Superfund expires in many cases. He expressed the view that at least a few states would not be able to obtain adequate assurances and that some who do attain them will not be able to really come through. He expressed the personal view that USEPA seemed to be making it hard for states to participate while saying they wanted states to be active.

The outspoken Minnesota official went so far as to suggest that the top echelon as USEPA sees its job under Superfund as protecting the fund rather than protecting the environment.

## CONCLUSIONS

It is impossible to even begin to address the real story of federal/state coordination under Superfund in a short paper since there are 50 distinct and separate situations. To try to access a general picture of how the process is going requires making general statements that might be rather misleading when applied to an individual state.

Some states like California, New York and New Jersey for example have clear funding mechanisms of their own but have so many problem sites that the possibility of them getting what they see as adequate funding under Superfund is virtually nil. Other states have almost no sites that they feel are requiring federal attention. Still other states may have real problem sites but will not submit them because they are not sure of getting the 10% match. Some observers say that this development could result in a situation where many dangerous sites do not become Superfund candidates until so late in the process that most of the money will have already been committed.

Ultimately the real success of federal/state coordination can not be determined until far in the future when it becomes clear how many sites actually got cleaned up and how well states are able to handle the long-term operation and maintenance costs. It will also hinge on the actions of state legislators who must decide whether to allocate funds for the state share.

# THE TCE RESPONSE IN ARIZONA

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## INTRODUCTION

The contamination of groundwater by hazardous and toxic wastes has become the environmental issue of the '80s. Throughout the nation, this valuable underground resource, once believed to be pristine and resilient, has been degraded as the result of man's casual disposal of wastes. Historically the disposal of wastes has not been closely monitored or regulated. Industrial wastes have been dumped into unlined surface impoundments, shipped to landfills, poured down abandoned wells or simply dumped in the dark of night in remote locations.

With the realization that the quality of the groundwater had been jeopardized by these activities, a national assessment of waste disposal sites was initiated. In Dec. 1979, The Arizona Department of Health Services (ADHS) completed a statewide surface impoundment assessment.<sup>1</sup> The report evaluated the potential for groundwater pollution by leachate from numerous surface impoundments and assessed the priority of these sites for further investigation. The Hughes Aircraft facility (Hughes) located in the area of Tucson International Airport was a high priority and had reportedly caused the contamination of nearby wells with chromium, cadmium and arsenic.

As a result of the surface impoundment assessment, a USEPA field investigation of selected uncontrolled hazardous waste sites was conducted in Arizona. The investigation of the Hughes facility in March 1981 revealed the presence of various contaminants in wells at and near the facility. The preliminary report<sup>2</sup> concluded that there was evidence of groundwater contamination and recommended further investigation. Additional sampling confirmed the presence of trichloroethylene (TCE), 1,1-dichloroethylene, 1,1,1-trichloroethane and chromium. The most predominant contaminant found was TCE, a degreaser used extensively by a variety of industries since the 1920s.

Subsequent groundwater monitoring in the Tucson International Airport area revealed a plume of groundwater contamination extending several miles, affecting 8 wells belonging to the City of Tucson (Tucson Water), four industrial wells at the Hughes facility and several semi-public or private wells. The highest concentrations were found at the Hughes facility. They exceeded 13,000 µg/l. Concentrations in the municipal wells ranged from 1 µg/l to 240 µg/l.

The discovery of TCE in Tucson led to testing in other areas of the State. The City of Phoenix initiated a TCE scan of distribution system samples in conjunction with quarterly trihalomethane analyses in Oct. 1981. This screening process detected a contaminated area near Indian Bend Wash in east Phoenix. Further testing confirmed the presence of TCE in seven municipal wells belonging to three different cities (Phoenix, Scottsdale, Tempe) and four irrigation wells. TCE concentrations in the Indian Bend Wash area ranged from 5 ppb to 1,000 µg/l.

ADHS, the regulatory agency with primary responsibility for groundwater protection, safe drinking water and control of hazardous wastes, has acted as the lead agency in coordinating all

local, State and federal TCE-related activities. The Departmental goals underlying the development of the TCE response were the protection of the public's health first, and secondly the protection of the groundwater quality in the State. In the absence of State or federal standards and regulations for volatile organic contaminants in drinking water or groundwater, ADHS has established a State action level for TCE and developed guidelines for managing TCE in public water supplies.

A State action plan was developed to identify the basic steps to be taken to clearly define the extent of groundwater contamination; to identify contaminated drinking water supply wells; and to evaluate potential solutions. A State "Superfund" known as the Water Quality Assurance Revolving Fund (WQARF) was established by the State Legislature to provide funding for the removal or reduction of man-made pollutants in drinking water supplies.

## STATE ACTION LEVEL

Federal drinking water standards have not been established for TCE or any of the volatile organic contaminants, although many of these contaminants are suspected carcinogens, thus the desirable concentration would be zero. USEPA has provided guidance based on health risks for selected contaminants. The guidance, known as Suggested No Adverse Response Levels (SNARL), identifies the concentration ranges that would increase the risk of excess cancer in a given population exposed over a lifetime.

ADHS has established an action level of 5 µg/l which is equivalent to USEPA's SNARL<sup>3</sup>, for TCE. It is the concentration at which one may expect to observe one additional case of cancer in a population of one million people consuming 2 liters of water per day over a 70 year lifetime. The action level is not an enforceable standard, but the level at which the public water supplier is asked to voluntarily remove a well from service while the magnitude of the problem is assessed and health impacts are evaluated.

## GUIDELINES FOR TCE IN PUBLIC WATER SUPPLIES

In Mar. 1982, ADHS released the final *Guidelines for TCE in Public Water Supplies*.<sup>4</sup> The guidelines were developed in response to requests and inquiries made by the impacted communities. The public water suppliers actively participated in the development process since it represented a concerted, cooperative effort to ensure the safe quality of the public water supplies in the State. The guidelines are not mandatory, nor are they enforceable.

The guidelines define acceptable levels in drinking water, requirements for initiation of testing and follow-up testing, procedures for sampling, reporting and public notification; steps to ensure safe drinking water supplies; and allowances for blending or short term use of water exceeding 5 µg/l. Although the guidelines specifically address TCE, they were structured so that they can be expanded to incorporate other organic contaminants as needed.

Initial testing may be conducted by ADHS or by the public water supplier in areas identified by ADHS to have a high risk of TCE contamination based upon an evaluation of land use and waste

disposal practices. Samples should be collected from all drinking water wells if possible, although representative points within the distribution system may be sampled in the preliminary testing. If TCE is detected in a distribution system sample, all wells contributing to that sampling location must be tested.

Wells containing less than 5 µg/l may remain in service with periodic testing to ensure that the TCE level has not increased. Any well that exceeds the action level is resampled and an analysis for the purgeable priority pollutants is completed. A sample is also collected from the nearest consumer's tap for the same analysis.

When it is verified that a well exceeds the action level, the public water supplier is advised to take it out of service while the necessary investigations are conducted and alternatives for future use are evaluated. Before the well is put back on-line, the water supplier should submit a written plan of action which defines the steps to be taken to ensure that the drinking water delivered to the customer will not exceed the action level.

The guidelines allow for limited delivery of water containing TCE in concentrations greater than the action level. Assuming that no other contaminants are present at levels that pose a health threat and the TCE concentration is less than 5 µg/l for the remainder of the year, the water supplier may deliver water containing between 5 and 10 µg/l for no more than 6 months, or 10 to 20 µg/l for no more than 3 months, or 20 to 40 µg/l for no more than 1½ months, or 40 to 50 µg/l for no more than 1 month.

Finally, the guidelines discuss the alternatives for use of wells which exceed the action level. Some of the possibilities are as follows:

- Replacement by alternate source
- Blending with acceptable source
- Seasonal usage of up to 50 µg/l
- Well modification to seal off contaminated zone
- Treatment to remove contaminants

#### **WATER QUALITY ASSURANCE REVOLVING FUND**

In April 1982 the Arizona State Legislature enacted a bill, H.B. 2207,<sup>1</sup> which established the Water Quality Assurance Revolving Fund (WQARF). The monies appropriated to the WQARF, \$500,000 for 1982, and all monies recovered by civil penalty against dischargers of hazardous wastes, were designated for the clean-up or removal of man-made pollutants from groundwaters of the State used for the purpose of supplying water for human consumption by any political subdivision.

The monies in the WQARF may be used in two ways: (1) to assist in the clean-up or removal of contaminants from groundwater, or (2) to provide State matching funds to the federal super-fund projects for groundwater-related remedial actions.

The legislation set forth the basic criteria for selection of sites to receive funds which included the level of pollution present in groundwater; the availability of alternative sources of water for human consumption; the length of time the pollution has existed; and the recent or future degree of impact on the public health and welfare. The specific conditions for eligibility that have subsequently been defined are as follows:

- Pollution of the groundwater must be the result of a man-made or man-induced alteration of the chemical, physical, biological or radiological integrity of the groundwater
- The level of pollution present in the groundwater must exceed a State standard as defined therein
- The polluted groundwater must have been used for human consumption
- The applicant must be a political subdivision of the State in accordance with Arizona Revised Statutes
- The applicant must own or operate the water system which supplies potable drinking water for human consumption
- The applicant's proposed project or clean-up/removal plan must remove or reduce the pollutant to within tolerable State standards
- The applicant must be willing and able to commit local matching funds at least equal to the total amount sought from the WQARF

The Legislation designated ADHS the lead state agency responsible for administering the WQARF. The Water Quality Control Council (WQCC), established by statute to develop water quality standards, effluent limitations, pretreatment standards, etc., was charged with developing and implementing criteria for project evaluation and prioritization.

The priority system<sup>6</sup> adopted by the WQCC in Aug. 1982 describes the mechanism for the evaluation of project eligibility, the adoption of the priority list, the procedures for additions and modifications to the priority list, the interface with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); and the distribution of funds.

The following criteria were established to assess the priority ranking of each applicant:

- Degree to which the pollutant in the drinking water source exceeds State standards
- Areal extent of contamination
- Estimated length of time the pollution has exceeded State standards
- Level of increase or decrease of pollutant
- Percentage of total existing potable water supply which will be in jeopardy within the next 10 years
- Percentage of total existing potable water supply which currently exceeds State standards
- Total number of persons which could be served by the potable water source if the pollution were removed or reduced
- Percentage of total existing potable water supply which could be replaced by developing an alternate source
- The ratio of the cost of developing an alternate source to the cost of proposed clean-up project
- Years of service life of proposed project

Priority lists will be developed and adopted by the WQCC each fiscal year that funds are available. ADHS will review all applications, clean-up proposals, and plans and specifications to verify compliance with WQARF guidelines and State rules and regulations. Construction of approved projects must be initiated within the funding year.

#### **STATE ACTION PLAN**

ADHS has developed a State action plan which identifies the basic steps to be taken by the State in response to the discovery of TCE in groundwater. The objective is to define the magnitude of the problem, isolate potential sources and evaluate feasibility of remedial actions.

Step 1. Monitor all public water supply wells in the vicinity of the contamination. The purpose of this monitoring is twofold: (1) to locate all drinking water wells that exceed the action level and, (2) to define the horizontal extent of the plume.

Step 2. Monitor all other wells—semi-public, private, industrial, and agricultural—in the area to further define the extent of contamination and characteristics of the plume.

Step 3. Compile and evaluate all available information on the wells such as well driller's logs, details of well construction, pumping capacity, static water levels and historical water quality data, in addition to local hydrogeological data to facilitate definition of the 3-dimensional characteristics of the plume.

Step 4. Define a study area based upon available information. Review all information on historical and current land use within the study area to identify potential sources of contamination, including a survey of surface impoundments, a review of old aerial photos, a summary of underground injection wells, NPDES discharge monitoring reports, landfill monitoring reports and complaints of illicit activities.

Step 6. Inspect and survey industries in the study area to verify that current practices for handling, storage and disposal of hazardous wastes are in compliance with State rules and regulations, to determine the types and quantities of solvents and chemicals used by the particular industry and to obtain information on past disposal practices.

Step 7. Collect shallow soil samples in suspected source areas to determine potential for contribution to groundwater contamination.

Step 8. Conduct deep soil borings at those locations where potential for groundwater contamination exists, as indicated in shallow soil samples.

Step 9. Based upon the results of the deep soil analyses, construct monitoring wells around the confirmed source area to define the vertical and horizontal distribution of the plume.

Step 10. Evaluate the feasibility of remedial action. Some of the alternatives may include the elimination of sources still contributing to groundwater contamination, rehabilitation of the highly-contaminated regions of the aquifer, application of treatment at the well for drinking water purposes, and utilization of the contaminated aquifer for other purposes.

## IMPLEMENTATION

The response to TCE in Arizona has been a cooperative effort. Many parties have combined their resources and expertise to accomplish the same objectives addressing a mutual concern. The various municipalities have contributed by performing pump tests on contaminated wells, renovating and sampling abandoned wells within the problem area, and reviewing historical water quality, well construction and water consumption records. The Pima County Health Department initiated an extensive monitoring program identifying and sampling private and semi-public wells in the Tucson International Airport area. The USEPA provided technical assistance, conducted extensive field investigations, and contributed analytical support. Their assistance was instrumental in getting the Tucson site onto the USEPA's Interim Priority Superfund List. The Arizona Department of Water Resources has conducted well inventories in the problem areas and provided well driller's logs and well specifications.

ADHS has been the central agency responsible for the overview and coordination of all TCE-related activities. Since the organizational structure and fiscal planning process had not allowed such an intensive "emergency response", resources and manpower had to be borrowed from existing programs, leaving obligated tasks unfinished. In the past year-and-a-half, responsibilities have shifted back and forth between safe drinking water, hazardous waste and groundwater protection programs. A special core group has now been specifically set up to manage the continuing investigations and implementation of remedial action in the TCE problem areas and to oversee the utilization of WQARF and CERCLA monies.

In the process of implementation of the programs discussed earlier, ADHS has encountered numerous obstacles and uncovered new issues. Among these are analytical capability and quality control, relative health risks of alternate water supplies, effects of well closure on contaminant migration, and resource allocation.

At the time that TCE was first discovered in Tucson, the State Laboratory was in the initial stages of developing the capacity to perform these analysis. Since that time, the laboratory's analytical capabilities have been expanded to encompass all 32 purgeable priority pollutants. The State Laboratory, however, is the only facility within the State with these capabilities; therefore, the majority of the analytical work in the TCE investigations has been performed by them.

The lab has a certification program for commercial laboratories in the State. To date this program has only applied to those analyses required by regulation; i.e., bacteriological, inorganic chemical and a limited number of organics in surface water samples. In order to help meet the State's needs, the laboratory is in the process of developing a certification program for volatile organics. Additionally, some of the affected municipalities have or are in the process of developing their own analytical capabilities to minimize the long term cost of surveillance.

In July of this year, the City of Phoenix closed two wells on the west side of the city in accordance with the TCE Guidelines. The

wells contained relatively low concentrations of TCE (9 to 30 µg/l) but fed directly into the distribution system with no blending.

To make up for lost production the City utilized the adjacent distribution system which contained a mixture of groundwater and surface water with a trihalomethane level of 87 µg/l. This trihalomethane level corresponded to an excess cancer risk of 295 per one million, significantly greater than the excess cancer risk of the TCE contaminated supply. ADHS is in the process of reevaluating the *Guidelines for TCE in Public Water Supplies* to determine if and how they should be revised to address this fissure.

Another issue that has been raised repeatedly, yet remains unresolved, is the questionable effect of well closure on subsurface contaminant movement. In the Tucson area, where some wells have been closed for more than a year, significant increases in TCE concentrations have been observed in downstream wells. It has been suggested that the closure of a contaminated well allows the contaminant, once contained by pumping, to migrate further. Increased pumping of nearby wells to make up for lost production may actually promote the migration of the contaminant. The behavior of TCE within the aquifer and the regional effects of pumping upon the contaminant plume are not well understood. In the absence of strong technical arguments, ADHS has elected to encourage closure of contaminated drinking water wells.

Finally, resources are always an obstacle when developing and implementing new programs. The legislation which created the WQARF, for example, did not allocate any funds for its administration. And, although the fund may be supplemented by monies recovered by civil penalty against hazardous waste dischargers, enforcement is difficult with rapidly diminishing resources. It is hoped that with a more efficient organization, the availability of WQARF and CERCLA monies and new legislation to allocate administrative funds the "TCE Response" will be much improved.

## FUTURE ACTIONS

The response to groundwater contamination in Arizona has just begun. ADHS will be involved in various activities over the next several years related to both corrective and preventative measures.

The investigations and implementation of remedial actions in areas of groundwater contamination will be continued to accomplish the following goals:

- To restore all regions of the aquifer used for drinking water to acceptable levels for all contaminants;
- To minimize further movement of contaminants within the environment;
- To eliminate sources of contamination that are or may still be contributing to groundwater pollution;
- To provide substitute water supplies to any impacted entity if necessary for present and future water demands;
- To conduct investigations and monitoring activities to evaluate all known or potential sources of contamination; and
- To ensure that all costs for groundwater contamination assessment and remedial action are borne by those responsible for the contamination.

In the Tucson International Airport area, a considerable amount of investigative work has already been completed, particularly at the Hughes Aircraft facility. Since the facility is located on property owned by the Air Force, the Department of Defense's Installation Restoration Program (IRP) has been instituted at the site. Interim remedial actions already have been proposed and are expected to be implemented within the next year.

Final remedial actions at the Hughes facility will be developed after the total regional solution has been defined. It is likely that all of the contamination in the area did not originate from a single source. The City of Tucson, the State, USEPA, the Air Force and Hughes are negotiating a memorandum of agreement which will define their respective roles and responsibilities in the source investigations, problem assessment and solution evaluation.

The Tucson International Airport area has been designated Arizona's top priority site on USEPA's Interim Priority List for Superfund (CERCLA), and it is also number one on the priority list for Arizona's WQARF. These monies (WQARF = \$250,000) will be spent on the continued investigation of potential sources and solution definition, development and implementation.

Several monitoring wells already have been installed in the area to help define the vertical extent of the plume. Solute-transport modeling will be utilized to project the extent of contamination caused by a particular source and to predict the effect of proposed remedial actions upon the regional aquifer.

Monitoring in the study area will serve a variety of purposes: to verify the predictions of the models, to provide additional data for further modeling, to determine the extent of contamination caused by known sources, to identify other sources, to evaluate the effectiveness and impact of interim remedial actions, and to identify and evaluate final remedial actions.

If all sources of funding (DOD-IRP, EPA-Superfund, Arizona-WQARF) are made available as anticipated, final remedial action may be underway in the near future.

Two municipalities in the Indian Bend Wash area (near Phoenix) have received the remainder of the WQARF monies. Both cities will be required to submit proposals for removal or reduction of TCE in their contaminated supplies unless the Indian Bend Wash site is named to the USEPA's National Superfund Priority List. If the site does make the final Superfund List, WQARF monies could be used as State match.

Most field activities in Indian Bend Wash thus far have been the product of a task force including representatives from the three affected municipalities (Phoenix, Scottsdale, Tempe), the Arizona Department of Water Resources, ADHS, the University of Arizona and Salt River Project (an irrigation/utility district). In view of limited resources, each of the participants will continue to contribute their individual expertise to approach the complex problem of groundwater contamination.

Groundwater contamination is a problem of which the nation has only recently become conscious. Subsequently, it is not well understood nor is it easily managed. Since groundwater moves slowly, with little mixing or dispersion, pollutants remain in a relatively well-defined plume which is highly concentrated and exists for a long period of time. An underground plume is very difficult to define, requiring the installation of numerous expensive monitoring wells. Although the plume may be contained by pumping, clean-up of an aquifer is expensive, if it is possible at all.

For these reasons, prevention of groundwater contamination is the best policy. The State strategy for the protection of groundwater quality is many faceted, involving water quality control and waste control programs. ADHS is in the process of developing the following regulations and programs:

- Underground injection control
- Permitting of municipal and industrial discharges to groundwater

- Water quality standards
- Hazardous waste control
- Hazardous waste management facility
- Pretreatment program

Implementation of these new programs will require additional resources. With diminishing federal funding, the success of these programs is questionable. The solicitation of increased financial support from the State Legislature will be an essential activity. Proposed revisions to State statute would enable the ADHS to collect fees for various activities. These fees would be placed in a fund which would be used solely for the environmental programs.

## CONCLUSIONS

Many have speculated that the discovery of TCE in the groundwater is only the "tip of the iceberg"; it is feared that other more harmful chemicals are present in the aquifer or will soon appear. In all of the study areas, samples have been collected from the most highly contaminated TCE wells to be analyzed for the 129 priority pollutants. The results have not indicated the presence of contaminants other than those commonly found in association with TCE. These contaminants are also industrial solvents, or components thereof, which were used in association with TCE: dichloroethylene, trichloroethane, tetrachloroethylene, chloroform.

It is difficult to predict whether or not other contaminants will be discovered in the future. ADHS will continue to evaluate information on land use and waste disposal to identify areas where the potential for groundwater contamination exists and monitor for a variety of contaminants. Through the development and implementation of the strategy discussed in this paper, ADHS has gained valuable experience. The necessary framework to respond to any groundwater pollution crisis has been established.

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# IMPLEMENTATION OF A STATE SUPERFUND PROGRAM: CALIFORNIA

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## INTRODUCTION

The primary goals of the California hazardous waste management program are to protect public health and the environment by ensuring proper and safe handling, storage, transport, and disposal of hazardous waste materials and cleanup of hazardous waste sites requiring remedial action. The program is committed also to the conservation of land, materials, and energy resources through the promotion and support of waste reduction, waste treatment, and resource recovery activities.

The hazardous waste management program in California is administered through the Division of Toxic Substances Control in the Department of Health Services. The program has experienced rapid growth of responsibility since its beginnings in 1973. Legislation since 1980, especially through the 1981 and 1982 legislative sessions, has added a number of key elements to California's overall toxics management program.

The element to be discussed herein is implementation of the California "Superfund" program which was established through enactment of State Senate Bill 618 in September 1981.

## CALIFORNIA SUPERFUND

Senate Bill 618, Statutes of 1981,<sup>1</sup> established a 10-year, \$10 million per year, Hazardous Substance Account and a multitude of program activities to be funded from that account. The total amount in the account is to be raised through a tax on the generators who submitted hazardous and extremely hazardous waste for disposal offsite, or who disposed of, on-site, such hazardous wastes, including wastes from the extraction, beneficiation, and processing of ores and materials; including phosphase rock and overburden from mining of uranium ore.

The base tax rate is established following receipt and tabulation of reports on the total amounts of waste disposed in the categories specified in statute. The account is limited to a maximum funding of \$10 million per year and accordingly, reductions to the tax rates are made when unexpended funds are carried over from prior fiscal years.

### Program Elements

The key provisions for which the account is to be used include the following:

- Funds to cleanup state hazardous waste sites that qualify as Superfund candidate sites
- Ten percent state matching funds to meet federal Superfund eligibility requirements
- Up to \$1 million per year for assisting local agencies in responding to emergency spills of hazardous chemicals
- Funds to support local and state agencies response to hazardous materials spills through the purchase of emergency response equipment
- Up to \$500,000 per year for health effects studies undertaken regarding specific sites or specific substances at specific sites
- Up to \$2 million per year for compensation of certain losses caused by the release of hazardous substances

## Program Staffing

A multidisciplinary team of engineers, chemists, toxicologists, epidemiologists, physicians, waste management specialists, geologists and lawyers has been assembled to carry out the California Superfund program. A multiplicity of inherent conflicts occur during the conduct of a program such as Superfund. Complexities are inherent in all phases of site impact assessment in establishing criteria and protocols for remedial response in evaluating remedial alternatives against selected mitigation criteria, in designing of remedial response plans, and in assuring adequate public health and environmental protection during and following site cleanup activities. Resolution of these conflicts requires both competent and aggressive technical and management staff. The 40-person staff assigned to fulfill program responsibilities are located primarily in the Toxic Substances Control Division in the following sections: Site Cleanup and Emergency Response, Hazardous Materials Laboratory, Epidemiological Studies, and Air and Industrial Hygiene Laboratory.

## SITE IDENTIFICATION

California's regulation of hazardous and nonhazardous waste disposal to land was initiated in about 1950 through the original agencies of the California Regional Water Pollution Control Boards. However, regulation was limited to "official" disposal sites and did not necessarily include onsite disposal, storage, treatment and handling facilities. Therefore, while many significant disposal sites were regulated, more were not at all or were regulated based upon less stringent environmental and health standards than exist today.

The state's proactive hazardous waste management program that was established in 1973<sup>2</sup> has improved efforts to locate, regulate and monitor sites used for disposal and/or sites of releases of hazardous materials. Through the program's enforcement activities and a special Abandoned Site Project search effort, sites were identified as candidates for Superfund consideration. The procedures used in the Abandoned Site Project were reported previously.<sup>3</sup>

In summary, the project's methodology provides for the gathering of all available data on a site to determine need for further evaluation. Extensive review of business directories, tax rolls, phone directories, and industrial association lists is made to locate inactive or potential abandoned sites. A survey questionnaire is sent to all companies possessing certain standard industrial classification (SIC) codes. The questionnaire seeks information on disposal methods used prior to 1972 and on locations where waste may have been disposed of prior to that year. Leads to other sites are developed through contact with community groups, individuals, and searches of records of other public agencies.

Further evaluation includes a site "drive-by" inspection to determine present use of the site, proximity of residents, evidence of material disposed or leaving the site, and security of the site. Evaluation may also include aerial photograph interpretation of site history. Additionally, an on-site inspection may be conducted



and samples collected for laboratory analyses.

Results of the project indicate that in the 12 counties completed, 8,280 potential abandoned waste sites have been investigated by staff of the project. Of those, 63 have been determined to in fact be abandoned waste sites that would present a potential significant public health and environmental hazard. In the six counties currently under investigation, 6,203 possible abandoned waste sites have thus far come under investigation. Additional potential sites are expected to be identified and contracted in those counties in 1982. No projection as yet can be made on how many of those sites may be determined to actually be abandoned hazardous waste sites which present a health hazard. From the results of the investigations conducted in the 12 completed counties, it would be expected to be somewhat less than 1%. However, experience gained in the first counties investigated has educated project staff in avoiding unproductive investigations and should increase the ratio of actual sites to potential sites.

### SITE RANKING

California's review and evaluation of the federal Hazard Ranking System<sup>4</sup> revealed that certain apparent deficiencies existed in the method used for establishing priorities for remedial action based on a total estimation of potential for environmental damage or public health hazard. Additionally, California's law<sup>5</sup> requires that the Department of Health Services adopt by regulation the criteria for the selection and priority ranking of sites and publish a priority ranked list of sites targeted for remedial action. Expenditures of state Superfund monies are to be based upon this ranked list.

Accordingly, the California criteria were developed using the federal system with significant modifications and additions to meet the requirements of state statutes and the Department's mandate for protection of public health. The resultant criteria<sup>6</sup> produced a relative ranking score which consists of the cumulative scores from the federal method of ranking on the basis of the Migration Hazard Mode, Fire and Explosion, and Direct Contact. In addition, two categories, Toxic Hazard and Potential Hazard were developed by state staff to represent variable waste concentrations and the potential impact caused by releases of more than one chemical waste.

The state considers concentration as a function of three routes: acute toxicity, persistence and bioaccumulative toxicity and carcinogens.

The acute toxicity route is derived from the toxicological hazard assessment in *Dangerous Properties of Industrial Materials* by N. Irving Sax and from the concentration at the site. The persistent and bioaccumulative toxicity route is based on the California Assessment Manual for Hazardous Waste, which lists trigger concentrations for inclusion as hazardous and extremely hazardous wastes. The carcinogen route uses the *Registry of Toxic Effects of Chemical Substances* as a standard reference to identify carcinogens and uses the concentration as a multiplier. This route has an acceptable exposure limit of zero. Sites with any carcinogens, no matter how small the concentration, will receive a score for this route. The criterion further distinguishes between suspected animal carcinogens, known animal carcinogens, and known human carcinogens.

The approach taken in the Potential Hazard criterion was included to reflect the estimated potential for release of hazardous substances into the air. This criterion addresses a specific problem where the Mitigation Hazard Mode failed to provide sufficient consideration. For example, zero points are assigned for potential release of toxic gases or fumes. Under the state system sites receive a score based upon this potential hazard.

### REMEDIAL RESPONSE

Once the annual priority list of sites is created, the process of administratively managing the list for remedial response is initiated. The top 15 sites are selected for evaluation and for preparation of site reports. The site reports include:

- Site description summaries
- Status of enforcement
- Description of the problem
- Identification of land ownership or responsible parties
- Proposed actions with tentative time schedules

From the site reports program strategies are formulated on the course of actions to be proposed at each site, including a time schedule and tentative estimate of costs. These strategies are used to prepare the Superfund program plan and the annual budget.

All site remedial response activities flow through four phases: (1) remedial investigation and site characterization, (2) development of mitigation criteria and analysis of remedial alternatives, (3) selection and design of the most effective remedial solution, and (4) implementation.

#### Remedial Investigation

This phase involves all tasks necessary to determine the degree of risk to public health and the environment, to characterize the nature of wastes onsite and their areal extent and potential or existing migration and to collect data for establishing mitigation criteria, evaluating alternatives and preparing the final remedial response design. Activities in this phase include:

- Soil borings in sufficient depth and numbers to estimate the size of the polluted area, and the contaminants on-site
- Quantitative chemical analysis of toxic substances in on-site wastes and in surface and groundwater
- Air monitoring data to determine current emissions and possible emissions during excavation
- Geophysical and hydrogeological site data
- Toxicological risk assessment of chemicals on-site

The conduct of this phase involves extensive coordination with other public agencies involved in environmental regulation and public health protection. Without complete interagency coordination and concurrent in the remedial response actions proposed to be initiated, serious conflicts occur. Such conflicts slow down implementation and, in severe cases, can stop progress.

Similarly, adequate public involvement must be planned for all phases, starting with the initial site characterization field studies. There is always pressure for an expedient cleanup response and often the pressure is to proceed without a comprehensive assessment of the extent of site problems and impact. The local public must be informed and be afforded an opportunity to share in the decisions relative to site mitigation. A fully informed, participating citizenry can be a significant assistance to resolving problems associated with site mitigation. Such assistance is particularly valuable when conflicting public agencies' opinions exist on the procedures to be used to protect the public health. In California, citizen participation is a principle element of the remedial response strategies.

#### Alternatives Assessment

Phase 2 of the process to attain cleanup involves a number of the most fundamental steps required to assure adequate worker safety and public health protection. This phase includes an interpretive analysis of the remedial investigation results, development of criteria for site mitigation, and identification and evaluation of all feasible remedial alternatives that lead to the selection of the least environmentally sensitive, most cost effective solution.

Mitigation criteria will relate typically to levels of odors, concentrations of organic and inorganic chemicals in the soil, limits on allowable air emissions for chronic and acutely toxic chemicals, and for limits on potential chemical contamination of surface waters and groundwaters. Additionally, criteria are developed to apply to the short-term worker and public health protection and environmental problems that might be caused during actual site remedial response activities.

All alternatives to be considered must meet all public health and environmental protection requirements. The first screening of alternatives will include estimating costs to a 50% level of accuracy and preparing an environmental assessment to consider major issues of obvious primary significance and all other environmental

issues that might be of secondary influence on the final environmental impact report prepared for the selected alternative.

### Remedial Design

Subsequent to selection of the "best" solution for mitigation of a site, the design phase is initiated. The consultant or staff must prepare specific plans and specifications, including safety and transportation plans, and construction documents complete enough to be used in receiving and evaluating contractor's bids for the site work.

The plan shows the staging of construction phases as required, schedules for coordination with utilities, regulatory and public health agencies and the public. Drawings are comprehensive and detailed to show all elements of earthwork, areas of treatment, neutralization or encapsulation, depth to background soils, initial and final grades, location and design of monitoring stations for water and air, location and measures for protecting environmentally sensitive areas, location and design of air scrubbing systems, and measures to be implemented for short-term protection during site disturbance activities. Selection and development of the plan for final mitigation is done in close coordination with local health, environmental agencies, and affected communities. Acceptance of the "best" remedial solution is difficult without such broad participation.

### Implementation

The contractor(s) selected to carry out the remedial response plan must have experienced personnel and specialized equipment in most hazardous waste site cleanups. In dealing with hazardous waste, nothing is simple. Precautions during construction must be backed up with support systems capable of reacting to on-site emergencies. Also the contractor(s) must be able to mobilize in a manner consistent with the safety plan and must have a site specific safety training plan for workers.

Typically, the overall site safety plan includes provision for the on-site representative to shut down or curtail site activities if either worker safety or public health is threatened. In California such on-site controls range from curtailment of some site activities if for example, a low level of adverse air emission is measured, up to a total shutdown of the day's site activities if the established maximum allowable short-term air concentrations are exceeded at a perimeter monitoring station.

The entire exercise of site remedial response design and implementation must be predicated on the principle that public health protection is the controlling factor for both short-term on-site project activities and long-term site mitigation criteria.

### MITIGATION CONSIDERATION

Final selection of sites subject to remediation can include criteria other than those relating to public health and environmental impacts. They may well include such factors as feasibility of remedial action as well as political impact concerning a specific site in the jurisdiction of a legislator. As mentioned earlier, the Department was required by law to develop a set of criteria and a priority ranking of sites within the state which would be used for expenditures of Superfund dollars. During this legislative session, however, at least four bills were introduced which directed the Department to expend a specific amount of monies for remediation of a particular site.

Legislative "ranking" of sites for remedial action is seldom based purely upon environmental and public health criteria. Legislative direction may also mandate selected mitigation technologies without sufficient consideration for feasibility. This problem results from the intense public focus on abandoned waste sites and a legitimate response to these public concerns by local legislators. This potential difficulty can be largely overcome by a concerted effort in public, community, and legislative education regarding Superfund programmatic activities.

Selection of alternative mitigation involves consideration of many factors. Given that some remedial action is necessary at the high priority sites, options for mitigation involve some form of on-site containment or excavation and remote treatment and/or disposal, or some combination of the two. Primarily, decisions

on which options are to be carried out are based on a technical evaluation of the effectiveness of selected mitigation technologies and the relative cost of these technologies. Comparative evaluations of on-site containment versus remote disposal and treatment are very difficult for a variety of reasons:

- Uncertainties in the long-term behavior of many substances in soils, liners, and aquifers. On-site containment may well involve long-term operation and maintenance costs of such features as pumping, leachate wells, and treatment plants.
- Excavation of problem wastes is confronted by such problems as uncommonly high costs, and potential for excessive short-term environmental and public health impacts
- A significant problem exists for the remote disposal of excavated material and the possibility of creating future problem sites from such land disposal
- Significant problems are also incurred by the transportation of large volumes of excavated materials
- Difficulty of treatment of contaminated soils
- Excavation of contaminated soils from problem sites causes particular difficulty in California in light of the newly published regulations on the restriction of a wide variety of materials from land disposal. In view of the fact that these restrictions include concentrated metal wastes and certain volatile wastes. Commonly excavated wastes from problem sites may include these categories and therefore if excavated, must be treated prior to disposal in the land.
- Migration of toxic substances through the air or water results in low, subacutely toxic levels of a large number of substances. The environmental and public health impact of these complex mixtures is extremely difficult to assess. Assessment requires extrapolation of high dose acute toxicity data to low dose chronic exposure, assumption of toxicological interactions, and relative sensitivities of environmental and public health targets. The public and their representatives usually take a conservative health view toward such uncertainties. Fund managers, be they public or private, more commonly take a less conservative position. When searching for a balance between cost and effectiveness, cost estimates are in general much more solid than are effectiveness estimates as measured in units of public health protection.

On a different level, commonly remediation is influenced by a strong public community feeling that remedial action must involve complete removal and remote treatment or disposal (i.e., removal of the wastes from my backyard). Communities are very reluctant to consider on-site containment as an effective solution and the concept of cost-effective solutions is not generally acceptable. Strong community feelings toward remote disposal or treatment can be translated into a legislative action mandating a particular remedial option.

California has approached these science, technology, public policy difficulties by making the whole process of site evaluation, mitigation assessment, and final resolution as public as possible. The uncertainties, technological, and fiscal limitations are openly discussed. This approach to date has minimized the confrontation between departmental program activities and the public.

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# AN INTERNATIONAL STUDY OF CONTAMINATED LAND

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## INTRODUCTION

In recent years many developed countries have faced problems from land that has become contaminated with substances hazardous to human health and the environment. International awareness has been kindled by well publicized cases such as Lekkerkerk in the Netherlands, Love Canal in the USA and Shipham in the United Kingdom. These sites have attracted interest not only from a technical, but also from a social viewpoint.

Each country has its own particular problems arising from a wide range of hazardous substances that have contaminated the land. In the USA hazardous, uncontrolled waste disposal sites have been of greatest concern; in the UK it is the many former industrial sites often located in urban areas where the demand for land is high that have been discarded through economic and technological changes.

Each country has its own national economic, social and political priorities for dealing with contaminated land problems, and must work toward their solution within the constraints of national legislation. The OECD Waste Management Policy Group provides an international forum for discussion of such issues in relation to waste disposal sites. But, whatever the origin of the problem or the context within which it arises, there is a common thread in the technical requirement for effective, long-term remedial measures.

The variety of problems encountered in the UK suggested that other countries might share similar experiences and in turn might have complementary experience and solutions to contribute. Accordingly, the UK made a proposal in 1980 to NATO/CCMS for a pilot study on contaminated land. In this paper, the authors describe how the study group has set about its task and outlines work in progress.

## THE STRUCTURE OF THE STUDY

An inaugural meeting was held at the Building Research Station, Watford, England in November 1981. Six countries were represented: Canada, Denmark, Federal Republic of Germany, The Netherlands, UK and USA. A further planning meeting was held in The Hague in April 1982 at which these countries confirmed their interest in, and support for, the study.

Work to date has comprised the establishment of priorities and work programs. A first meeting of experts to discuss progress on each of the five active study areas (see below) took place in Washington immediately following this conference.

At the start of the study, each country outlined its own perception of contamination problems and identified topics of particular interest. In discussion, the group agreed that the study should concentrate on land that could be regarded as contaminated according to the following definition proposed by the UK:

"Contaminated Land" is land where substances are found that, if present in sufficient quantity or concentration, could be hazardous to workers, or to the eventual users or occupiers of the

site, or to a wider population due to transport of the substance from the site, for example by wind action or pollution of water. It also embraces the presence of substances that may be harmful to plants and animals, pathogenic organisms, and substances that are aggressive to building materials.

This definition hinges on the presence of hazardous substances, and not the past use that has given rise to the existence of contamination. It is therefore wide enough to encompass the uncontrolled hazardous waste sites of particular concern in the USA, as well as the many types of former industrial sites (for example metal mining and processing, chemical production and coal gas production) of particular concern in the UK and Western Europe. It also includes land that has become contaminated by over-application of sewage sludge rich in "heavy metals" or other contaminants.

All participants, irrespective of any national policy context, saw the need for identification or development of adequate technical solutions. It was agreed that a NATO study on the technical aspects of tackling contamination would provide a useful complement to the OECD Waste Management Policy Group's work on administrative and legislative issues. The most pressing requirement identified by all members was the need for remedial measures of proven long-term effectiveness and capable of meeting a range of applications. Participants were agreed that such solutions should be identified and, where they did not already exist, developed taking into account both the variety of hazardous substances and the type of exposure, its targets, and risk after treatment.

A two or three year pilot study could not hope to take, or benefit from, new research initiatives. However, the value of the group as a forum for exchange of expertise and experience meant that substantial benefits might flow from evaluating existing national research effort. The product would then be a practical review of available remedial techniques and methods of assessing their performance. Such a review would be of value by increasing the stock of knowledge available to individual countries in the group and, if published would benefit the wider international community.

The first meeting of participating countries agreed on the topics that should be covered by the Pilot Study. They comprise two main groups (Table 1): (1) priority topics for active study, and (2) topics of lower priority, to be restricted to an exchange of information. Other topics were also considered for inclusion in the study—principally questions of identification and assessment. However, considerable published information already existed both from the USEPA<sup>1,2</sup> and the OECD.<sup>3,4</sup>

With limited resources and time, it was agreed that progress could best be made by countries with particular national problems setting out an initial review on a priority topic of particular interest to themselves as a basis for wider debate in the CCMS study group. Five projects are at present in progress following this approach and in the remainder of this paper, the authors introduce briefly these five study areas. A tentative offer to lead a sixth project (H) has been made by the USA.

**Table 1.**  
**Priority Projects**

**A *In-situ* treatment of contaminated sites—Lead country—USA**

Methods of treating without excavation the bulk material on a contaminated site by detoxifying, neutralizing, degrading, immobilizing or otherwise rendering harmless contaminants where they are found.

**B On-site processing of contaminated soils—Lead country—The Netherlands**

Methods of decontaminating or otherwise reducing the potential environmental impact of the bulk of contaminated material on a site by: excavation; treatment to detoxify, neutralize, stabilize or fixate; and usually re-deposition on-site.

**C Covering and barrier systems—Lead country—United Kingdom**

To study the design of systems to prevent the migration of contaminants vertically or laterally, or to prevent ingress of surface or ground water into contaminated sites.

**D Control and treatment of groundwater and leachate—Lead country—Canada**

Primarily concerned with those operations designed to control or treat the liquid phase on contaminated sites including design of cut-off systems, hydrogeological modelling and leachate treatment.

**E Organic Chemicals and Plants**

To study the tolerance to, and the uptake of, organic chemicals by plants and their implications for site assessment, human health and site reclamation. Initially the study would concentrate on a few substances considered to be of general interest, e.g., creosols and chlorinated hydrocarbons.

**F Rapid on-site methods of chemical analysis**

To find methods of chemical analysis allowing determinations to be made on "soil", water and air samples on-site so as to speed and reduce the costs of site investigations.

**G Long term effectiveness of remedial measures—Lead country—Federal Republic of Germany**

To collect information on examples of remedial and restoration actions that can be demonstrated to have worked for a number of years and methods for the monitoring of sites for long term effectiveness of remedial measures.

**H Toxic and Flammable gases—Lead country—USA (tentative offer)**

To be concerned with problems in the measurement and assessment of the amount of gas being produced in relation to the design of buildings to prevent ingress of toxic and flammable gases.

**Table 2.**  
**Information Exchange Topics**

**I Social impact of contaminated sites**

To collect information on the impact on, and the response of the public to contaminated sites.

**J Soil quality criteria**

Collection and dissemination of information of national and other guidelines relating levels of contamination to acceptability of land for particular end-uses including site specific examples. It is not intended that any attempt should be made to propose common criteria.

**K Multi-national register of "important" sites**

Collection in standard format of data on sites judged by participant countries to be of importance because of the nature of contamination or remedial measures adopted.

**L Information on key sites**

The collection and dissemination of brief but comprehensive authoritative statements about sites such as Lovè Canal, Lekkerkerk and Ship-

ham that have attracted world-wide interest. It is considered valuable to have reliable information on sites that are often referred to as examples of the penalty of development of contaminated sites.

**M Contamination and specific industries**

Collection and dissemination of information on the contamination characteristics of specific industries or processes.

**N Research register**

Collection and dissemination of information on relevant research in a standard format.

**O Site identification in urban areas**

Method of identifying contaminated sites in urban areas as opposed to identification of specific site types, e.g., hazardous waste "problem" sites on a national or regional basis, a problem that is being dealt with adequately elsewhere.

## STUDIES IN PROGRESS

### *In-situ* Treatment of Contaminated Sites (A)

This project will deal with methods of treating, contaminated material in bulk without excavation. Contaminated sites have typically been treated either by the excavation and removal of the offensive material (for disposal elsewhere or permanent destruction) or by containment using cover often in conjunction with lateral barriers. Both approaches may be expensive to implement.

Excavation and disposal of large volumes of contaminated material may pose considerable logistical and environmental problems; many factors may affect the long-term effectiveness of covering systems and are the subject of further investigation. Hence means of treating the mass of material without its excavation are attractive. Existing technology in civil engineering, mining and waste disposal offer a number of possibilities using injected fluids to stabilize, neutralize or leach out contaminants. Other techniques such as deep ploughing or electro-osmosis may also be applicable. As a first stage the US are preparing a review of stabilization techniques drawing on local experience.

### On-site Processing of Contaminated Soils (B)

Project B is concerned with methods of decontaminating or otherwise reducing the environmental impact of contaminated material by treatment on-site. As pointed out above current methods for dealing with contaminated sites or "problem" hazardous

waste sites can present a number of technical and environmental difficulties. *In-situ* techniques may also have considerable limitations, principally of quality control to ensure, for example, that all the contaminated material has been in effective contact with injected fluids. A further option to current practice may rest in excavating contaminated material and treating it on site prior to re-deposition in a safe and stable form.

The Project will draw on experience at Lekkerkerk<sup>1</sup> and on research currently in progress in The Netherlands on other on-site techniques. It will encompass simple mixing of clean and contaminated materials to reduce the concentration of the latter as well as chemical processing and incineration techniques already employed for the disposal of hazardous wastes. The project will look at the practical considerations of applying these technologies on site as a means of avoiding substantial transport and disposal costs.

### Covering and Barrier Systems (C)

The objective in treating contamination by the technique of containment is to prevent both the upward and outward migration of contaminants and the ingress of water. Much of the current practice is adapted from experience with landfill sites where they are used to limit the movement and volume of leachate.

A wide variety of different materials and techniques have been employed from simple covering with soil materials to the use of natural materials such as clays as "break" or "barrier" layers

and impermeable membranes or "geotextiles". Often these techniques have to be linked with adequate site drainage and interception of ground and surface waters.

#### **Control and Treatment of Groundwater and Leachate (D)**

Project D is predominantly concerned with those operations designed to control or treat liquids on contaminated sites but also includes some work on modelling of contaminant migration.

Pollution of surface and ground waters is often associated with contaminated land. Many cleanup operations have required chemical or microbiological treatment of considerable volumes of leachate or polluted ground water. If they are to be effective, remedial measures must control the volume of water and leachate and incorporate adequate provision for the interception and treatment. Whilst the physical and chemical role of barriers has been subjected to some study, specific design requirements to meet hydrogeological conditions are also sometimes necessary.

#### **Long-term Effectiveness of Remedial Measures (G)**

Project G seeks to identify examples of remedial and restorative actions that can be demonstrated to have worked for a number of years. It will also identify suitable methods to monitor the long term effectiveness of remedial measures on sites.

Reclamation schemes for contaminated sites are generally prepared on the basis of current knowledge and professional judgement. Schemes are often required to be effective for long periods—from a minimum of 20 years to perpetuity. However, because reclamation technology is still in its infancy there is little evidence on the long-term effectiveness of treatment, and it is difficult to simulate field conditions in laboratory or other accelerated testing regimes. As further treatment options become available, monitoring of their performance will be required if both comparative and absolute effectiveness are to be assessed.

#### **CONCLUSIONS**

Before setting out on any major new initiative concerned with the protection of the environment, it is important to share experience. Only by doing this will real problems become apparent,

so that the world's resources of expertise and research can be deployed to maximum advantage. The problem of contaminated land is indeed one of the "challenges to modern society" on an international scale and it is therefore fitting that NATO/CCMS should have accepted the subject for this pilot study.

The work is still in its early stages, but it is to be hoped that the experience of individual members of the group, some of which is described in other papers to the conference, will highlight the potential benefits of the study. Resources are limited, not least because the field is very active. Any further offers of assistance, or requests to participate in the study, would be welcomed—whether they come from other countries with particular experience to share or from government's partners in industry who may have expertise to contribute or may be concerned with developing products for application in the field of land reclamation. Their active support for the study would be of special value if it broadened the range of technical solutions available to deal with the problems now being faced.

#### **ACKNOWLEDGEMENT**

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# LONG TERM EFFECTIVENESS OF REMEDIAL MEASURES

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## INTRODUCTION

The long-term effectiveness of remedial measures is a complex subject, and conclusions cannot be generalized. Different remedial measures, i.e., *in-situ* treatment or on-site processing of soil or waste, covering and barrier systems, and control and treatment of leachate must be discussed separately. Perhaps, it will even be necessary in the future to make a more detailed differentiation.

## CLASSIFICATION OF REMEDIAL MEASURES

Initially, it seems to be reasonable to group remedial measures into two categories:

- Remedial actions, where the contamination is changed
- Remedial actions, where migration of contamination is minimized by artificial measures

### Change of Contamination

This situation encompasses *in-situ* treatment and on-site processing. Questions as to long-term effectiveness include:

- How long will it take until the required decrease of contamination in the soil is reached?
- Is the change of contamination stable or is remobilization of contaminants possible? In what time period will this happen and is it due to external influences?
- Can one restrict the migration of contamination? This condition encompasses encapsulation of contaminated sites, but also may include lowering of the ground water table or changing of ground water flow.
- Does the effectiveness of remedial action change due to external influences or due to the influence of contaminants?
- When must the remedial action be repeated?
- Is long-term management of remedial action possible?

If the migration of contaminants should be restricted, without changing the contaminant itself, regular repetition of remedial action will be necessary. Time periods between will not be longer than usual in civil engineering solutions. Possibly they will be shorter, due to contamination, which is not sufficient for evaluation.

If hindrance of migration is combined with changing of contamination, long-term efficient control is necessary and must be assessed, of course, with regard to the time of decrease of contamination.

## LONG-TERM EFFECTIVENESS

The long-term effectiveness of remedial measures can be determined by monitoring the efficiency of reduction of contaminant flow after construction or a given length of time (in the case of continuous measures). Changes caused by time to the contaminants as well as to the measures to restrict migration must be evaluated on the basis of laboratory and field tests.

In many cases of remedial action, measuring the effectiveness for the total area under treatment is a significant problem. At present, effectiveness can only be evaluated by measuring the decrease in impacts, e.g., on ground water pollution.

The disadvantages are obvious: (1) delayed evidence of effectiveness or ineffectiveness, (2) uncertainties, due to proper or wrong location of groundwater control wells, and (3) in case of partial ineffectiveness, e.g., leakage in a cut-off wall, impossibility to localize the failure.

## MONITORING THE EFFECTIVENESS OF REMEDIAL MEASURES

### Effectiveness of Micro-encapsulation

Barry<sup>2</sup> discussed, in a report on treatment options for contaminated land, the effectiveness and the monitoring of the effectiveness, of described treatment options, but only in few cases did he mention long-term effectiveness. It seems reasonable to cite Barry's remarks or recommendations on "monitoring effectiveness" in order to establish a basis from which requirements for long-term effectiveness may be evaluated. With regard to micro-encapsulation by shallow grouting, Barry assessed the possibilities for monitoring effectiveness as follows:

"Standard engineering tests can be used for checking the resultant permeability of treated ground. In many cases this can be a good indicator of effectiveness. It is not practical, however, over a large area to monitor vertical permeability, a factor which will normally be critical in contaminated land".

If this is true, then only groundwater monitoring is an appropriate monitoring approach with the well-known disadvantage of time lag and unreliability between release of contaminants from the contaminated site and occurrence in monitoring wells.

### Effectiveness of Grouting and Ground Leaching

Discussing "grouting in landfill", effectiveness and monitoring effectiveness is referred to only, as: "...it can be difficult to test efficiency of the grouting in place".

The importance of effectiveness of grouts or ground injection to build up barriers against groundwater is perhaps greater if ground leaching or *in-situ* detoxification of contaminants is the remedial measure chosen. In these cases, the flow of contaminants is large and they must be hindered from escaping into the environment. Whether long-term effectiveness of containment construction is necessary depends on the time necessary to decrease contamination. Here, too, some difficulties arise concerning monitoring effectiveness:

"As mentioned earlier when dealing with grouting, there is no simple way of checking the full effectiveness of the application. Analyzing leachate gives the average concentration; it does not define the range of concentration. Similarly the residual contamination can only be measured by soil sampling, at the same locations as earlier samples".

### Effectiveness of Cut-off walls

Last, but not least, Barry assesses monitoring effectiveness of cut-off walls:

"All forms of cut-off are imperfect and some leakage is always accepted in engineering applications. The extent of this leakage can, of course, only be tested after the event and to give any meaning to such tests it is necessary to have measured the ground permeability before installation. This is particularly true of grout curtains where, as discussed earlier, the grout permeation factor is critical".

### Effectiveness of Redevelopment of a Hazardous Waste Site

Describing investigation and reclamation at Thamesmead site, Lowe<sup>1</sup> discussed "short term and occasional risks". He stated:

"It would be unrealistic to assume that statutory or local authority operatives will be kept informed of possible health risks in the long term so where necessary, recommendations are made for backfill of trenches to take a form which will reduce the risk of contact and the spreading of foul material over clean surfaces during re-excavation".

If Lowe is right in general, some remedial actions, in particular ones such as containment, must be reconsidered.

With regard to remedial measures adequate for the Thamesmead site, Lowe required long-term research.

"The most difficult aspect of reclamation at Thamesmead has been the lack of any authoritative guidelines on such matters as the upward migration of metals through covering layers and the effectiveness of different forms of fill as barriers to contamination. It must be said that under such circumstances a 'fail-safe' attitude has had to be adopted in deciding on remedial measures in the knowledge that this may involve additional and heavy costs both in advanced civil engineering work and the construction of buildings.

"It is fortunate that research into these matters is now under way and gratifying that Thamesmead has been chosen as one of the sites where long-term research can be conducted. Liverpool University are currently operating an experimental site".

Whether such an approach is appropriate to answer questions about long-term effectiveness is discussed later in this paper.

### Effectiveness of Redevelopment of former Gas Work Sites

In a comprehensive study on problems arising from the redevelopment of gas works and similar sites, Wilson and Stevens<sup>1</sup> wrote:

"The effectiveness of the various remedial actions, particularly in the long-term, has not been systematically studied. The only documented evidence available appears to be at Battle, case B.1, where analytical results are available both before and immediately following the remedial work".

The above-mentioned follow-up survey at the Battle site, which can also be said to monitor effectiveness, is described in the following section.

#### Initial Survey

A total of 12 trial pits were dug; of these five were in clean soil and no samples were taken; one pit hit concrete and was abandoned; the remaining six pits were sampled...No groundwater was encountered in any of the pits.

In addition, two trenches were dug at right angles in the vicinity of the pond. Heavily contaminated tarry material was found to a depth of about 3m. Several pipes were observed to terminate in the pond area and other pipe runs appeared to be heading for it...

The results show patchy contamination with much of the site being relatively clean. The clay soil has limited migration of the pollutant. It was recommended that material from the pond area and from other hot-spots adjacent to buildings be removed from the site.

### Remedial Measures

Contaminated material from "hot-spots" was excavated and segregated into two heaps according to appearance and smell. The most contaminated soil was sent to a landfill, while the least contaminated was reburied at the base of the excavation. The site was then regarded and levelled.

#### Follow-up Survey

A second survey was undertaken with the aim of checking the effectiveness of remedial measures. As housing with shallow foundations was planned for the site, the pit depth was restricted in the second survey to 0.3m.

One sample only was taken from the base of each of the 13 pits. Analysis was restricted to species which were found to be of concern in the first survey.

It was concluded that the remedial action had been successful. Limitations were noted, however, with regard to the limited depths of sampling and to the lack of information from areas covered by concrete. In addition, the Regional Water Authority advised against piling in order to minimize the possibility of groundwater pollution.

#### Surface Sealing of a Landfill Site

Remedial actions proposed to abate and prevent pollution from the Windham, Conn. landfill included:

- Regrading of the landfill to maximize surface water runoff and minimize infiltration
- The placement of a 20-mil PVC top seal
- Covering the top seal with approximately 18 in. of final cover
- Revegetation

The remedial actions were designed to be passive to insure minimum future maintenance.

A monitoring system was installed; it consisted of suction lysimeters and pan lysimeters to determine the movement of moisture through the refuse, a groundwater monitoring system consisting of wells to determine fluctuations in the water table as well as the rate and movement of leachate in the groundwater, and surface water monitoring system consisting of staff gages in nearby ponds. Monitoring of the landfill has continued for several years establishing complete baseline data, and will continue for two years following the installation of the remedial action alternatives to determine their effectiveness.

This monitoring system is mainly to evaluate the effectiveness of remedial action immediately after action has been finished. Although that is, of course, important, there are some questions that must be asked concerning the long-term effectiveness: (1) When will it be necessary to replace the PVC membrane totally because of deterioration and subsequently loss of impermeability against water? (2) How can damage of the membrane by digging or ploughing, by plant roots, or mice or rats be detected? (3) How can damage to the membrane due to settlement of the landfill body be determined?

The aim is to insure that future maintenance is a minimum between periods of replacement of the sealing membrane. The remedial action yields no "eternal" solution because erosion of the sand and clay cover, subsequent damage to the membrane by ultraviolet light or pinholes is to be expected. If this happens, pollution will occur again, as hazardous materials in the landfill body will be still available for further leaching.

### CONCLUSIONS AND RECOMMENDATIONS

The effectiveness of widespread remedial actions can only be proved in the field by a decrease in contamination, e.g., decreasing groundwater pollution.

"Absolute" effectiveness is in practice not achievable.

Inorganic contaminations will not change without specific measures, e.g., chemical reactions due to injection of agents or due to leaching processes. Thus encapsulation measures have to be repeated *ad infinitum*. Organic contaminants change very slowly



without acceleration of microbiological processes. Like organic contamination, organic material used for encapsulation, is not durable forever. The same is true for inorganic materials, e.g., steel, concrete, bentonite, etc.

Thus the aim of assessment of long-term effectiveness is to find the point in time, at which a remedial action must be repeated. Constructional sealing measures can be expected to be effective for a maximum period of 50-100 years, which is accepted as a reasonable depreciation period in civil engineering.

Whether particular chemical or microbiological strains at a contaminated site causes a shorter useful life time, must be checked by monitoring.

Whether particular chemical or microbiological strains at a contaminated site causes a shorter useful life span, must be checked by monitoring.

If the contaminants, which contained by capping or barrier-system are not changed within this "calculated" lifetime, so that the hazardous contamination, present at the beginning of remedial action, has decreased to an acceptable threshold, a new remedial action scheme has to be designed. However, the degree of contamination present at this time may require less stringent remedial methods.

The objective of monitoring these facilities is to check the accuracy of the assumption of long-term effectiveness, so that the remedial measures can be renewed before if needed at the appropriate time.

The obligation for continuous monitoring of remedial measures such as capping or installation of barrier systems forces the development of proper legal management, so that monitoring will indeed be performed.

How can one ensure that someone is responsible for contaminated sites where remedial measures have been taken but where the actual contamination has neither been changed nor disposed of?

How can one ensure that contaminated sites never will be forgotten but will be attended to forever, the remedial measures being continually checked, repaired and renewed?

Remedial measures, which could be rendered ineffective by some defect or other, should not be used unless the site can be permanently monitored to see the containment system is still intact.

If remedial measures which require monitoring are chosen, they should be such that they require checking only every six months, or even better, every 1-2 years. In this way, is there a chance that they will actually be monitored.

Monitoring has to be performed: (1) on site by visual control and using a checklist, and (2) by analyzing samples of soil, sealing material and/or groundwater.

When locating monitoring points and deciding how frequently monitoring is necessary, the mobility of contaminants in groundwater and soil must be considered. Future users of contaminated sites and the responsible authorities have to be informed about the contamination and the remedial measures taken. Appropriate entries should be made in deeds to the land (in the Federal Republic of Germany the "Grundbuch").

If there is a change of usage of restored areas, i.e., a change from industrial usage to installation of a children's playground, the prior in-ground construction has to be checked. The obligation to check long-term effectiveness of a remedial measure (i.e., necessity of maintenance, repair and replacement or improvement of measuring devices) also has to be transferred to the future user of the site.

The new user of the site has to take over the maintenance, repair and replacement of a remedial measure.

## RECOMMENDATIONS

In writing a report for project "G", the author's first attempts at compiling examples systematically, shows the subproject report would contain, to a large extent, case-studies of remedial measures of subprojects A, B, C and D, in which measurement of long-term effectiveness would be particularly stressed, without sharp definitions of long-term effectiveness. This would have caused insufficient categorization of monitoring studies. The report for subproject "G" would have become partly a repetition of subproject reports A, B, C and D, as well as a supplement to project report K "Register of important sites" or to project report M "Register of key sites".

However, it seems to be important, to delineate questions for "long-term effectiveness, in general or in an individual case so clearly, that they can be answered by technical solutions. Answers must be given in relationship to remedial measures.

What questions must be put to get answers to the question, "What is the long-term effectiveness of remedial measures for contaminated sites"?

### Questions on real effectiveness after finishing remedial action:

- Which parameters have to be measured in laboratory or in the field to describe effectiveness?
- What values (range of values) describe insufficient/sufficient/good/excellent long-term effectiveness?
- What changes of measured parameters for defining effectiveness are possible/conceivable?
- What influence on the restored site, but also on single parts of construction, are necessary to cause changes in the measured parameters: (1) physical/remedial, (2) chemical, (3) biological, and, (4) microbiological?
- Are changes in the measured parameters to be expected? Suddenly or continuously? If so, at what time and in what functional relationship of time?
- How can effectiveness of remedial actions be measured in field?
- What relevance do the results of measurement in the field have?
- How can changes in the effectiveness be simulated?
- What relevance have results of simulations?
- What costs result, at what point of time, for measurements/simulation?
- What reserves are necessary for maintenance, repair and replacement of remedial actions?

Answers to these questions can be collected in a subregister "Long-term effectiveness of remedial actions" which has to be connected directly with the register of important sites.

In a separate register "Long-term effectiveness measures" information, e.g., on durability of plastics, injection agents, monitored remobilization of heavy metals, etc., could be collected, which might be results of a case study or of an R & D project.

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# LEACHATE TREATMENT AND MATHEMATICAL MODELLING OF POLLUTANT MIGRATION FROM LANDFILLS AND CONTAMINATED SITES

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## INTRODUCTION

Pollution of both ground and surface water by toxic contaminants migrating from dangerous hazardous waste storage and disposal sites, and particularly from areas of land contaminated by various industrial activities, is a widespread problem. In this paper, the authors review and attempt to assess the current remedial technologies used in NATO/CCMS countries, with special emphasis on control and treatment of leachate and of contaminated groundwater.

This overview includes the engineering design of various cut-off barriers, grout curtains, clay fill trenches, etc. required to contain contamination, but does not include an analysis of the physical and chemical effectiveness of such barriers as it is covered in another project. The focus of this paper is also on mathematical modelling, a proven tool in site-specific situations but perhaps a more controversial one from the viewpoint of general applicability.

## INFORMATION GAINED BY NATO/CCMS COUNTRIES

The importance of operations designed to control and treat the liquid phase on contaminated sites is more easily understood if one remembers that approximately 90% (by weight) of the hazardous industrial wastes produced in North America are produced as liquids; of these, 60% are organic and 40% are inorganic. The remaining 10% are sludges, slurries and solids. In other words the methods used to prevent contamination of both ground and surface water by toxic contaminants migrating from sites polluted by hazardous waste are costly and complex not only because the wastes are hazardous but also because they are mostly liquids, usually delivered to these contaminated sites in tank trucks or in drums.

In this paper, "contaminated sites" mean either special hazardous waste disposal sites or landfills where hazardous waste is co-disposed together with non-hazardous waste, and in one instance an area of land polluted by a spill resulting from industrial activities.

Based on the information and space available, this paper discusses, in chronological order:

- Prevention techniques designed either to limit the quantity or the danger of the leachate produced such as, new classification, segregation, stabilization, co-disposal
- Containment techniques such as barriers
- Passive and active treatment techniques

## Prevention Techniques

The form of wastes disposed on land will affect the quantity of leachate produced. Since hazardous wastes in their untreated form are predominantly liquid, the leachate they generate consists of disposed liquids in addition to any component dissolved from other wastes or the various types of soils found or brought to the site.

Conversely wastes in the solid form are obviously less likely to generate as much leachate as that from liquid waste disposal. Thus, stabilization of liquid chemical wastes prior to disposal has been

considered as an option designed to reduce the volume of leachate generated. Various studies indicate that chemical stabilization or inorganic sludges prior to disposal is a promising method to reduce leachate generation. Recent studies indicate that stabilization of liquid organic wastes does not work as well as the treatment of inorganic sludges, however, research is underway to develop processes to also stabilize organic hazardous waste. Another approach which seems promising is encapsulation of solid hazardous waste in polymeric material so as to prevent the release of toxic constituents to leachate.

Another management practice that influences the character of leachate is segregation, that is the establishment of separate cells within large landfill settings, or separate disposal sites, specifically to receive particular wastes. Highly reactive wastes that threaten the health and safety of landfill workers should obviously not be mixed and disposed together. Similar consideration should also be given to the disposal of hazardous wastes that generate leachate of an especially unfavorable or dangerous character.

The disposal areas for different types of hazardous wastes should therefore be segregated, where possible, to minimize interactions between wastes, thereby simplifying predictions about the anticipated characteristics of the leachate and how it might behave in the hydrogeological environment if off-site migration does occur. However, the co-disposal of compatible hazardous wastes that interact to produce a leachate with favorable characteristics should occur where feasible. Unfortunately, there is a lack of information in the literature concerning the co-disposal of compatible wastes.

The above discussion emphasizes the necessity of a joint worldwide effort to promote and establish some sort of new hazardous waste classification system in order to assess the types of wastes which have been or could be co-disposed with municipal wastes, and to assess the compatibility of the various types of hazardous wastes for co-disposal. Some types of hazardous wastes may be considered incompatible for co-disposal with municipal wastes or other hazardous wastes due to chemical reactions which could result in ignition, explosions or the release of harmful gases during landfilling operations. The identification and differentiation of the various types of hazardous wastes and an understanding of their properties are required in order to control the behavior of the wastes in disposal sites and assess their compatibility.

A classification system for hazardous wastes applicable to co-disposal should ideally enable operators of co-disposal hazardous landfill sites to provide a go/no go decision for the disposal of a particular hazardous waste with municipal wastes or other hazardous wastes. The waste producer, however, will likely identify the wastes delivered to a disposal site according to their chemical composition or disposal properties. A hazardous waste classification system should relate the various waste producing industries and types of processes producing the wastes to the general chemical composition of the hazardous wastes. Knowledge of the chemical composition of the wastes is required to enable an assessment of the compatibility of different types of wastes for co-disposal to be made.

A number of classification systems for categorizing wastes by their origins or by their properties have been reviewed and investigated for suitability as guides for determining whether specific industrial wastes may be safely co-disposed and landfilled. These classifications have not, generally been prepared specifically for co-disposal purposes, and not surprisingly each shows some inadequacy for this use. Any system providing data so that landfill operators can determine the acceptability of a given waste class will tend to be either cumbersome (due to the large variety of chemical wastes and disposal parameters), or oversimplified. An international effort in the classification field may be therefore needed as mentioned before.

## Containment Techniques

### Restricting Infiltration

Because infiltration of precipitation and surface runoff provides much of the moisture responsible for the generation of leachate within a landfill, it is important to minimize the amount of infiltration into the landfill during and following the deposition of the wastes. This can be achieved using a variety of cover materials and engineered designs.

Various cover materials have been used for capping. The most commonly used covers have consisted of natural geologic materials such as clays and silts; however, synthetic liners or membranes may be used to complement, or in place of, soil covers. In normal landfill practice, a compacted soil layer is placed over each day's waste to minimize the influence of wind and infiltration, in addition to the final thick cover of compacted soil applied prior to close-out. The choice of cover material and design can also be influenced by other functions to be served by the cover: minimizing the effects of surface water erosion, resisting long-term deterioration under particular climatic conditions, providing a base for vegetative growth, controlling animal and insect burrowing and minimizing settlement by maximizing compaction.

Several documented cases of failure of covers of geologic material on landfills occurred in 1981 in the State of New York. These failures were primarily a result of poor compaction of waste materials and the introduction of excessive quantities of liquid hazardous wastes (or infiltration water) during the active life of the landfills. Following the close-out and the emplacement of final soil covers, differential settlement occurred, cracks and fractures developed and excessive infiltration resulted. Leachate generation at these sites has been so excessive that leachate had to be pumped from the landfill and treated following collection.

In the literature, there is little quantitative information on the performance of covers on landfills, neither with respect to the long-term infiltration rates through the covers, nor with respect to the long-term effects of erosion or weathering. A study of soil and vegetation covers on municipal landfills in Florida indicated that these covers were only of use in reducing surface infiltration during severe rain storms.

### Restricting Leakage from Landfills

The landfill in a shallow hydrogeologic setting cannot be totally "secure" in areas of humid climates because, regardless of engineering design or practice, some contaminants will be released to the environment, although the rate of release may be very slow and the quantities released may be very small. By adopting various engineered controls, however, the introduction of contaminants to local, off-site groundwater systems may be limited to acceptable levels.

Leakage to the surface via springs or side seeps can be eliminated if the "bathtub" effect is not allowed to develop within a landfill. The "bathtub" effect results as a consequence of the rate of infiltration into a landfill exceeding the rate of seepage out. In humid climatic regions and where a landfill is located in low permeability material, or has a liner of low hydraulic conductivity, the landfill can gradually fill with leachate if excessive infiltration occurs because of defects in the landfill cover. When the landfill fills, leachate springs or side seeps develop around the perimeter of the

landfill at the ground surface. To prevent this type of contaminant release, it is essential to maintain cover materials so that the rate of infiltration does not exceed acceptable rates of seepage through the base of the landfill to the groundwater.

To prevent unacceptable rates of seepage from the base of landfills to the shallow subsurface environment, landfill liner systems have been used with some degree of success. Liners can be constructed of geologic and/or synthetic materials, and will not be discussed in this paper as their specific properties and effectiveness are covered in another project.

Grouting is another engineering approach used to stabilize waste in place. Basically appropriate materials are injected into porous geological units to reduce hydraulic conductivity which in turn can restrict the movement of contaminants.

A variety of grouting materials have been used in engineering practice: cement, cement slag, resin, asphalt and several different colloidal and low viscosity chemicals. The choice of grout used for a specific problem would depend upon the desired lifetime and the hydraulic conductivity of the unit.

In engineering practice, grouting is often used to construct a low hydraulic conductivity wall or curtain in the subsurface. Because grouts in unconsolidated materials may not invade the formation evenly or very far, it may be necessary to grout along closely spaced lines of boreholes to achieve the required degree of control. Environment Canada believes that grouting techniques are unsuited to the problem of controlling hydraulic conductivity throughout several extensive deep geological units which include relatively impermeable zones.

Other engineering modifications can improve the level of subsurface environmental protection in the vicinity of hazardous waste landfills. These include slurry walls, vertical grout curtains, interceptor trenches and wells, drains at the surface to intercept leachate springs, and various pumping schemes to create hydraulic gradients toward the landfill and help prevent groundwater flow and contaminant migration away from the landfill site.

All these measures are very useful but probably do not provide a permanent solution. Today there is uncertainty as to the long-term effectiveness of "secure landfills." There is doubt that the "secure landfills" built in the U.S. and Europe will be totally effective for permanent containment of contaminants. For instance the landfills in Ontario that have been used almost exclusively for the disposal of chemical wastes have all caused problems due to the off-site migration of contaminants. There is evidence that the larger municipal landfills where the same materials have been placed in co-disposal with a variety of wastes have caused less of a problem.

Studies that have been done in Ontario at major landfills in which large quantities of liquid industrial waste have been dumped do not appear to have pollution hazards that are significantly greater or different from those where liquid waste has not been dumped. There is evidence that highly permeable ground, particularly ground that has a low lime content, may be undesirable for deposition of large quantities of liquid industrial waste. The limy soils in southern Ontario, apparently have the capacity to handle large quantities of industrial waste without adverse effect.

## Treatment Techniques

Regardless of preventive measures adopted to limit leachate generation, a leachate is still likely to be formed, especially in areas where precipitation exceeds evaporation and/or at sites used for disposal of liquid hazardous wastes. The treatment of that leachate will be simplified if certain types of wastes were segregated in separate cells at the site or in certain cases excluded altogether.

Leachate collector systems have recently been designed in conjunction with lined landfills. These systems allow the collection of excess leachate and its treatment prior to its ultimate disposal or recirculation back through the landfill with the objective of further attenuation. Such active control requires continuous on-site supervision and maintenance and means that such a hazardous waste landfill is not a disposal facility but a waste storage facility.

Because hazardous waste leachates vary widely in composition and often contain a diversity of constituents, the actual treatment technologies are case specific and often comprise a combination of different treatment processes. However, the review and description of these processes is beyond the scope of this paper. The USEPA lists for example 20 possible treatment processes.

Some brief examples of remedial actions taken in Canada and by some NATO/CCMS countries are listed instead.

At a polychlorinated biphenyl (PCB) spill in Regina, Saskatchewan, Canada, contaminated glacial till was excavated for treatment and disposal. A slurry wall to a depth of approximately 10 m in the glacial till around the entire spill site was emplaced in an effort to restrict contaminant migration to the surrounding hydrogeologic environment. The slurry wall was installed between temporary metal sheet piles driven into the ground which were subsequently removed following the pouring of the bentonite slurry. Although this was not a designed disposal site the remedial actions taken could be applied in the vicinity of hazardous waste disposal sites.

Another example of remedial action is that in 1981 at the Rocky Mountain Arsenal waste disposal site in Denver, Colorado. A combination of a slurry wall to impede groundwater flow and a series of interceptor wells through which contaminated groundwater was removed and treated prior to its return to the groundwater through wells down gradient of the slurry wall was used to rectify the groundwater contamination problem.

As regards treatment of groundwater polluted by contaminants migrating from soils contaminated specifically by hazardous waste little data is available, as most of it is related to ordinary solid waste disposal sites. Four cases of groundwater treatment in the F.R.G., are summarized as follows:

- A paper given in 1981 in the Netherlands says that oxidation processes in an aquifer caused by injection of oxygen containing water can improve the groundwater quality and protect the groundwater against pollutions. The so-called subterranean groundwater treatment has been applied in several European countries for some years. Stream and transport mechanisms and chemical and biological reactions as well were described. The recharge system, in a most practical manner, uses the pumping well for injection of oxygenated water into the soil.
- Another investigates the treatment of groundwater contaminated by methyl chloride by the activated carbon method.
- A third describes the treatment of groundwater polluted by a spill of mineral oil and by leachate from a chemical waste disposal site. Water from four deep wells is pumped to a reaction tank, mixed with ozone and then allowed to infiltrate back into the ground. Two problems with this approach are: (1) infiltration changes the elevation of the groundwater table and hinders the flow from the source of contamination to the water catching area, and (2) oxygen in the water increases biological activity. On the positive side ozonization decreased the chemical oxygen demand (COD).
- Finally an article "Seeping and distribution of mineral oils and chemicals in the ground", published in May 1982, describes the "purification procedures of saturated aquifers" and gives more detailed information on the distribution of oil in the groundwater.

## MATHEMATICAL MODELLING OF POLLUTANT TRANSPORT BY GROUNDWATER

### The Nature of Mathematic Models

Fried<sup>4</sup> has noted that the modelling of groundwater pollution consists of describing, by mathematical expressions, the following processes:

- The advection of the contaminant, i.e., its transport by groundwater flowing at the mean velocity
- The dispersion of the contaminant, i.e., its spreading due to velocity variations of the groundwater within pore spaces about this mean value
- The chemical interaction of the contaminant with the solid matrix of the aquifer system, e.g., adsorption

- The decay of the contaminant due to biodegradation or radioactive disintegration

These last terms describe the attenuation of the contaminant. Mercer and Faust<sup>6</sup> have pointed out that hydrogeologists have available to them two types of mathematical models with which to analyze groundwater flow and contaminant transport:

- Analytical models, in which a simplified form or transport equation is solved by an exact solution for the initial and boundary values stipulated
- Numerical models, in which the partial differential equation describing the behavior of a continuous variable are approximated numerically by finite-difference or finite-element methods resulting in a finite number of algebraic equations which may be solved by matrix techniques

Since 1960, much interest has been shown in the development of numerical models of groundwater flow (i.e., the advective flux) and contaminant transport (i.e., the advective and dispersive fluxes with various attenuation terms).

In the following section, the authors give a brief review of the utility of mathematical modelling for studying both flow and transport problems at waste-disposal sites. The usefulness of the procedures depends entirely on acquiring adequate, reliable data for use in the modelling operation. No more eloquent a caution can be given than the concluding remarks of Wang and Anderson<sup>10</sup> in their book *Introduction to Groundwater Modelling*:

"The answers generated using a mathematical model are dependent on the quality and quantity of the field data available to define the input parameters and boundary conditions. Modelling can never be a substitute for field work. Used in conjunction with good field data, a model can provide insight into the dynamics of the flow system and also serve as an invaluable predictive tool."

### Groundwater Flow Models

Following the acquisition of a complete set of data defining the hydrogeologic condition and properties of the groundwater flow system within which the waste-disposal site is situated (e.g., hydraulic heads and conductivities, geometries of the permeable and impermeable units comprising the flow system), it is possible to begin to model the pattern of groundwater flow by numerically solving the groundwater for equation (Mercer and Faust<sup>6</sup>):

$$\frac{d}{dx} \left( K_{xx} \frac{dh}{dx} \right) + \frac{d}{dy} \left( K_{yy} \frac{dh}{dy} \right) + \frac{d}{dz} \left( K_{zz} \frac{dh}{dz} \right) + R = S_s \frac{dh}{dt} \quad (1)$$

Where  $x$ ,  $y$  and  $z$  are the spatial coordinates,  $K_{xx}$ ,  $K_{yy}$ ,  $K_{zz}$  are the hydraulic conductivities (L/t) in the  $x$ ,  $y$ , and  $z$  directions,  $h$  is the hydraulic head (L),  $R$  is a source or sink term (l/t) and  $S_s$  is the specific storage (l/L).

A best fit of simulated, with observed hydraulic heads, is obtained by trial and error adjustment of the geometries and hydraulic conductivities. The first attempts at modelling will likely result in a desire to collect further field data so that better fits of simulated with observed values can be obtained. Consequently, there will be cycles of field and modelling studies resulting in the prediction of the hydraulic head pattern within the flow system from which groundwater and contaminant flow patterns may be deduced. Furthermore by employing Darcy's Law, which relate the specific discharge of groundwater ( $q$ ) to the hydraulic-head gradient ( $dh/dl$ ) and hydraulic conductivity ( $K$ ), a map of the groundwater velocities ( $V$ ) may be drawn in which:

$$v = q/n = \frac{K dh/dl}{n} \quad (2)$$

where  $n$  is the porosity. The velocities are essential to the next step of groundwater modelling.

## Contaminant Transport Models

During the 1960s, it was customary to study contaminant transport in groundwater for systems either by the use of analytical solutions<sup>7</sup> or by groundwater flow models in the method described above<sup>3</sup>. In the last 12 years, however, great progress has been made in developing numerical solutions to the advective-dispersion equation describing contaminant transport (Wang and Anderson<sup>10</sup>):

$$D_L \frac{d^2C}{dx^2} + D_T \frac{d^2C}{dy^2} - v_x \frac{dC}{dx} = \frac{dC}{dt} \quad (3)$$

where  $C$  is the concentration of contaminant in question and  $D_L$  and  $D_T$  are the longitudinal and transverse dispersion coefficients of that contaminant, which can be written:

$$D_L = a_L v_x \quad (4)$$

$$\text{and } D_T = a_T v_x \quad (5)$$

Therefore, the dispersion coefficients are a measure of the rate at which the concentration gradients are dissipated.  $a_L$  and  $a_T$  are the longitudinal and transverse dispersivities (Units: L) and can be considered to be measures of the dispersive capacity of the hydrogeological system being modelled.

All early numerical modelling of contaminant transport treated the dispersivity as a constant which could be used as a fitting parameter in the same way as the hydraulic conductivity is used in groundwater flow models. Consequently, a wide range of dispersivity values were reported, from centimetres in sand aquifers to tens of metres in fractured basalt rocks. Pickens and Grisak<sup>9</sup> have shown that this is partly due to the heterogeneous nature of hydrogeologic systems and the dilution of groundwater samples when large-diameter wells rather than small-diameter sampling systems are used. Since dispersion causes dilution of the contaminant, any dilution of the contaminant clearing sampling implies a greater dispersivity.

In recent years, groundwater modelers in the USA, Canada and France have begun to treat the dispersivity value as a function of the mean travel distance or travel time of the contaminant. Stochastic modelling techniques used by Gelhar in New Mexico and de Marsily in France suggest that the dispersivity is dependent on the time of travel of the contaminant from the waste-disposal site and should reach an asymptotic value at large travel times when or distances where hydrogeological boundaries are encountered or a significant transverse velocity develops.<sup>2</sup>

Many contaminant transport problems require a chemical reaction term to describe the adsorption of heavy metals, radionuclides, organic compounds or other contaminants during their transport through the groundwater flow system. This can be done by adding the term  $-p_b K_D (dC/dt)$  to the left-hand side of Eq. 3 in which  $p_b$  is the bulk density of the aquifer material and  $K_D$  is the distribution-coefficient describing the partitioning of the contaminant between adsorbed and solution phases (Units: L/mass).

The distribution coefficient is usually measured by laboratory batch procedures in which care is taken to reproduce the groundwater environment. The application of the  $K_D$  approach assumes that the adsorption process is instantaneous and reversible and that it is described by a linear adsorption isotherm. When the contaminant is present only in trace quantities, the quantity observed frequently does vary linearly with its concentration in solution, however, the adsorption reaction is not always fast or reversible and therefore may not reach equilibrium. Much research work in NATO/CCMS countries is currently diverted at finding improved ways of measuring adsorption and other chemical reaction terms in groundwater models, including the development of *in-situ*  $K_D$  measurements which produce operationally useful parameters but of little or no thermodynamic significance.

Consequently because of difficulties in measuring and interpreting values of dispersivity and the distribution coefficient, contaminant transport modelling is still at an evolutionary state of trying to obtain an improved understanding and approximation of basic phenomena.

## Application to Remedial Measures

The nature of groundwater flow and contaminant transport models have been outlined and the opportunities for their use in decontaminating aquifers and/or controlling contamination in aquifer systems have been discussed. In fact their ability to predict system responses to remedial actions make them essential to any program of site restoration. Cole and McKown of Battelle<sup>1</sup> have summarized their uses in such situations as:

- (1) To aid in the design of the site investigation program
- (2) To help assess whether remedial measures are required and which ones would be the most effective
- (3) To assist in the design of a site monitoring program

To date, the authors are aware of the use of mathematical modelling techniques for remedial-measures work by several groups in NATO/CCMS countries, e.g. Battelle (PNL, Richland, Washington, USA), GEOTRANS (Washington, D.C., USA) and GTC (Ottawa, Canada).

In the future, hydrogeologists will have available to them not only powerful groundwater flow and contaminant transport models, but also combined transport and optimization codes for the assessment of waste disposal operations and decontamination-well location. However, all models will require a prodigious amount of reliable hydrogeologic (field) information without which the modelling will be ineffectual.

## SUMMARY

In summary groundwater models provide an indispensable aid in:

- Evaluating the hydrogeologic conditions at waste disposal sites and determining the additional field activities (e.g., drilling, piezometer installation) to be conducted
- Predicting the migration of groundwater contamination (from a calibrated model)
- Assessing the likely effects and costs of various remedial measures (e.g., purge wells, grout curtains, etc.) on contaminant migration and concentration

The model results, however, depend on the quality and quantity of the hydrogeologic data used. Nevertheless, allowing for the uncertainties in the data, groundwater modelling permits rational development of a program of remedial-measures at landfills and contaminated sites.

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# DEVELOPMENT OF AN INSTALLATION FOR ON-SITE TREATMENT OF SOIL CONTAMINATED WITH ORGANIC BROMINE COMPOUNDS

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## INTRODUCTION

Soil contamination is one of the most pressing of the environmental problems existing in the Netherlands. Over the last few years particularly, much attention has been given to this subject. At the present time, a large number of hazardous waste sites that need to be cleaned up have been discovered.

Current methods for treating highly contaminated soil mainly involve excavation of the soil followed by thermal treatment elsewhere. This method is rather expensive and furthermore cannot be applied in all cases. Thus there is a need for less costly methods of cleaning up contaminated soil.

A large number of process alternatives for cleaning up contaminated soils can be given. Some examples of these alternatives are extraction, chemical conversion and biological degradation of the contaminations in the soil. With the exception of thermal treatment, however, no other method of treatment has been developed for practical use so far. Much research and development work still have yet to be carried out with the attendant practical problem that each type of soil contamination is different. This also means that the method of treatment has to be adapted in each particular case.

The investigation described in this paper deals with the development of an on-site treatment method for a soil strongly contaminated with organic bromine compounds. The contaminated site is located in the neighborhood of the Dutch municipality of Wierden. The main problem is the potential danger of the contamination of groundwater used for the production of drinking water. To clean up this site, the Ministry of Public Health and Environmental Protection ordered the Dutch research institute TNO\* to investigate the possibilities of an on-site treatment method based on extraction. This investigation, carried out in cooperation with HBG\*\*, a Dutch company specializing in transport and handling of soil, was finished recently.

\*TNO: "Netherlands Organization for Applied Scientific Research".

\*\*HBG: "Hollandsche Beton Groep N.V."; P.O. Box 81, 2280 AB Rijswijk, The Netherlands.

## CHARACTERISTICS OF THE CONTAMINATED SITE

A schematic presentation of the contaminated site concerned is shown in Fig. 1. This figure shows a schematical cross section of the site at which a factory for the production of organic bromine compounds was formerly located.

The penetration depth of the bromine contaminations generally varies between 4 and 7 m; the groundwater level is approximately 7 m deep. The total surface area of the contaminated site amounts to about 300 m<sup>2</sup> while the total amount of contaminated soil at the site is estimated to be some 30,000 tons.

Several types of contaminated soil are distinguishable. The bulk of the soil is yellowish brown sand with a particle size distribution from about 40 to 300  $\mu$ m. The top and sub-top layers contain a relatively large amount of organic humus-like substances. Besides sand and humus-like substances the contaminated site contains

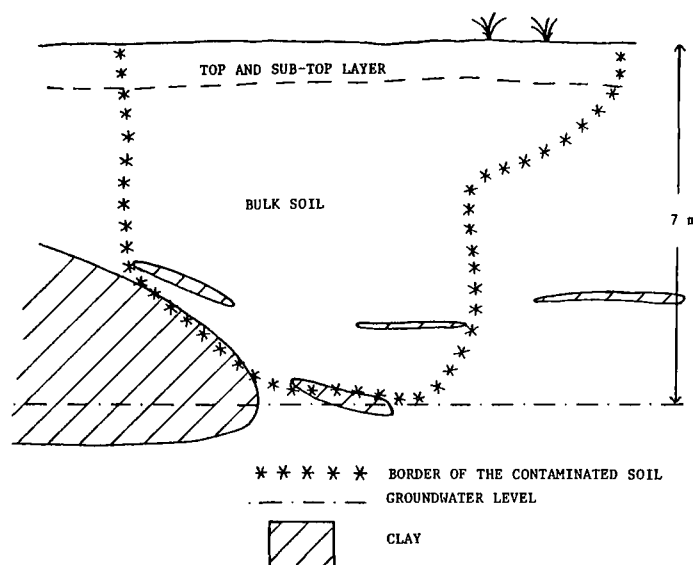


Figure 1.  
Cross Section of the Contaminated Site

several clay tongues. Based on analysis of a large number of samples taken from the site, it is estimated that the quantity of humus-like substances and the quantity of mineral particles smaller than 40  $\mu$ m both amount to about 1% of the whole.

The contaminants in the soil almost entirely consist of organic bromine compounds (Table 1). Some of these compounds is rather volatile; most of them have a low solubility in water. However, the concentration of the bromine compounds varies markedly within the contaminated site. The highest (total) bromine content measured was about 3000 mg/kg of soil in some locations in the top and sub-top layer. In the investigation described in this paper the total bromine concentration in water and soil was always measured by means of neutron activation analysis. The detection limit of this method is about 0.6 mg/kg. The soil was considered to be clean if no total bromine could be detected by this method of analysis.

Table 1.  
Average composition of the contamination in three highly polluted samples of soil

Compounds	Concentration (mg/kg)
Dibromo ethylene	90
Tetrabromo ethanes	690
Tribromo ethylene	170
Dibromo butanes	80
Dibromo alkanes (C <sub>5</sub> - C <sub>10</sub> )	1040
Other bromine compounds	1500



## LABORATORY SCALE INVESTIGATIONS

Each soil extraction process basically comprises a step in which soil and an extracting agent are intensively mixed, a step for separation of the treated soil and extracting agent, a washing step for removing rests of extracting agent from the treated soil and a step for the purification of the polluted extracting agent.

Due to the relatively unknown nature of the bromine contaminations, the different adsorption properties of the various bromine compounds on the soil and the presence of different types of soil particles, experimental research is needed in order to select the most suitable extracting agent. This too is valid for the process steps to be applied in the process for the purification of the polluted extractant.

### Extraction of the Soil

A laboratory test procedure was set up to test the extraction behavior of potentially suitable extracting agents. In this test procedure, 0.5 kg of contaminated soil was added to 0.75 kg of extracting agent in a flask. Soil and extracting agent were intensively mixed by rotating the bottle for a period of about one hour. Subsequently, the mixture of soil and extracting agent was poured into a processing column which was provided with a porous bottom. The mixture of soil and extracting agent in the column was washed in upflow conditions with, successively, non-polluted extracting agent and water. The superficial liquid velocity in the column was about 3 m/h. In this way only a very small fraction of soil particles was dragged out with the liquid flow. The soil was analyzed for total bromine content before and after extracting and washing.

Some of the most important results of the extraction experiments with soil, originating from the bulk are shown in Table 2. In this table the effect of the type of extracting agent and the composition of this agent on the cleaning efficiency are shown. One can see that the soil can be cleaned, reducing the total bromine content of less than the detectable limit (0.6 mg/kg) by extraction with hot water or an aqueous solution of sodium carbonate or soft soap. In the use of these two extraction agents it appears to be important that the pH value of the extracting agent remains above 7.

The good extraction properties of these extractants can be explained by the fact that an aqueous solution of sodium carbonate or soft soap has a dispersant effect. This probably results in a colloidal dissolution of a part of the organic bromine compounds. Furthermore, it can be expected that humus-like substances will dissolve, especially at higher pH values. The result is that organic bromine compounds, preferably adsorbed to these humus-like substances, go into a colloidal solution. Moreover it can be expected, especially at high pH values, that a part of the organic bromine components hydrolyze into inorganic bromide, which dissolves very well in aqueous media.

Extraction of soil from the top and sub-top layers was carried out with aqueous solutions of sodium carbonate or sodium hydroxide.

Table 2.  
Effect of type of extraction agent on the cleaning efficiency of bulk soil

Extraction agent	pH after extraction	Total bromine content in soil after extraction and washing (mg/kg)
Water	4.1	1.5
Hot water (70°C)	4.4	< 0.6
Aqueous solution of 0.1 % soft soap	4.4	3.6
Aqueous solution of 1 % soft soap	7.0	< 0.6
Aqueous solution of 0.1 % Na <sub>2</sub> CO <sub>3</sub>	7.4	< 0.6

Total bromine content in untreated soil: about 120 mg/kg

ide. The impression given by the results of the extraction process of soil from the bulk is generally confirmed by the experiments carried out with soil from the top and sub-top layers. However, these layers generally contain a much higher total bromine concentration and a much higher total organic matter (humus-like) content, the latter resulting in a higher buffer capacity. As can be expected, extraction of these types of soil with aqueous sodium hydroxide and sodium carbonate solution is therefore more difficult. Consequently, a higher pH value of the extracting agent is required. This is clearly illustrated in Table 3.

Table 3.  
Effect of concentration of aqueous Na<sub>2</sub>CO<sub>3</sub> or NaOH solution on the cleaning efficiency of top and sub-top layer

Extraction agent	pH after extraction	Total bromine content in soil after extraction and washing (mg/kg)
Aqueous solution of 0.1 % Na <sub>2</sub> CO <sub>3</sub>	7	24
Aqueous solution of 2 % Na <sub>2</sub> CO <sub>3</sub>	10.8	14
Aqueous solution of 1 % NaOH	12.8	6.3
Aqueous solution of 3 % NaOH	13.4	8.2

Total bromine content in untreated soil: about 1000 mg/kg

A mixed sample of the first two types of treated soil, mentioned in Table 3, was extracted a second time. For this extraction step, an aqueous solution of 2 % sodium carbonate was used. The result was a reduction of the total bromine content to about 4 mg/kg.

In addition to the use of water and aqueous solutions of sodium hydroxide, sodium carbonate or soft soap, which may generally be considered as acceptable agents from environmental hygienic point of view, other types of extracting agents were tested, among which were 1-1-1 trichloroethane and an aqueous solution of sodium hypochlorite. However no positive results were obtained with these extracting agents.

Among the agents which were found to be suitable for carrying out the extraction process, an aqueous solution of sodium hydroxide is considered to be the most promising. This conclusion is based on the fact that to increase the pH value, especially for strongly buffered systems, sodium hydroxide is more effective than sodium carbonate. In the matter of the use of hot water as an extracting agent, the impression gained from the experiments was that in treating soil of top layer and sub-top layer, this agent is not as suitable as an aqueous sodium hydroxide solution.

### Purification of the Polluted Extracting Agent

After the extraction process, the polluted extracting agent (sodium hydroxide solution) assumed the appearance of a dark brown liquid. In addition to the colloidal and dissolved bromine components, it contained also other organic compounds, such as humus-like substances and mineral particles with a diameter less than about 40 µm.

From laboratory scale centrifuge experiments, it was evident that no separation was obtained between the bromine compounds and the clay fraction, not even at relatively low g-values. The reason for this is probably due to the fact that in addition to mineral particles, colloidal bromine containing particles also settle in the centrifuge. Only normal gravity settling and washing of the settled particles with water created the possibility of separating a part of the mineral fraction free from bromine compounds.

The extracting agent, from which the mineral particles having diameters between 40 and about 20 µm were removed by settling, could be purified to a total bromine content of less than the detection level. The treatment process to achieve this comprised the steps of coagulation and flocculation at neutral or slightly acid pH value, sedimentation, adsorption of organic bromine components to ac-

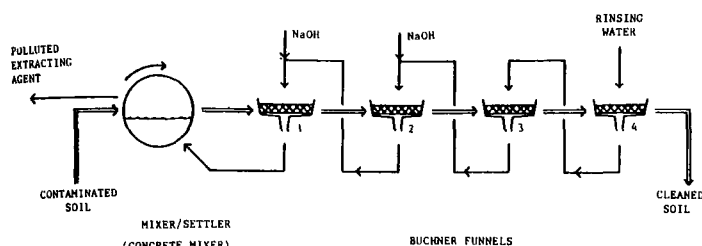


Figure 2.  
Setup of Experiments Using Mixer/Settler and Buchner Funnels

tivated carbon and removal of inorganic bromides by means of an ion exchanger. However, an excess of activated carbon and ion exchanger was used in these experiments.

### SEMI-TECHNICAL AND PILOT-PLANT SCALE INVESTIGATIONS

On the basis of the results obtained from the experiments carried out on a laboratory scale, a further study of the extraction process was made on a semi-technical scale (30 to 100 kg of soil/h) and a pilot-plant scale (500 to 1000 kg of soil/h).

In order to limit the amount of the extracting agent as far as possible, it is necessary to apply a countercurrent flow of extracting agent and soil. In carrying out the experiments two extraction methods with countercurrent flow were chosen. The first of these comprised a mixing/settling step, followed by a washing step of the settled soil in a stationary layer on a vacuum filter. The washing step applied here is comparable within a vacuum filtration and washing process on a sieve belt filter. In the second method a modified screw conveyor or a modified sand screw classifier were used for extracting and washing.

In addition to studying the extraction process, treatment of the polluted extractant was also studied. The latter study was carried out on a scale of 50 to 100 kg extraction agent per hour.

The experimental set up devised for the semi-technical and pilot-plant scale investigation was primarily destined to acquire the data necessary for the pre-design of a treatment plant which can be used in practice. An aqueous solution of sodium hydroxide was used as the extracting agent in all of the experiments.

#### Extraction by Means of a Mixer/Settler and Vacuum Filtration

The experiments were carried out using contaminated soil which had been pre-treated in a low speed pen mill, to reduce the large clods in size. Approximately 30 kg of the pre-treated soil and about 20 kg of extracting agent were intensively mixed for a period of 5 min in a concrete mixer. After settling of the soil the extracting agent was separated. The soil was subsequently washed in countercurrent flow at four large scale Buchner funnels in order to remove the remaining extracting liquid and part of the bromine compounds still present. The extracting and washing process is schematically shown in Fig. 2.

Water was used to wash the soil at the last Buchner funnel. An aqueous solution of sodium hydroxide was added to the filtrate of the second and third Buchner funnel to increase the pH value. The filtrate of the first Buchner funnel was used as the extracting agent in the concrete mixer.

Sample data obtained from the extraction experiments carried out with bulk soil samples are given in Table 4. The final total bromine concentration in the treated soil is below the detection limit after two washing steps in the Buchner funnels.

Soil from the top and sub-top layers could only be cleaned to a sufficient degree if the mixing/settling step in the concrete mixer was carried out twice. The extracting agent was renewed after the first of these steps. Furthermore, it was necessary to maintain the pH value above 11. The necessity to employ a more intensive extraction and washing procedure is clearly caused by the presence of

Table 4.  
Some Results of the Experiments Using Mixer/Settler Apparatus and Buchner Funnels

Process step	Extracting agent	Total bromine content in treated soil (mg/kg)
Mixer/settler	Aqueous solution of 0.46% NaOH	5.8
1st Buchner funnel	Aqueous solution of 0.33% NaOH	1.2
2nd Buchner funnel	Aqueous solution of 0.10% NaOH	< 0.6
3rd Buchner funnel	Water	< 0.6
4th Buchner funnel	Water	< 0.6

Total bromine content in untreated soil: about 40 mg/kg

relatively large amounts of organic humus-like substances in the top and sub-top layers of the soil and the higher concentration of organic bromine compounds.

The results obtained from the mixer/settler and Buchner funnel experiments generally confirm the results of the laboratory scale experiments.

#### Extraction in a Modified Screw Conveyor

Extraction and washing was carried out in a modified screw conveyor. This unit was comprised of a helicoid flight, mounted on and driven by a shaft within the confines of a trough. The length of the screw extractor was approximately 2 m and its diameter was approximately 0.15 m. Throughout the experiment the speed of the shaft was always 5 rev/min. In order to obtain countercurrent flow, the extractor was inclined at an angle of about 30° to the horizontal (Fig. 3).

The soil to be treated was fed to the lower end of the apparatus. At the upper end, an aqueous solution of sodium hydroxide was supplied as extracting agent. In the majority of the experiments, the ratio of the mass flows of soil and water was approximately unity. Washing the soil with water after the extraction step was carried out in a manner similar to that used in the extraction process itself.

It was also possible to extract and to wash simultaneously. This could be achieved by feeding pure water at the top of the screw extractor while adding a concentrated aqueous sodium hydroxide solution mid-way along the length of the screw extractor.

Here again, in the majority of the experiments with the screw extractor, the soil had been priorly treated in a pen mill in order to reduce the size of large clods. The mass flow of the soil through the screw extractor was 50 to 100 kg/h.

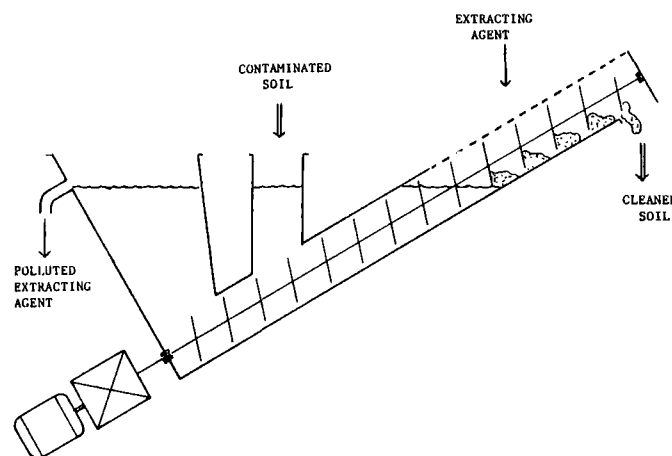


Figure 3.  
Longitudinal Section of the Modified Screw Conveyor for Extracting Experiments

Experiments with soil taken from the bulk showed that it is possible to reduce its total bromine content from approximately 50 mg/kg to less than that of the detection level in an extracting step and a separate washing step. The pH of the extracting agent in these experiments was approximately 11.

For efficient treatment of soil from top and sub-top layers it was found necessary to pre-treat the soil in a mixer/settler (in this case the concrete mixer mentioned previously). Furthermore, it was found necessary to adjust the pH of the extraction agent to a minimum value of 11. Doing so it is possible to reduce the total bromine content of the soil from approximately 50 mg/kg to less than the detectable level.

One experiment with the screw extractor was carried out with a mixture of soil originated from the top and sub-top layers, and of soil originated from the bulk, in a ratio of one to nine. The choice of this mixture stemmed from the fact, that in the performance of an actual cleanup process of contaminated soil, treatment of mixtures of several types of soil can hardly be avoided. The quoted ratio of one to nine corresponds roughly to the amount of soil from top and sub-top layers and the amount of soil from the bulk as found in the actual situation. The total bromine concentration in this mixture, that was not treated in the concrete mixer, can be reduced to a value below that of the detectable level.

#### Extraction in a Modified Screw Classifier

Evaluation of the mixer/settler-Buchner funnel experiments and those carried out with the modified screw conveyor showed that for practical purposes of application, the principle of applying the screw extractor to be the most attractive one, particularly when large treatment capacities are required. The latter requirement was the reason why the experiments on pilot-plant scale were focused on the use of the screw extraction process.

The pilot-plant experiments were carried out using a screw classifier, an apparatus commonly used for wet classification of soil and gravel. For the extraction process, this screw classifier was adapted in order to ensure an efficient countercurrent flow extraction process and intensive local mixing of soil and extracting agent. On adaption, the operating principle of this screw extractor was similar to that of the 50 to 100 kg/h scale extractor. However, the shape of trough was slightly different and paddles instead of a helicoid flight were mounted for more intensively mixing at the lower end of the extractor.

The mass flow ratio of soil to extracting agent in the experiments was approximately one. The soil flow through the extractor amounted to 500 to 1000 kg/h. In all cases, clods of soil present were reduced in size before extraction took place. Soil washing after extraction was carried out in the 50 to 100 kg/h scale extractor.

The experiments with the pilot-plant scale screw extractor were carried out with soil from the bulk. The average total bromine content in this soil amounted to about 10 mg/kg. From the results of several experiments it was observed that the total bromine content in the soil after extraction and washing was always less than the detectable limit (0.6 mg/kg). In all cases a pH value of the extractant above 11 was necessary.

#### Treatment of the Polluted Extracting Agent

On a scale of 50 to 100 kg per hour, the purification of the polluted extracting agent (originated from the modified screw classifier experiments) was investigated. Two treatment processes were studied. The first comprised the steps of neutralization of the extracting agent with hydrochloric acid followed by coagulation with iron chloride and flocculation with polyelectrolyte. After settling, the sludge so formed was separated and dewatered by centrifuging.

The overflow from the settler was then treated over a deep bed sand filter, in order to remove small particles, and was thereupon fed to an activated carbon filter for removal of the organic bromine compounds. The effluent from the activated carbon filter was subsequently treated in an anion exchanger in hydroxide or

chloride form, to remove (anionic) bromide. These process steps however did not lead to an acceptably low total bromine concentration level. The reason for this was the high chloride concentration in the effluent from the activated carbon filter. As a result, the ion exchange process was not very effective in removing bromide ions.

In order to prevent the occurrence of a high chloride concentration an alternative purification process for the polluted extracting agent was investigated. Instead of carrying out the steps of neutralization with hydrochloric acid followed by coagulation with iron chloride, a direct coagulation of the polluted extracting agent was carried out using lime. Insofar as the rest of the purification process is concerned, it was similar to that already described. In this manner a total bromine level below the detection limit was obtained in the effluent from the ion exchanger in the hydroxide form.

The total sludge production per ton of treated soil will amount to approximately 50 kg (with a dry matter content of 25%).

#### PRE-DESIGN OF A FULL SCALE INSTALLATION FOR ON-SITE TREATMENT

On the basis of experimentally obtained results, it is possible to design a full scale installation for cleaning up soil reducing its total bromine content to less than 0.6 mg/kg. The extraction step of the treatment process can be carried out effectively with use of a screw extractor. In principle other types of extraction units such as belt filters, mixer/settlers, hydro-cyclones or combinations of such apparatus may be used. However, from the experiments carried out so far, most experience had been gained from the use of the screw extractor. The design of the treatment installation and the technical and economic evaluation of this installation is therefore essentially based on the application of screw extractors.

#### Process Scheme

A flow diagram for the process to treat contaminated soil is given in Fig. 4. In the process unit, the excavated soil is first passed over a coarse sieve having a mesh width of 100 mm in order to separate large objects therefrom. Large clods of soil are reduced in size to about 20 mm or less by means of a crusher. After crushing, the soil is transported by a belt conveyor to a wet screening device. A second crusher is located at the end of the belt conveyor.

In the second process unit, the wet soil is run over a screen having a mesh width of 10 mm. Any clods of soil present there, will be further reduced in size by water sprays. Stones and other objects having a maximum dimension of larger than 10 mm are washed and removed.

Following this process, the wet soil from the screen is fed to a mixing tank to which sodium hydroxide is added to raise the pH. Then, the soil is fed from the pH adjustment tank to two identical screw extractors, the first of which is used for the extraction process proper, and the second is used to wash the soil as a post-treatment step. The second screw conveyor is fed with a purified extraction agent. If necessary, sodium hydroxide is added to obtain the desired pH. The conditions under which the screw extractors operate are such that particles larger than approximately 40  $\mu$ m in diameter will remain in the treated soil.

In the sixth process unit the soil is dewatered on a screen; the water content is reduced to 12.5% and the hydroxide is neutralized by the addition of hydrochloric acid.

On leaving the first screw extractor, the extraction agent is fed to a settling tank where the fine mineral fraction, having a sufficient settling velocity is separated from the water phase and washed with an aqueous hydroxide solution in a side stream. The overflow of the settling tank is coagulated with lime in a static mixer and subsequently flocculated by polyelectrolyte. The resulting flocs are separated in a parallel plate settler and additionally dewatered in a centrifuge. The dewatered sludge must be considered as a hazardous waste material because it contains a large fraction of the bromine compounds, humus-like substances and very fine mineral particles.

Further treatment of the overflow from the centrifuge is carried out in process unit nine. Here, the flow passes a deep bed sand filter

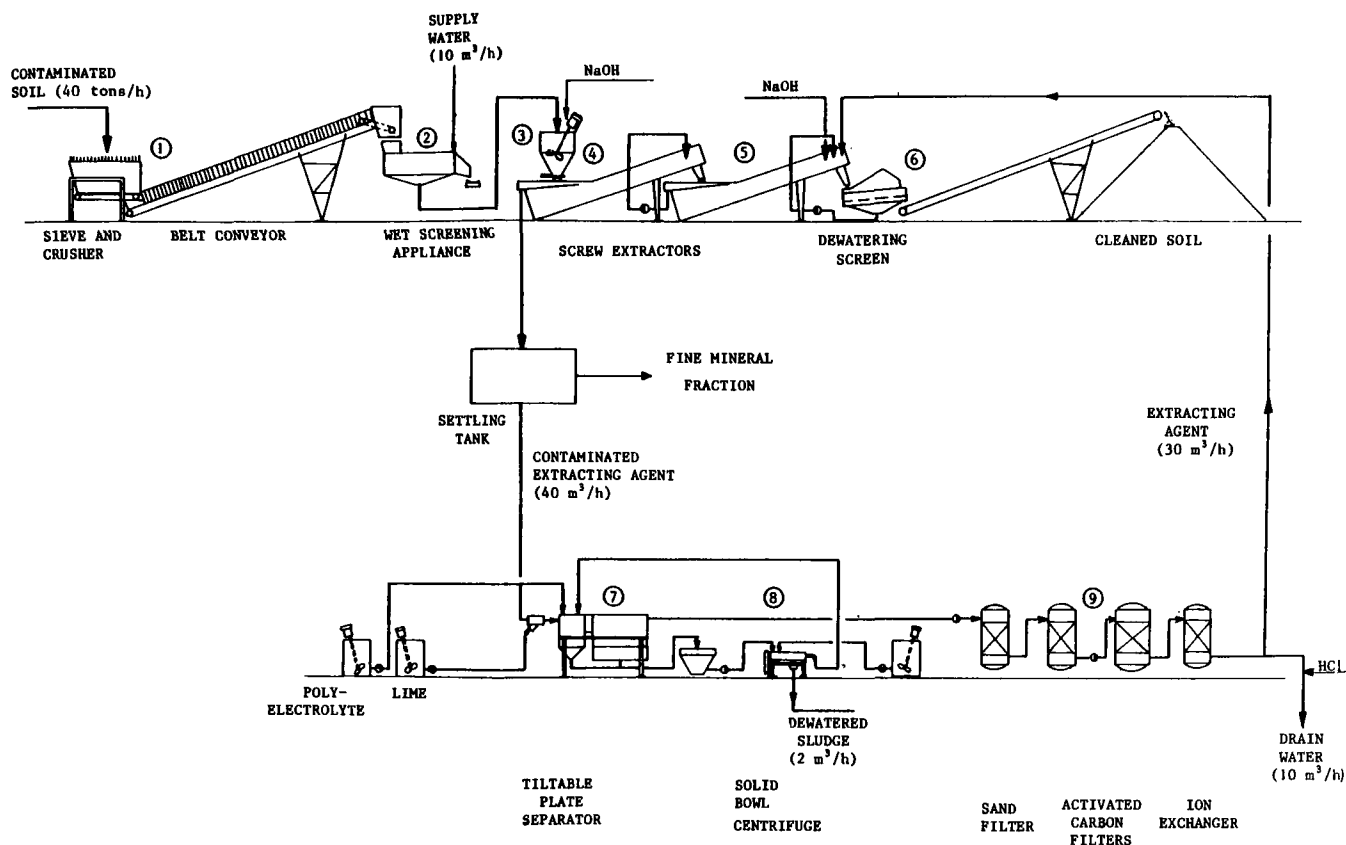


Figure 4.  
Process Scheme of the Proposed On-Site Treatment Installation

to remove particles still present. The filtrate is subsequently fed to two activated carbon filters in sequence. In these filters the organic bromine compounds are adsorbed. Finally the extraction agent is treated in an ion exchange column containing a strongly basic ion exchanger. Chlorides, sulfates and bromides are exchanged for hydroxide ions. Regeneration of the saturated ion exchanger is effected with an aqueous sodium hydroxide solution.

The purified extraction agent, in which the total bromine content is assumed to be less than 0.6 mg/kg, is partly recycled and partly discharged into the sewage system or into surface water after neutralization has been effected.

#### Process Conditions and Capacities of the Apparatus

The main starting points and the conditions under which a treatment plant based on the previously considered process scheme operates, are as follows:

- The handling capacity of the treatment installation is 40 tons of soil/h. The water content of the soil is 10%.
- A flow of 40 tons of extracting agent per hour is required for the extraction process using screw extractors.
- An aqueous solution of 0.2% sodium hydroxide is used as extraction agent.
- The average total bromine content in the soil to be treated is approximately 100 mg/kg.
- The total amount of contaminated soil to be treated contains less than 1% of total organic substances and less than 1% of fine mineral particles having diameters less than 40 $\mu$ m.
- It is assumed that the total organic fraction, half of the fine mineral fraction and a substantial part of the bromine compounds are concentrated in the sludge resulting from the coagulation/flocculation process.
- 75% of the purified extracting agent is recycled. The remainder is discharged.

- The total bromine concentration in the treated soil and purified extracting agent is less than 0.6 mg/kg.
- The amounts of chemicals needed for the process are given in Table 5.
- The final water content of the soil after passing the dewatering screen amounts to 12.5%.

The capacities of the most important of the process units and the main waste streams of the treatment process can be calculated on the basis of the foregoingly quoted starting points and process conditions (Table 6). The most important waste streams are:

- Sludge (75% water) 2000 kg/h
- Regenerate from the ion exchanger 500 kg/h
- Activated carbon 16 kg/h

#### Operating Costs

The total investment costs of an installation for on-site treatment of soil contaminated with organic bromine compounds would be approximately 2.5 million Dutch guilders.\*

\*\$1 U.S. = 2.7 Dutch guilders.

Table 5.  
Amounts of Chemicals for Treatment of the  
Polluted Extracting Agent

Chemical	Amount (per cubic meter of extracting agent)
Lime	2 kg/m <sup>3</sup>
Polyelectrolyte	0.05 kg/m <sup>3</sup>
Activated carbon	0.03 kg/m <sup>3</sup>
Aqueous NaOH-solution (10% for regeneration of ion exchanger)	0.01 m <sup>3</sup> /m <sup>3</sup>

**Table 6.**  
**Capacities of the Most Important of the Process Units**

Process unit	Capacity solids (tons/h)	liquids (tons/h)	Remarks
Coarse sieve	40		100 mm mesh width
Fine sieve	40	10	10 mm mesh width
Mixing tank	40	10	volume: 2 m <sup>3</sup>
Screw extractors	40	40	mod. screw classifier
Dewatering screen	40	15	
Parallel plate separator		55	
Solid bowl centrifuge		15	scroll type
Deep-bed sand filter		40	volume: 3.5 m <sup>3</sup>
Column for activated carbon		40	volume: 9 m <sup>3</sup>
Column for ion exchanger		40	volume: 3.5 m <sup>3</sup>

The operating costs for treating an amount of 30,000 tons of contaminated soil on-site, are specified in Table 7. More than 75% of the costs are attributable to interest and depreciation costs of the installation. The total operating costs are approximately 120 Dutch guilders per ton of treated soil, assuming the installation has no residual value after use.

The costs of excavating the contaminated soil, redepositing the treated soil on the site, disposal of the resulting waste (activated carbon, sludge, regenerate) are not included in the costs presented in Table 7. Neither are the costs relating to overhead, safety measures and profits. Although these costs are not included, it can be concluded from the operating costs of 120 Dutch guilders per ton of treated soil that on-site treatment of the contaminated soil by means of an extraction process is an attractive alternative to having to transport the total amount of soil to a site destined for the disposal of hazardous waste materials (not generally available in the Netherlands) or excavation and thermal treatment of the soil somewhere else.

## CONCLUSIONS

- From experimental investigations carried out on laboratory, semi-technical and pilot-plant scales it appears that soil, contaminated with organic bromine compounds having a mean concentration between 10 and 100 mg/kg, can be cleaned, with a final bromine concentration of less than 0.6 mg/kg.
- An aqueous solution of 0.2% of sodium hydroxide is suitable as an extraction agent.
- The extraction of the soil can be carried out efficiently by using a screw extractor in which soil and extractant are flowing counter-

**Table 7.**  
**Operational Costs of the Soil Cleanup**

	Dutch Guilders *10 <sup>3</sup>
Depreciation and interest on capital equipment	2800
Erection and disassembling	100
Labor	250
Analyses	100
Insurance, maintenance	100
Ion exchanger resin	75
Activated carbon	50
Chemicals	100
Energy	25
Total costs	3600

Costs per ton of treated soil : 120 Dutch guilders

currently and the soil/extractant mass flow ratio is one.

- Based on the experimental results, a design of a full scale installation for treating 40 tons of contaminated soil/h has been produced. The treatment process effected by this installation comprises the following main process steps:

- extraction of the contaminants in a screw extractor with aqueous sodium hydroxide, followed by washing of the treated soil
- treatment of the extracting agent for reuse by subjecting it to a process of coagulation/flocculation, activated carbon adsorption and ion exchange
- post-treatment of the soil by neutralization with hydrochloric acid

- The total investment costs of the treatment installation proposed is estimated to be 2.5 million Dutch guilders.
- The operating costs for treating contaminated soil are estimated to be about 120 Dutch guilders/ton excluding the costs of excavation and redeposition of the soil, the costs for disposal of residual waste materials (about 50 kg/ton treated soil), overheads, profits and costs for safety measures.

## ACKNOWLEDGEMENTS

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# DEGRADED AND CONTAMINATED LAND REUSE—COVERING SYSTEMS

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## INTRODUCTION

As a result of proposals made by the United Kingdom in 1980, a NATO/CCMS pilot study on contaminated land has been established. A range of study areas and subjects for information exchange have been selected which is described elsewhere by M. Smith in these proceedings. Study Area C in this project is UK lead, and will examine systems designed to prevent the migration of contaminants vertically or laterally or to prevent the ingress of surface or ground water into contaminated sites. In this paper, the authors discuss the desirable properties of covering systems and by example describe their use in the UK.

## CONTAMINATED LAND

For the purposes of this report the Pilot Study Group have accepted the following definition of contaminated land:

“Contaminated land is land where substances are found that if present in sufficient quantity or concentration, could be hazardous to construction workers, or to the eventual users or occupiers of the site, or to a wider population due to transport of the substance from the site, for example by wind-action or pollution of water.” The definition also embraces the presence of substances that may be harmful to plants and animals and may include substances that are aggressive to building materials.

The hazards to human health may be short term such as those presented to workers by the presence of aggressive chemicals such as acids or of flammable gases, or long term such as might be presented by the uptake of toxic elements such as cadmium and lead by food crops grown on contaminated soil or by the presence of carcinogens in soil.

The contamination of sites arises from their previous uses and examples of sites that are commonly found to be contaminated are former coal-gas manufacturing plants, sewage works and chemical plants. Typically also much former railway land and dockyard land, and land used for secondary metal recovery (i.e., scrap-yard<sup>s</sup>) is contaminated.

This definition encompasses hazardous waste “problem” sites or “uncontrolled” hazardous waste sites as defined by the OECD and the United States Environmental Protection Agency respectively.

Two important points should be noted about this definition:

- The emphasis on the presence of potentially harmful substance rather than on past use of the land
- That a “problem” is only defined after site investigation, and evaluation of data on a site-specific basis which takes into account land-use

## COVERING SYSTEMS

The majority of contaminated land sites are dealt with by isolation or encapsulation which normally includes superimposition of cover material, which may consist of several layers. In the treatment of such land the covering systems are likely to be required to perform three main functions:

- To prevent exposure of the population at risk (site workers and end users) to potentially harmful contaminants
- To sustain vegetation
- To fulfill an engineering role such as accommodating self-imposed stress, i.e., uneven settlement, or even supporting buildings

The effectiveness of any covering system based on soil or soil related materials to fulfill the above criteria will depend on a number of factors. These include:

- Control of upward and lateral migration of contaminants through the ground
- The ability of the cover material to immobilize pollutants through chemical and physical absorption
- Its effectiveness to control water ingress
- The interaction between covering systems, the contaminants and the biology, e.g., plant root systems
- The engineering behavior of the system and its component materials

Where contaminated land sites are treated by the use of cover material rather than by removal of the pollutants, the covering layers take a variety of forms. The cover may range from simple superimposition of a soil layer, or a combination of several layers which can include an impermeable layer of clay or synthetic material.

The properties of covering materials and the design of cover itself to incorporate the range of requirements described above have received much attention in the United States, principally in the field of new landfill site management and solid waste disposal<sup>1,2</sup>. To date there has been little systematic investigation of remedial and ameliorative systems which might be appropriate to contaminated land including waste disposal sites in the UK. However, a number of research projects are underway funded by the Department of the Environment and the National Coal Board which will enable guidance for contaminated land treatment to be produced similar to that for landfill in the United States.<sup>1</sup>

## CONTAMINATED AND DAMAGED LAND OCCURRENCE

In the UK contaminated land and controlled hazardous waste sites are viewed as just one part of the more general problem of rehabilitating land made derelict by past industrial use. Although there is no statutory definition, a working definition of derelict land adopted in the UK is “land so damaged by industrial or other development that it is incapable of beneficial use without treatment.” As such, it encompasses land which would be considered to fall within the definition of contaminated provided above. As many former industrial sites have been contaminated by “*in situ*” waste disposal, and many mineral extraction areas are associated with waste disposal, it is often difficult to distinguish between the various categories.<sup>3</sup>

While there are no statistics available solely for the distribution and occurrence of contaminated land in the UK, there are figures available for derelict land. Much of this will be contaminated in some way for the reasons described above.

The total area of officially recognized derelict land in England

approximates to 45,000ha<sup>4</sup> of which 75% is said to be eligible for restoration. Approximately 5% of this land has been used previously for waste disposal.

Encouragement for the treatment of derelict land in the UK has been provided by the availability of grants to local authorities under a number of Acts of Parliament.<sup>5</sup> In addition, the occurrence of derelict land in England amounts to 0.35% of the land surface. Comparative studies for the United States in the 1970s revealed that 0.18% of the land surface could be considered to be derelict.<sup>3</sup> The population density of Britain per unit area is of the order of 15 times greater than that of the United States, so the impact of damaged land is much greater on the former population.

As a result of the above pressures which must include a greater desire by the public for improved environmental quality, many of the reclamation schemes for contaminated sites have been carried out on an *ad hoc* basis. This has generally been related to availability of cover material rather than its specific properties. In addition, covering systems have largely been used to solve one or two immediate problems for a site rather than the whole treatment proposed by Lutton *et al.*<sup>1</sup> The need for rapid decision making and the method of funding reclamation schemes has not facilitated long term field trials or the monitoring of reclaimed sites in general and information is not readily available on their continued success. A number of UK sites can, however, be considered to be successful, or potentially successful, examples of what can be used to illustrate the use of a variety of covering systems to resolve a range of environment problems.

#### Parc Mine, N. Wales

Former metal mining of the North Wales ore body during the last century has resulted in a number of abandoned tailings spoil heaps rich in lead and zinc. At one such mine, Parc Mine in the Conwy Valley, 260,000 tonnes of tailings spoil had been deposited on the banks of a tributary of the river Conwy.

Continuous stream and gully erosion of the unstable surface resulted in serious damage to some 6ha of agricultural land in the flood plain 2km distant from the mine by contamination with lead, zinc and cadmium.<sup>6</sup> The contamination was sufficient to inhibit cereal production and grazing on this land. In addition, shellfish production was also adversely affected by heavy metals from this source 20km distant at the estuary mouth.<sup>7</sup>

The total area of the site covered 2.2ha and its visual disamenity was insignificant in the context of its surroundings. However, some rapid and permanent surface stabilization was required to prevent the transported pollutant problem.

Steep tip slopes prohibited the use of conventional soil covering because of the potential for slippage and renewed erosion. Direct development of a metal tolerant grass sward on the tailings surface was also rejected because of the serious consequences of even small areas of sward failure. A combination of the two systems was eventually selected. A covering layer of readily available quarry overburden of 100mm and 5 tonne/ha of crushed limestone was spread over the site and seeded with a grass clover sward containing 60% *Festuca rubra* Merlin. This is a grass developed for its tolerance to high soil concentrations of lead and zinc.

Unlike many covering layers which are designed to inhibit root penetration, the quarry overburden allowed the tolerant grasses to root into the underlying contaminated material. Thus the surface amendment was bound to the mine tailings beneath. This, together with the growth of non-tolerant species on the overburden alone, has resulted in a stable surface and control of the erosion problem which is still operating 3 years after its establishment.<sup>8</sup>

#### The Beckton Gas Works, London

Former sites of town gas production from coal and the by-products industry present a major source of severely contaminated land. These sites are usually associated with dense urban areas in the UK where land is at a premium and redevelopment pressures

are high. One such site is the former Beckton Gas Works in London where over 100 years of production generated the largest works of its kind in Europe.

Byproduct waste in this case was disposed of on site during its working life resulting in a solid waste tip covering an area of 5ha with an average height of 16m. The intrusive nature of this tip earned it its local name of the "Beckton Alps". The estimated 430,000 cubic meters of waste was made up of boiler ash, clinker, iron oxides and lime residues. Associated with these deposits were potentially dangerous concentrations of cyanides, phenols, sulphides and other compounds. Large quantities of solid and liquid tarry wastes had also been disposed of on this tip.

Much of the surrounding site was suitable for conventional redevelopment to industry and housing, but redevelopment of the tip itself was restricted. Removal of the waste materials was uneconomic because of handling and subsequent disposal problems and the tip is scheduled for "*in situ*" development to open space.<sup>9</sup>

Unlike the former example, open space development on this site presents a series of after-use problems. Firstly, there is the major difficulty of establishing hard wearing vegetation cover on material which is extremely inhospitable to plant growth. Secondly, there is a need to isolate the toxic materials from site users and services. Provision of a cover layer in this case has required specification of a multipurpose system using available natural material.

The decision to open the site to public access requires sufficient thickness of protective layer to prevent toxic materials reaching the surface either directly or via the biological activity of the plants which are to cover the final surface. This is to be achieved by a seal of London clay of 1.2m covered with 300mm of topsoil.

Other requirements of the covering system necessitate exclusion of percolating water into the tip mass. A 225mm thick gravel drainage blanket has been proposed immediately beneath the clay together with a surface drainage system. A further problem arises because of the complex nature of the wastes. It is likely that earth-moving and tip moulding will result in mixing of the wastes, resulting in the potential for gas generation. The permeable drainage blanket has been designed to also act as a gas drainage channel to a strategically located venting system.

#### McKechnie's Tip, Widnes, Cheshire

An alternative approach to physical separation of contaminated material from the final restored surface is provided by the use of chemical barriers. At the above site over 50 years of copper refining and associated waste disposal resulted in some 10ha of tip seriously contaminated with copper, zinc and cadmium, and significant quantities of barium from a paint pigment works. On closure of the works, the waste tip area was acquired by the local authority for redevelopment to a golf course.

Concentrations of copper in excess of 14000 ppm together with a variety of other readily available heavy metals resulted in a surface which was extremely inhospitable to plant growth. The presence of barium further necessitated the provision of an adequate isolating or covering system.

Top soil sources and other covering materials are at a premium in this locality and were not available for use on the scale required. The site is, however, located in an area which was once the UK center of the Leblanc process for production of sodium carbonate from sodium chloride. The waste product of this industry provided a readily available source of highly alkaline material with a pH range of 9-12.

The alkaline waste has been used to provide a 0.5m cover over the metal rich waste. The high alkalinity and salinity of the cover material in itself will inhibit plant growth, but will reduce the solubility of the metals in the original waste and reduce their potential for movement. The revegetation requirements for the golf course have been overcome by provision of a further layer of 150mm of topsoil. Site restoration has begun and there is no evidence of sward regression in those areas which have been established during the past 12 months.



## SUMMARY

Treatment of contaminated land and its recognition as an environmental problem will differ between individual countries. The United Kingdom, for example, places emphasis on the restoration of contaminated land so that it can be put to some beneficial use such as housing, public open space, agriculture or industry. This emphasis is the result of pressures created by the need to regenerate land in urban areas made available by declining industries, and to conserve the stock of agricultural land. At the other extreme is the concern in the United States for remedial action often by isolation on uncontrolled hazardous waste sites which can cause serious environmental damage. Between these two extremes other countries have experienced a range of problems.

While there has been little systematic investigation of ameliorative measures including covering systems until recently in the UK, a number of reclamation schemes provide examples of the requirements of covering systems. The guidance produced in the United States for cover for landfill sites is an indication of what can be achieved once the basic principles and requirements are understood. The NATO/CCMS study group under Project C intends to draw together the major existing sources of information, determine the variety of covering system requirements, assess their performance by reference to example and to highlight the areas of uncertainty and research needs.

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# IN SITU TREATMENT OF UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Problems associated with contaminated lands—lands used directly as waste disposal sites or contaminated as a result of industrial or other activities—are common throughout the NATO alliance and many other industrial nations. These problems range from imminent health and environmental hazards posed by contaminants, to the increasing pressures to reclaim the land for safe, beneficial use.

The North Atlantic Treaty Organization's (NATO) Committee on the Challenges of Modern Society (CCMS) is studying *in situ* treatment of contaminated lands. Portions of the study are being conducted in several nations. The Netherlands are evaluating *in situ* treatment applications in gas works and other chemically contaminated sites.<sup>1</sup> The United Kingdom has completed a grouting feasibility study and is evaluating an experimental study of shallow-depth grouting problems.<sup>2</sup> The Federal Republic of Germany has treated arsenic-contaminated soils and groundwater by injection of permanganate solution, and has investigated the effects on groundwater of silicate-gel injections used to consolidate foundation soils.<sup>3,4,5</sup> The United States has recently completed a study on *in situ* techniques of solidification/stabilization using one actual site as a scenario for evaluating the feasibility of such treatment.<sup>6</sup> These studies represent a substantial effort in the evaluation and application of *in situ* treatment techniques.

In the report of the second meeting of the Study Group for the NATO/CCMS Pilot Study on Contaminated Land,<sup>7</sup> the term "*in situ* treatment" is defined as "methods of treating, without excavation, the bulk material on a contaminated site by detoxifying, neutralizing, degrading, immobilizing or otherwise rendering harmless contaminants where they are found." The aforementioned studies conducted in the Netherlands, the United Kingdom, the Federal Republic of Germany, and the United States all address some treatment techniques that fall outside this definition as well as techniques that conform to the definition. In this paper the author does not dwell on the "almost but not quite *in situ*" techniques, but focusses on the strictly *in situ*, while referring the reader to the published study reports for a more complete description of the scope and content of the respective studies.

Certain of the *in situ* treatment techniques serve not only to reduce the pollution impacts from contaminated soils, but also to improve the properties of the soils for certain end uses of the site. Selected grouts, for example, not only immobilize specific pollutants, but can increase the load-bearing properties of the soil in a contaminated area intended for eventual use as a building site. The same treatment techniques may also adversely affect other end uses, as discussed later in this paper.

## THE NETHERLANDS ACTIVITIES

In response to a directive from the Minister of Public Health and the Environment, the Laboratorium voor Grondmechanica at Delft developed a general inventory of "soil reconstruction" techniques. The inventory includes techniques in use or under devel-

opment in several countries, but emphasizes their applicability (or lack thereof) to situations in the Netherlands. The types or categories of techniques developed in this study are:

- Civil engineering techniques to restrict the spread of pollution,
- Physical and/or chemical techniques to restrict the spread of pollution (immobilization),
- *In situ* cleaning techniques,
- Excavation,
- Removal of polluted soil,
- Mobile installations for the cleaning of the soil, and
- Water purification.

Only the first three of these categories involve *in situ* techniques. Specific techniques encompassed by the first category are identified in Table 1, and those in the second and third categories are listed in Table 2. The inventory presents a brief description of the specific techniques, and includes diagrams of some of the more prominent, such as jet grouting (Fig. 1) and infiltration accompanied by leachate pumping (Fig. 2). The report also presents an

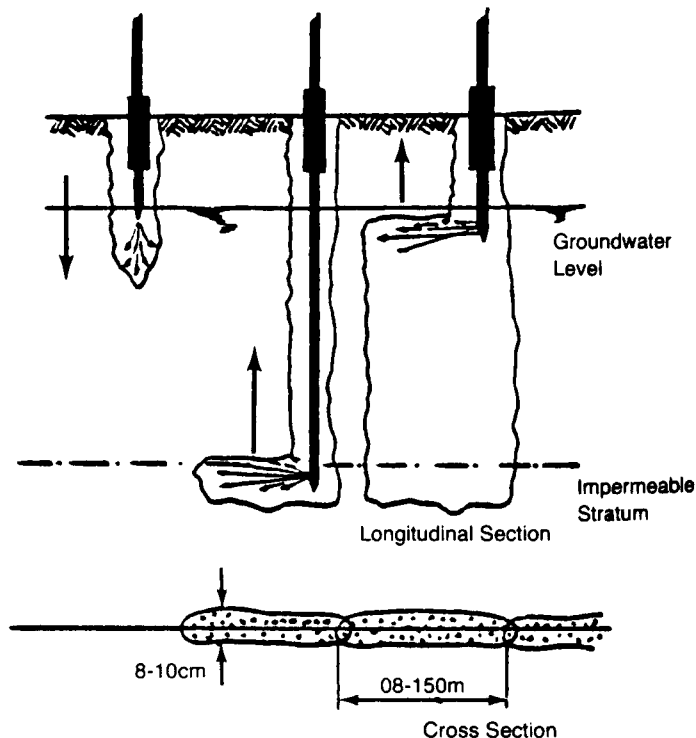


Figure 1.  
Infiltration in Combination with Groundwater Pumping.

interesting summary evaluation for specific techniques in most of the above listed categories. An example of the summary format,

here applied to the vertical screening of the category, is shown in Table 3.

In this study, the authors present a total of 22 conclusions and recommendations of which 10 that pertain to *in situ* techniques are summarized as follows:

- There are as yet no standards to be met by the reconstruction techniques and the materials used in the reconstruction. Issuance of such requirements in the near term is recommended.
- Civil engineering techniques for the restriction of contamination from large sites (screens, etc.) are considerably cheaper than complete excavation. The opposite is the case for smaller sites.
- *In situ* cleaning techniques are attractive (when applicable) because large quantities of soil can be treated at once and because the waste processing problem is of a fairly limited size. Further development of these techniques is recommended.
- *In situ* cleaning techniques, in particular biological and chemical methods, will in many cases have to be used in combination with screening vertical barriers in order to limit the risk of pollutant migration.
- Development of less expensive techniques for vertical screening is recommended.
- The use of immobilization to restrict the spreading of contamination at large sites is much more expensive than the application of civil techniques. Little is known so far about the effectiveness and durability of the immobilization techniques.
- Soil contamination conditions vary so greatly that it is necessary to determine which technique should be applied on a site-by-site basis. As a rule, the combination of techniques may be required.
- The selection of techniques is determined in part by the desired end use of the site. If construction is to take place, then cleaning of the soil will probably have to be undertaken on short notice. If construction is not involved, then techniques which limit only the spread of the contamination may be selected.
- In order to minimize the number of required measurements, it is necessary to find the most sensitive parameters (parameter sensitivity analysis).
- The continued development of computer simulation models of contaminant spreading and removal for the characteristic contaminants and characteristic soils is desirable. By means of simu-

**Table 1.**  
**Soil Reconstruction Techniques in Netherlands Inventory—**  
**Civil Engineering Techniques**

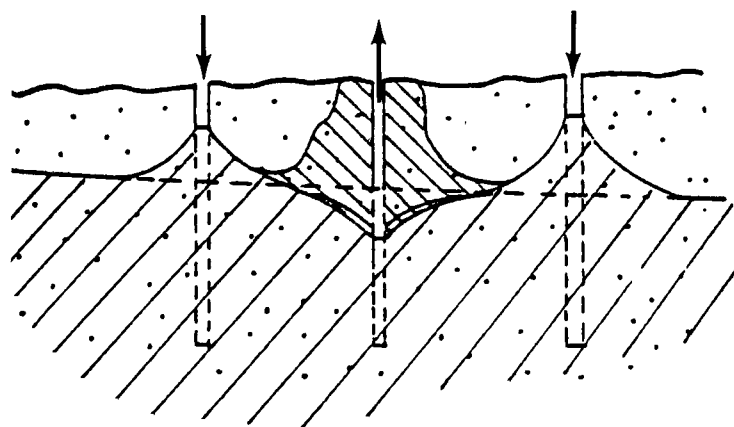
- **Vertical Screening\***
  - thin membranes (plastic foil, bituminous)
  - thin membranes in combination with draining or channeling machines
  - open cuts
  - slurry trenches
  - thin screen walls (bentonite/cement)
  - steel dam walls (sheet piling)
  - timber or concrete walls
  - cutting piles
  - jet grouting
  - vertical injections (pressure grouting)
- **Well Point Dewatering**
- **Coverage Against Precipitation**
  - bituminous membrane or synthetic foil
  - clay cover
  - bentonite layer
- **Horizontal Screening\* under Contaminated Soil**

\*In the context of the Netherlands study, the term "Screen" denotes a physical barrier and "Screening" denotes the emplacement or installation of such a barrier.

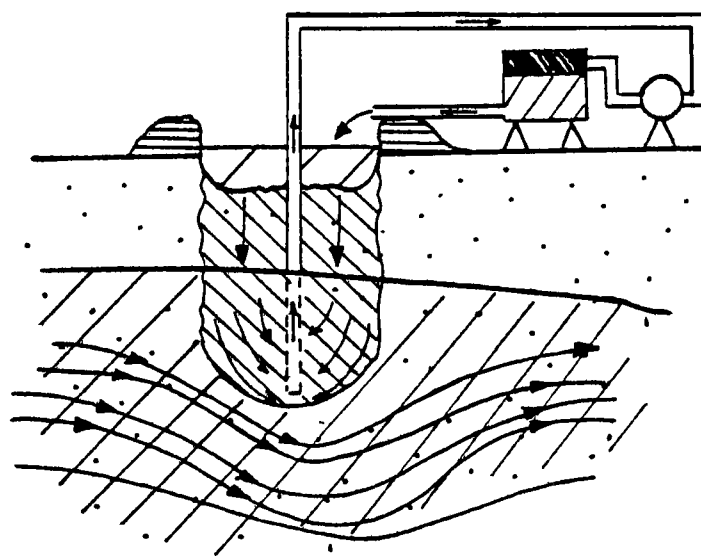
lation it will then be possible to optimize reconstruction techniques for cleaning effect, costs, etc., and to compare alternative techniques.

#### UNITED KINGDOM ACTIVITIES

Under a commission from the United Kingdom Department of Environment, the firm of Atkins Research and Development performed a thorough evaluation of the technical and economic feasibility of a wide range of techniques for treating contaminated land. The appraisal covered *in situ*, on-site, and off-site systems. Emphasis was accorded to the *in situ* techniques such as grouting and ground injection of chemicals, which offer the potential for improving the engineering properties of the ground while aiding the control of pollution. Estimates costs of applying the various techniques are presented, and methods of measuring their effectiveness are discussed. Specific techniques evaluated in the At-



a) Infiltration via Wells



b) Infiltration via  
Surface of Contaminated Area

Source: Reference 1

Figure 2.  
Installation of a Vertical Screen by Jet Grouting

**Table 2.**  
**Additional *In Situ* Techniques in Netherlands Inventory**

*Physical/Chemical Techniques to Restrict the Spread of Pollution (Immobilization)*

- Applications
  - injected as vertical or horizontal screen
  - to harden a site
  - cover layer on top of contamination
  - to restrict above-ground leakage
  - to make contaminated sludge layers firm
  - to restrict leaching
- Types of Immobilization Agents
  - cement-based
  - lime-based
  - oil absorbents
  - silicate-based
  - urea formaldehyde

*Techniques for In Situ Cleaning of Soils*

- Removal of Groundwater by Pumping
- Groundwater Pumping in Combination with Infiltration of Water (Flushing) via
  - wells
  - surface of contaminated area
- Groundwater Pumping in Combination with Infiltration of Chemical Solutions
- Biological Cleaning
- Thermal Treatment

**Table 4.**  
**Principal Characteristics and Specific Techniques of United Kingdom Study**

**Emphases**

- Emphasizes Grouting and Ground Injection*
- Benefits of These Techniques*
  - the ground and ground levels need not be disturbed;
  - contamination is in limited contact with those treating it;
  - ground conditions (e.g., stability) can be improved at the same time;
  - treatment can be localized;
  - treatment can be applied at considerable depth;
  - treatment can (within limits) be applied after development.

**Treatment Techniques Evaluated**

- In Situ Techniques*
  - ground injection techniques—general
  - grouting for lateral containment
  - microencapsulation by shallow grouting
  - grouting in landfill
  - ground leaching, chemical stabilization/detoxification
  - electrochemical processes
  - cutoff techniques
  - stabilization (mechanical properties of soils)
- Other On-Site Techniques*
  - deep or other ploughing
  - soil covers, additives, cappings and membranes
  - chemical fixation and encapsulation
- Off-Site Treatment and Disposal*
  - disposal to landfill
  - chemical fixation and replacement

kins study are listed in Table 4. The following paragraphs describe a few of the most interesting and promising of the *in situ* techniques.

The Atkins study distinguishes between the term "grouting", and "ground injection". Here, "...grouting" is used solely in the

'normal' engineering sense, namely, the injection of appropriate materials—usually a viscous fluid under pressure—into pores and cracks of another material so as to decrease permeability of compressibility, or increase strength, or a combination of the two. The term 'ground injection' is used to encompass injection of fluids

**Table 3.**  
**Summary Characteristics of Vertical Screening Techniques**

	Application in soft, mixed hard soil	Chemically resistant	Life longer than 50 years	Reliability for given function	Little sensitive to execution quality	Inspection for execution	In situ easily adjustable	Obstacles less objectionable	Little nuisance in execution	k-value (m/sec)	Production capacity (m <sup>2</sup> /day)	Price indication (guilders/m <sup>2</sup> )	Applicable depth (m)	Thickness of the wall (m)	Number of Dutch contractors capable of executing this construction (both contractors and construction according to inventory)
Key: + = yes o = sometimes - = not ? = unknown  Source: Reference 1															
Membrane constr. in development	+	+	?	+	+	o	o	-	+	zero	400	100	15-20	10 <sup>-3</sup>	a few
Draining machine	+	+	+	+	+	+	+	-	+	zero	high	30	5	10 <sup>-3</sup>	very many
Open cut	++	++	+	+	+	+	+	+	--	10 <sup>-7</sup>	75	75		1-2	very many
Slurry trench	+	+	+	+	+	+	+	+	-	10 <sup>-8</sup>	125	100	15	0.6-1.5	a few
- deep wall screens	+	+	+	+	+	+	+	+	-	10 <sup>-8</sup>	125	150	50	0.6-1.5	many
- screen walls	o	+	+	+	-	o	+	-	o	10 <sup>-8</sup>	500	50		0.1-0.2	many
- steel dam wall (heavy vibr.)	+	-	o	+	+	o	+	o	+		200	200	20	10 <sup>-2</sup>	very many
Steel dam wall (light, injected)	o	-	-	+	o	o	+	o	+		250	65	15	2.10 <sup>-3</sup>	many
Cutting piles	o	+	+	o	o	o	+	+	-	10 <sup>-7</sup>	100	350	30	0.6-1.5	sporadically
Jet-grouting (being developed)	+	+	+	+	-	o	+	-	o	10 <sup>-8</sup>	200	75	20	0.1-0.2	sporadically
Injections	o	o	+	o	-	o	+	+	o	10 <sup>-7</sup>	125	350	50	1-2	a few

also where the treatment objectives do not necessarily coincide with the normal engineering objectives just mentioned: for example, the use of chemical neutralization agents or forced leaching. The techniques and equipment are identical to those employed in grouting for engineering purposes...It is treatment objectives, and hence, treatment agents, that distinguish them."

### Grouting in Contaminated Soils

When grouting is applied to treat contaminated soils, it is often necessary to inject at shallow depths (less than two meters), since the contaminated volume is generally in the soil mass immediately below the surface. One of the basic characteristics of grouting is the need for adequate overburden pressure to ensure that the grout does not escape to the surface through fissures before it permeates the target areas. To overcome this problem, two solutions are suggested:

- Applying a temporary overburden, such as a suitable concrete block (aided on the surface and moved about, as necessary, by crane).
- The use of electro-osmosis to improve the receptivity of the soil to grouting, or as part of the grouting process. It has been shown that the presence of an electric field reduces the grouting pressures necessary and induces movement of the grout. The electric energy requirements are not well established but appear modest—in the range of 3 to 25 kwh/yd<sup>3</sup> of material.

### Grouting in Landfill

Problems arise from the heterogeneous nature of many landfills and the on-going chemical and biological activity that may be occurring within the fill. The potential for leachate production and gas generation must be taken into account.

The principal potential applications of grouting in landfills are considered to be:

- Control of groundwater entry
- Control of leachate egress
- Extinguishing fires in the landfill
- Inducing anaerobic conditions (thus reducing potential for fires)
- Maintaining top temperatures (thereby improving bacterial activity—this can also be achieved by capping)
- Control of gas migration
- Improvement in ground stability

The principal disadvantages of grouting are:

- Application may be difficult and uncertain depending on composition of the fill material
- It may adversely influence gas generation and leachate quality
- Ultimate stabilization of the fill may be delayed

A related observation, made in the context of a different application of grouting, is that when the end use of the site is for construction, the presence of hard, cementitious grout in the soil may interfere with the installation of foundations and underground waterpipes, electric lines, and other utility conduits; also, the presence of certain chemical grouting material may corrode such conduits. Advantages and disadvantages of grouting are summarized in Table 5; most of these apply to ground injection as well.

### Ground Leaching; Chemical Stabilization/Detoxification

This approach involves application of a liquid to a contaminated soil mass, followed by collection of the liquid for disposal or reuse. The liquid may be water to leach out soil contaminants, or may contain chemical or biological agents that would react with contaminants to form innocuous products. This technique is being used in Sweden to reclaim a former herbicide factory site over a 5 to 6 year period. Here, water is applied by means of perforated pipe laid in a ditch through the contaminated area. The water permeates the affected soil, is collected by drainage pipes, then treated by activated carbon.

Other methods for applying the water or treatment liquid include: (1) direct application to the surface, and (2) underground

**Table 5.**  
**Advantages and Disadvantages of Grouting/Ground Injection**

#### Advantages

- Versatile; useful for wide range of objectives
- Can be used for injecting any fluids
- Can be used to reach specific targets
- Well established, relatively straightforward technique
- Contaminated soil is treated *in situ*
- Can be used at considerable depth
- Can be used to protect services
- Can be used in tight situations
- Unlikely to affect adjoining areas
- Unlikely to be limited by treatment volumes or site area
- Wide range of fillers and chemical grouts readily available
- Applications can be staged (preventing overdesign)
- Equipment not overly cumbersome or heavy

#### Disadvantages

- Generally very expensive
- Cannot usually be applied at shallow depth (normally 1.5m)
- Permeation not guaranteed; may require repeated application
- Soil and contamination regimes are likely to be heterogeneous and complex, requires matching of application strengths and viscosities to contamination and geotechnical conditions
- Applications (of grout) can interfere with subsequent groundworks (e.g., excavations for sewers and other services)
- Durability of grouts not proven in potentially aggressive underground environments
- Robustness of application has to be proven
- Chemical grouts, solvents can present some operator hazards
- Applications may create supplementary contamination

**Table 6.**  
**United Kingdom Activities**

#### Recommendations

- Test forced leaching techniques on sites with 'soluble' contaminants
- Test temporary surcharge and electro-kinetic methods for overcoming shallow ground injection problems
- Study feasibility of choosing treatment techniques for a specific contaminated site so as to develop optimum solutions for different end-uses
- Determine the practical potential of a) dispelling oil by fluid injection and/or b) the use of filler grouts for stabilization on unstable oil-contaminated ground
- Examine the ability of jet-grouting to form impermeable barriers at relatively shallow depths in various soil types
- Examine the effects of filler grouts in landfills on engineering properties, leachate control, groundwater influx, and biodegradation
- Determine technical and economic potential of using on-site chemical fixation plants for treatment of contaminated soil
- Develop procedures for forming effective grout seals around load bearing piles driven through impermeable strata underlying contaminated materials

pressure injection by use of grouting equipment. The latter is of greatest interest in this study because it offers the potential for faster, more localized application, and can accommodate gaseous treatment fluids (e.g., air or oxygen for aeration) as well as liquids. In this approach, as with many grouting applications, injection at shallow depths may be a problem because of inadequate overburden pressure. The report outlines a test employing pressure injection of liquid to suitably sized sections (or "cells") of a contaminated area, with suitably located drainage lines and a leachate treatment system.

#### Recommendations

The Atkins report gives eight recommendations that apply to a range of land treatment techniques (Table 6). Two of these apply directly to the *in situ* treatment topics discussed above.

- Perform Tests of Ground-Injection Forced Leaching  
These ground injection forced leaching tests could be extremely valuable particularly where large volumes of material are concerned and where the source contaminant is soluble.

**Table 7.**  
***In-Situ Treatment of Arsenic Contaminated Ground Water in the Federal Republic of Germany***

	<i>Arsenic Content in Ground water Near Smelter Site</i>			
	1971	1975	1977	1979
pH (range)	3.1-7.0	4.8-7.0	5.5-7.8	5.8-8.2
Eh mV	—	-110- +20	-110- +440	-120- +440
As mg/l	0.01-56	0.01-26	0.01-0.3	0.01-5.6
As average mg/l	22.7	13.6	0.06	0.4
FE <sup>3+</sup> + mg/l	0.2-140	0.1-93.3	—	—
SO <sub>4</sub> <sup>2-</sup> - mg/l	152-2010	80-1670	—	—
Spec. electrical conductance S/cm	—	440-2300	600-2250	650-2150

The values vary according to the site and depth of the observation wells.

Source: Reference 3

#### •Develop Solutions to Shallow Ground-Injection Problems

Since most contamination is at relatively shallow depths, normal ground injection procedures must be amended to meet the essential requirement of overburden pressure. This can be in the form of a temporary surcharge (such as superimposed material or a concrete block) and/or the use of electro-kinetic aids. On-site testing should be conducted to test and develop these techniques.

#### FEDERAL REPUBLIC OF GERMANY ACTIVITIES

The reports describing *in situ* treatment activities in Germany discuss the application of specific techniques to specific problems, and the results obtained.

Reference 3, "*In Situ Treatment of Arsenic Contaminated Groundwater*," reports the use of an oxidizing agent, potassium permanganate, to reduce arsenic concentration in groundwater in the vicinity of a zinc ore smelter near Cologne. The smelter operated from 1913 to 1971. In the latter year, arsenic concentrations of as high as 56 mg/l were detected in groundwater at 20m depth. The natural background concentration is less than 0.01 mg/l. By 1975, the concentration at the same location had dropped to about 26 mg/l.

Extensive monitoring was conducted at wells and piezometers installed within a roughly oval area about 300m by 450m on the axes. Monitoring data revealed that the arsenic was in trivalent form in the regions of higher concentration (greater than 1 mg/l), and in pentavalent form in regions of low concentration (less than 0.1 mg/l). These results, together with observations of arsenic compounds precipitated on soil samples, suggested that most of the dissolved arsenic was present in the trivalent state and that transformation into pentavalent species in the presence of calcium and ferrous ions would cause an appreciable fraction of the arsenic to precipitate.

From December 1976 to May 1977, a solution containing 29 kg potassium permanganate was injected into 17 wells and piezometers. As shown in Table 7, the average arsenic concentration in groundwater samples decreased from 13.6 mg/l in 1975 to 0.06 mg/l in 1977. However, this average value had increased to 0.4 mg/l by 1979.

Reference 4, "Groundwater Impact on Silicate Gel Injections," describes an investigation of the groundwater impacts of silicate gel injection widely used for chemical soil consolidation. The impacts are reported in quantitative form in the referenced document, and are summarized briefly as follows:

- Alkalinity increases as a result of the alkaline components of the water glass (an aqueous solution of sodium silicates— $\text{Na}_2\text{SiO}_3$  and  $\text{Na}_4\text{SiO}_4$ ) or alkaline and alkaline-earth precipitants.
- Organic content increases when organic precipitants are used, causing  $\text{O}_2$  consumption and reduction of  $\text{O}_2$ -containing com-

pounds, resulting in the temporary occurrence of a strongly reducing environment.

- Heavy metal content increases because of impurities of the water glass (an aqueous solution of sodium silicates— $\text{Na}_2\text{SiO}_3$  and  $\text{Na}_4\text{SiO}_4$ ) or dissolution from the sediment by the action of  $\text{CO}_2$ .
- Heavy metals precipitate as sulfides in a reducing environment only.

Reference 5, "Protection and Improvement of Groundwater Quality by Oxidation Processes in the Aquifer," describes the injection of oxygen-enriched water to improve groundwater quality and protect against pollution. The suggested mechanism is that concentration of certain ionic species in groundwater varies with oxidation and reduction reactions. Biological decomposition of organic matter in soil and groundwater consumes oxygen and decreases redox potential. The redox potential can be increased either by adding oxidizing agents (usually atmosphere oxygen) to the soil, or by injecting oxygenated water into the groundwater. In addition to this basically inorganic mechanism, the increased level of oxygen in soil and groundwater can also promote biological reactions beneficial to water quality.

#### UNITED STATES ACTIVITIES

The principal purpose of the U.S. study was to investigate the feasibility of solidifying or stabilizing hazardous industrial wastes that had been placed in the ground. In the context of this study, the term *in situ* treatment of waste materials means that the treatment is applied while the waste remains in the ground.

The USEPA has been involved in research, development, and demonstration of methods for the proper management of hazardous wastes. USEPA's Municipal Environmental Research Laboratory (MERL) has sponsored much of the research and development on methods for managing solid and hazardous wastes, including the study now being reported. The work was performed under contract by The MITRE Corporation.

#### Methods of Solidification/Stabilization for *In Situ* Application

In USEPA's "Guide to the Disposal of Chemically Stabilized and Solidified Wastes," the term "solidification" implies that the product of treatment will be in solid form (such as pellets, grains, blocks, large masses of undefined shape) while "stabilization" implies that the hazardous components of the waste will be rendered insoluble or otherwise immobile or that their hazardous characteristics (e.g., toxicity) will be neutralized.

In this study, treatment techniques to solidify or stabilize hazardous wastes were identified through examination of the literature and communication with vendors and researchers. The principal categories of techniques are shown in Table 8. Technical descriptions of the specific techniques in each category were compiled together with their associated problems, limitations, and a listing of advantageous or disadvantageous characteristics. An example of the latter is shown in Table 8 for one of the major categories (methods involving crystalline matrices).

Each of the techniques was then assessed in terms of its applicability for *in situ* treatment of landfilled wastes. In this study, the primary intent of treatment is the control of environmental pollution and reduction of hazards from the wastes; little attention was accorded the engineering properties of the site or treated wastes. The assessment quickly led to three conclusions:

- The preponderance of research and practical experience with most of the techniques had involved *non-in situ* treatment, either before wastes had been placed in landfills or after they had been evaluated.
- Most of the listed techniques require thorough mixing of a solidifying or reactive additive with the waste, and the required degree of mixing is generally not achievable during *in situ* applications.
- No single technique or combination of techniques is widely applicable for most landfills.

There are, however, a few exceptions to the second of these conclusions, and these exceptions represent the techniques of greatest interest in the study. They are:

- Injection or surface application of chemical agents (in combination with leachate collection and removal)
- Thermal fusion/vitrification
- Macroisolation (that is, surface capping, bottom sealing, vertical barriers, and other structural procedures)

As one basis for assessing the applicability of alternative techniques, a scenario was established in which the techniques were conceptually applied. This scenario involved a site at which a highly diverse combination of wastes—demolition debris, toxic inorganic and organic chemicals, lesser qualities of sanitary wastes and municipal solid wastes—had been placed in an abandoned quarry over a period of some 20 years. The total volume of wastes deposited at the site was about a quarter-million cubic meters, of which about 10 percent was arsenical material. The bottom of the quarry, and hence the waste pile, lay below the water table in some areas, so there was groundwater flow through the wastes. The filled area covered about three hectares and was about 10 m thick at its maximum depth. Portions of the fill rested on highly fractured bedrock, which overlies an important aquifer system. The site was in close proximity to a river and to populated areas. An approximate cross-section is shown in Figure 3. The objective in this study was to investigate whether it is feasible to achieve a high degree of pollution control at the scenario site by means of techniques applied *in situ*.

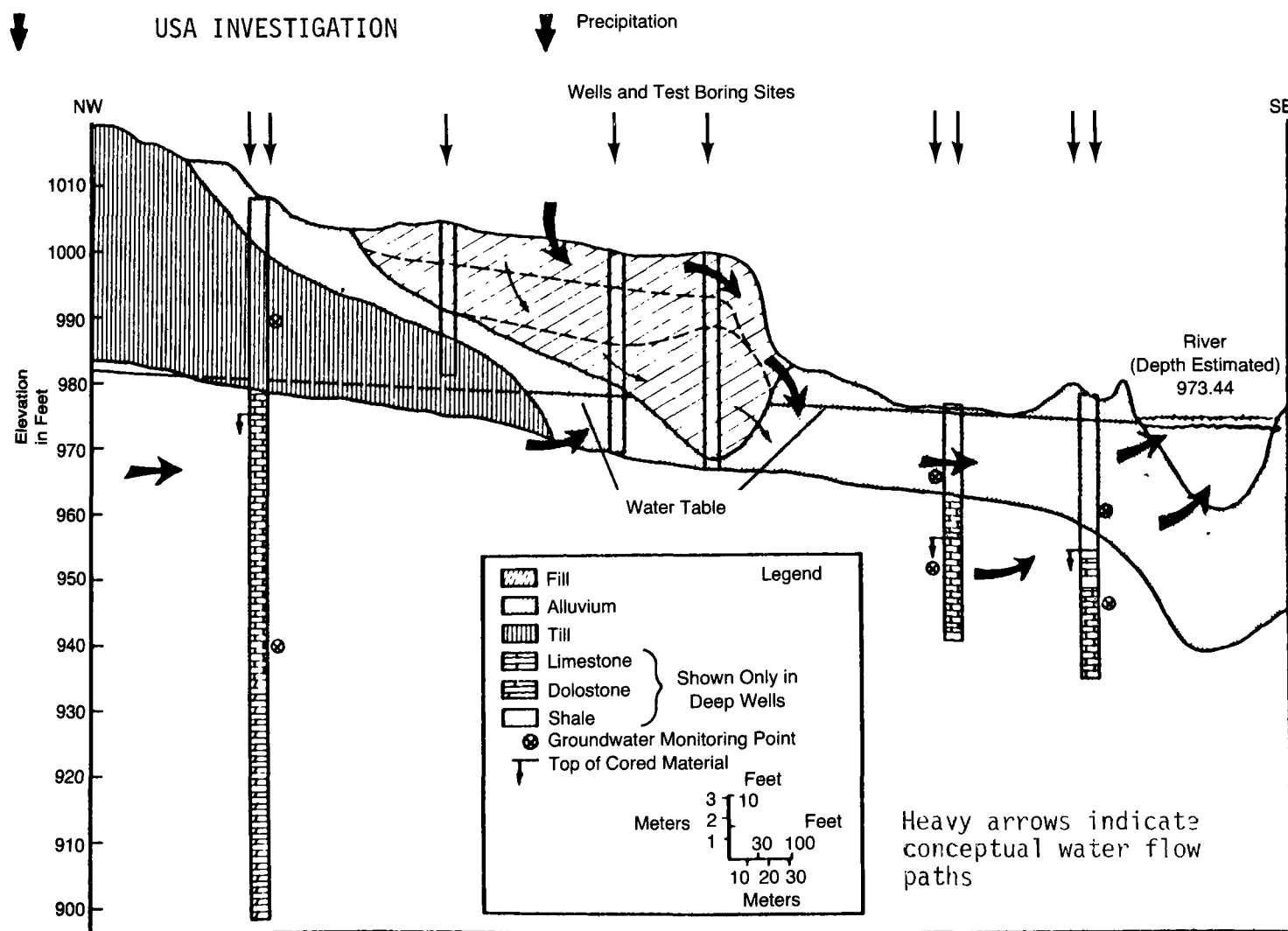
The majority of techniques listed in Table 8 were excluded because they require more thorough mixing than can be practically achieved *in situ*, and because of possible interference by waste constituents with the setting actions of cements, polymers, and gels. Thus, the list was narrowed to three conceptually feasible options:

- Injection of water or reactive chemicals (with leachate removal)
- Thermal fusion/vitrification
- Macro-isolation

Their application to the scenario site was reviewed in detail. This review took careful account of the highly heterogeneous characteristics of the site with respect to its chemical, physical, and hydrogeologic characteristics.

Leaching with injected water did not appear to be feasible because of the insoluble nature of toxic, inorganic constituents known to be present in large quantity.

Injection of reactive chemical fluids was not considered attractive because of the variety of chemical pollutants in the waste. Addition of a particular chemical to attack one type of hazardous constituent might cause antagonistic or counterproductive reactions with other constituents. For example, an oxidizing agent intended to destroy a specific organic compound might also change the valence state of a metallic ion, increasing the toxicity or mobility. A secondary reason for rejecting this approach is the not insignificant problem of collecting the leachate in the specified hydrogeologic setting, without serious risk of contaminants' entering nearby aquifer or surface waters.



Source: Reference 6

Fig. 3.  
Cross Section of Scenario Site



**Table 8.**  
**Categories of Treatment Techniques in USA Investigation.**

- Solidification
  - crystalline matrix (cement based) methods
  - lime/siliceous matrix (pozzalanic based) methods
  - thermoplastic methods (including bitumens)
  - organic polymer methods
  - gelation
  - thermal fusion/vitrification
  - surface encapsulation
  - microencapsulation
  - macroisolation
- Stabilization without Solidification
  - injection/surface application of chemically reactive agents

Example of Comparative Advantages of  
Crystalline Matrix Methods

Advantages	Disadvantages
High Load-Bearing Solid	Pretreatment of Certain Wastes Required
Inexpensive Raw Materials	May Release Ammonia from Wastes
Technology Well Known	Energy Intensive
Non-Specialized Labor	Final Product Heavy, Bulky
Dewatering Not Required	Uncoated Product May Require Special
Tolerant of Chemical Variety	Landfill
Product Can Be Sealed by Coating	Organic May Interfere With Setting

The thermal fusion/vitrification technique appeared technically feasible at first inspection because it accommodates to a great variety of waste material and produces an inert, strong solid mass of very low solubility. However, there are some practical limitations to its use. The technique employs electric energy at a rate sufficient to heat a mass of buried wastes to temperatures above the fusion point of surrounding soils and rocks. The electric energy is applied through electrodes inserted in the landfill on either side of the wastes (or portions thereof) to be fused. The electrodes are placed in the ground or fill by drilling or other appropriate means, and a strip of graphite in contact with the fill material is connected across the electrodes to act as a "starter" in melting the fill. A cover is placed over the surface of that portion of the fill which will be fused at a given placement of the electrodes. The cover is intended to capture gases released during the fusion. Captured gases are ducted to a treatment unit as necessary.

While the "vitrification by electrification" approach has been successfully demonstrated on masses of soil to the order of ten tons, the effective volume of any given application, using currently available equipment, is a cube six meters on the side. While the technique may be readily adaptable to wastes buried no more than 6m below the surface, its application to a relatively deep land-

fill as in the scenario site would appear to require considerable excavation, and thereby violates our definition of *in situ* treatment. An ancillary reason for considering this technique infeasible is its substantially high cost relative to the cost of excavation and *non-in situ* treatment.

The remaining *in situ* option—macro-isolation—was considered to be feasible from a civil engineering standpoint, but environmentally undesirable (although not necessarily unsound) because of the massive amounts of contaminated soil and rock that would have to be excavated, whether by mechanical or hydraulic means, and the potential pollutant-release that could result.

Thus, the study concludes that strictly *in situ* techniques are not a feasible approach to controlling pollution at the scenario site. However, it appears probable that they could be effectively employed in conjunction with *non-in situ* control measures.

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# ALLOCATING SUPERFUND LIABILITY

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## HOW THE PROBLEM OF ALLOCATION ARISES

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 ("CERCLA"), 42 U.S.C. §9601 *et. seq.*, popularly known as the "Superfund Act", provides new legal authority for dealing with the release of hazardous substances to the environment. As the legislative history of the law makes clear, its principal goal is to enable the government to abate dangerous conditions caused by leaching contaminants from inactive disposal sites.<sup>1</sup> Under CERCLA Section 104, the United States may directly undertake cleanup operations at offending sites, using money from the Superfund, which is created and reserved for such activities by other provisions of the Act. But if there are known "responsible parties", they may be compelled to clean up a site at their own expense in accordance with administrative orders issued pursuant to CERCLA Section 106.

The term "responsible party" refers to any individual or business entity that is a potential defendant in a suit brought under CERCLA Section 107 to recover: (1) costs incurred by the federal government or a state, or by "any other person" in responding to an actual or threatened release of hazardous substances, or (2) compensation for any ensuing damage to publicly controlled natural resources. The class of persons subject to Section 107 liability includes the current owner or operator of a facility from which there is a (threatened) release, as well as persons who owned or operated the facility at the time hazardous substances were deposited there. In addition, waste generators who arranged to have hazardous substances disposed of or treated at the facility, as well as transporters who selected the facility and carried such substances to it, qualify as members of this class of potential defendants.

It seems likely that most Section 107 actions will be brought by the federal government after it is forced to respond to a release because cleanup orders have been ignored by responsible parties, or because responsive action had to be undertaken before responsible parties could be identified. Since defendants are strictly liable under Section 107, i.e., liable for the costs and damages associated with a release even if they took reasonable precautions to prevent it and complied with all applicable regulations for managing hazardous substances, the odds that the government will prevail in such actions are relatively high. For it need not prove that the defendants were "at fault" in order to win a case. As plaintiff, the United States must carry the considerably lighter, although by no means trivial, burden of establishing that the defendants own(ed) or operate(d) the releasing facility, generated and arranged for the disposal of hazardous substances there, or selected the facility and carried such substances to it.

Winning a law suit and collecting a judgment are, however, two different matters. And one of the most troublesome legal issues that will be raised in Superfund cases is whether Section 107 liability for costs and damages should be apportioned among the multiple defendants, or whether that liability is joint and several. Unfortunately, neither Section 107 itself nor its legislative history conclusively resolves the issue.

In general, if the rule of joint and several liability governs the disposition of a Superfund suit, a successful plaintiff could recover the full amount of costs and damages from any one of the multiple

defendants. Although the paying defendant may have the opportunity to seek "contribution" from the others for some part of the plaintiff's award, his ability to secure contribution depends on the solvency of his co-defendants. In contrast, if the rule of joint and several liability is not applied, each defendant would be responsible for paying an apportioned share of costs and damages to the plaintiff. In this situation, the plaintiff bears the risk of not being able to recover his entire loss, should one or more of the defendants be insolvent and unable to pay his apportioned share.

The question of how Superfund liability should be allocated is a hot topic of debate in the legal community<sup>2</sup>—a debate raising the policy considerations and issues of statutory construction which are the focus of this essay. However, since an analysis of these matters is more easily presented once the reader is better acquainted with the underlying principles of allocation, they are discussed next.

## COMMON LAW BACKGROUND

The principles for allocating liability were developed at common law, i.e., they were fashioned by judges in the course of deciding suits brought by plaintiffs seeking damages for injuries to their persons or property allegedly caused by the "tortious" or wrongful conduct of others. These principles have evolved over the years, and today are applied differently in different jurisdictions. In general, however, the modern trend is that damages are apportioned among multiple defendants whose concurrent acts have caused a plaintiff to suffer: (1) distinct injuries, or (2) a single "divisible" injury. An injury is divisible if there is a reasonable basis for calculating the extent to which each defendant's activity contributed to its occurrence. Although the plaintiff must introduce evidence showing that the activity of each defendant was a legal cause of the harm complained of, once this *prima facie* case is established, the burden of proving that apportionment is appropriate is on the defendants. If they fail to carry this burden, each is charged with responsibility for the entire "indivisible" harm. In other words, they are held jointly and severally liable, and the plaintiff may collect his entire damage award from any one of them.<sup>3</sup>

Evidentiary problems aside, apportionment is undoubtedly proper in this sort of case: *D1* disposes of mercury at a site adjacent to property owned by *P*, and *D2* deposits benzene there. By some quirk of hydrogeology, one of *P*'s wells is contaminated by mercury and the other by benzene. In this situation, there are two clearly distinct injuries, and *D1* should pay *P* for the loss of the mercury-contaminated well, and *D2* should pay for the loss of the other.

The controversial cases involve concurrent acts that combine to cause a single harm. Although the rule is that if there is a reasonable basis for calculating each defendant's share of responsibility for the harm, joint and several liability will not attach, it is difficult to predict whether a court will hold that such a basis exists, given a particular set of facts. Suppose, for example, that *P* owned only one well, which was contaminated by 100 µg/l. mercury and 200 µg/l benzene. Does the fact that each defendant contributed different amounts of distinct contaminants to the well provide a reasonable basis for apportionment? Or is the harm indivisible? Suppose that for 10 years *D1* owns and operates a facility that dis-

charges mercury into an adjacent stream, and then sells the facility to D2. D2 continues to operate the facility in the same manner until the date of suit, 15 years after the date of sale. Should the damage sustained by the downstream plaintiffs as a result of using contaminated water be divided among the defendants according to their respective periods of facility ownership, or should they be saddled with joint and several liability?

As the footnote material indicates, in cases involving situations similar to the ones described in the last two hypotheticals, some courts find a divisible harm, others do not. In principle, however, information regarding the quality and/or quantity of pollutants attributable to each defendant obviously provides a theoretical basis for apportionment. It is the failure of the defendants to introduce sufficient evidence in this area that explains some decisions characterizing pollution as an indivisible harm. Such decisions may also turn on (unarticulated) equitable considerations. Thus, if one or more of the defendants is insolvent and unable to pay any apportioned share, joint and several liability might be imposed in order to ensure that the innocent plaintiff is made whole.<sup>4</sup>

Because most jurisdictions now afford a right of contribution to the defendant from whom a plaintiff has collected damages for a so-called "indivisible harm", imposition of joint and several liability does not necessarily mean that the one defendant will ultimately bear the entire cost of the plaintiff's judgment.<sup>5</sup> Rather, it means that the paying defendant must bear the risk that all or some of his co-defendants are insolvent. From the solvent ones, he may recover money paid to the plaintiff in excess of his fair share of the damages. For purposes of a contribution claim, a defendant's fair share is traditionally calculated by dividing the plaintiff's award by the number of defendants.

The type of pollution case raising the most difficult allocation problems for the common law is one that has been characterized by a prominent commentator as involving defendants with "dissimilar functions,"<sup>6</sup> e.g., hazardous waste generators and the owner or operator of the disposal facility to which they sent their wastes. There are few cases directly on point.<sup>7</sup>

1. See e.g., *Landers v. East Texas Salt Water Disposal Co.*, 151 Tex. 251, 248 S.W. 2d 731 (1952), where the court held that an oil company owning a pipeline running near plaintiff's property and a salt water disposal company owning an adjacent pipeline could be held jointly and severally liable for damages sustained by the plaintiff when both pipelines broke, pouring oil and salt water into his lake. Cf. *City of Perth Amboy v. Madison Industries, Inc.*, N.J. Super. (L-28115-76, Law Div., C-4474-76, Cl. Div., July 31, 1981), where liability was apportioned when a wellfield was contaminated by organic chemicals from one defendant and by heavy metal from another. Each paid for the different remedial measures required to correct the pollution caused by their respective contaminants.

2. See e.g., *State of New Jersey, Department of Environmental Protection v. Ventron Corp.*, N.J. Super. (A-1395-79, App. Div., Dec. 9, 1981), where the court imposed joint and several liability upon successive owners of an industrial facility that had discharged mercury into an adjacent stream. It concluded that the harm complained of—mercury contamination—was an indivisible injury, without addressing the point that length of facility ownership apparently provided a reasonable basis for apportioning damages. Cf. comment c to the Restatement (Second) of Torts, §433A: "[I]f two defendants, independently operating the same plant, pollute a stream over successive periods, it is clear that each has caused a separate amount of harm, limited in time, and that neither has any responsibility for the harm caused by the other."

3. But see *Ewell v. Petro Processors of Louisiana, Inc.* 364 So. 2d 604 (La. App. 1978), cert. denied, 366 So. 2d 575 (1979), where a facility owner/operator who negligently permitted toxic wastes to leak onto plaintiff's property and a generator who continued to use the facility after learning of the problem were held jointly and severally liable for the contamination of plaintiff's property; *State of New Hampshire v. Mary Charpentier*, Hillsborough County Superior Court (June 1982), where a jury held the owner of a hazardous waste dump site liable for 10% of the clean-up costs, but found the occupant and manager of the site, a number of chemical waste haulers and a chemical waste disposal company jointly and severally liable for the rest of the costs.

In theory, however, damage caused by contaminants released from a facility might be allocated among such defendants along these lines: a court could hold each generator jointly and severally liable with the facility owner or operator for each generator's respective share of responsibility for the damages. Shares would be apportioned among these jointly and severally liable pairs on the basis of the number of barrels of waste, for example, that particular generators contributed to the facility. Each jointly and severally liable defendant from whom the plaintiff collected a portion of his damages—i.e., either a generator or the facility owner or operator—would have a right of contribution against the other. In the absence of sufficient evidence germane to apportionment of generator liability, or in the face of evidence that the facility owner or operator and a majority of the generators are financially insecure, all of the defendants might be held jointly and severally liable for the entire damage award.

## SUPERFUND LIABILITY—TEXTUAL AND HISTORICAL ANALYSIS

Paragraph (a) of Section 107, the operative portion of CERCLA's liability provision, does not specify how Superfund liability is to be allocated. In general, it merely defines the classes of generators, transporters and facility owners or operators—the responsible parties described at the beginning of this paper—who are liable for response costs and for damages to natural resources occasioned by a release of hazardous substances. However, a careful textual analysis of Section 107(a) suggests a possible congressional intent that the liability be joint and several.

In pertinent part, Section 107(a) provides that when "a" hazardous substance is released from a facility, its current owner or operator, the person who owned or operated it at the time any hazardous substances were deposited there, generators who arranged for the treatment or disposal of their hazardous substances at the facility, "and" transporters who selected the facility and carried such substances to it, "shall be held liable" for "all" response costs.<sup>8</sup> Arguably, the quoted language indicates that each defendant is liable for the entire expense incurred by the plaintiff in responding to a release, regardless of the extent to which the released material contains substances that a particular defendant generated, transported or otherwise managed. In short, the defendants may not be allowed to show that there is a reasonable basis for apportioning Superfund costs. Consequently, a successful plaintiff would, as a practical matter, be assured of full recovery from any solvent defendant.

In the final analysis, however, the interpretation of Section 107(a) as a provision designed to impose joint and several liability as a matter of law, i.e., regardless of whether apportionment is appropriate under common law principles, should be rejected. The section provides for strict liability, placing the costs incurred by a plaintiff in responding to a release on specified parties regardless of whether they were at fault for that release. At least when the solvency of these possibly "innocent" parties is not seriously in doubt—when the plaintiff can probably be made whole even if damages are apportioned—it seems only fair to let defendants limit their respective liabilities in the first instance by showing, if they can, a factual basis for apportionment. Certainly the cryptic text of Section 107(a) does not provide sufficient evidence of congressional intent to override such an equitable consideration in order to insulate the plaintiff from any risk, however small, that his recovery will be less than 100%.

Indeed, an examination of CERCLA's legislative history indicates that the language of Section 107 suggesting joint and several liability (quoted above) is but a vestige of competing bills considered by Congress before Senator Stafford introduced S. 1480, which became CERCLA. Some of these bills explicitly provided for the imposition of strict, joint and several liability.<sup>9</sup> Although

4. More precisely, they are liable for all response costs "not inconsistent with the national contingency plan." CERCLA Section 105 directs the President to prepare an NCP delimiting the appropriate types of response measures.

S. 1480 dropped this provision, the standard of strict liability was nonetheless retained, as the legislative history of the Act makes clear.<sup>8</sup> Further, according to what is now CERCLA Section 101(32), the term "liability" is to be construed as it is under Section 311 of the Clean Water Act, 33 U.S.C. §1251 *et. seq.*, and the courts have routinely interpreted Section 311 as imposing liability in the absence of fault for discharges of oil or hazardous substances into navigable waters of the United States.<sup>9</sup>

In contrast, the effect of deleting the earlier language of joint and several liability from S. 1480 was more controversial. On the one hand, the legislative history indicates that some members of Congress were persuaded to support S. 1480 because they believed it did away with joint and several liability altogether:

The drafters of the...substitute have recognized [the] unfairness and lack of wisdom in eliminating any meaningful link between culpable conduct and financial responsibility. Consequently, all references to joint and several liability in the bill have been deleted.<sup>10</sup> Indeed, these statements aside, one could argue that, by actually considering and then rejecting language expressly incorporating the rule of joint and several liability, Congress indicated that this rule should not apply.

On the other hand, the managers of the bill in the House and Senate made these comments:

[T]he terms joint and several liability [were] deleted with the intent that the liability of joint tortfeasors be determined under common or previous statutory law.<sup>11</sup>

[The issue of joint and several liability is left to] traditional and evolving principles of common law.<sup>12</sup> And the *Congressional Record* contains legal memorandum from the Justice Department indicating that imposition of joint and several liability is the common law trend in pollution cases, as well as a Justice Department opinion to the effect that joint and several liability is the appropriate standard under Section 311 of the Clean Water Act.<sup>14</sup>

If the Justice Department's interpretation of Section 311 had been fully accepted by Congress, then the enactment of CERCLA Section 101(32), which cross-references Section 311, would have indicated an intent to adopt the standard of joint and several liability. CERCLA's legislative history as a whole, however, suggests that the views of the Justice Department were discounted or forgotten. Moreover, they may have been incorrect.<sup>15</sup>

#### COMMON LAW IN THE FOREGROUND AGAIN

In light of its legislative history, the text of Section 107 cannot be said to reveal a congressional intent that joint and several liability should apply in Superfund cases as a matter of law. On the other hand, neither does CERCLA define the circumstances under which apportionment would be reasonable. Largely by default, then, the federal courts have received a mandate to develop and apply common law principles in allocating costs and damages in Superfund actions. The nature of the federal common law and the circumstances under which it is applied are highly technical matters, beyond the scope of this paper. In general, however, when important federal interests are at stake, "statutory interstices" in federal acts may be filled by the federal common law.<sup>16</sup> Although in fashioning this law, federal judges frequently turn to the salient decisions of various state courts for guidance,<sup>17</sup> these are not binding. In particular, courts have held that the federal interest in remedying pollution, and in doing so through consistent adjudication of cases brought under environmental statutes, is sufficiently strong to warrant the development of such independent federal common laws as may be needed to fill legislative gaps.<sup>18</sup>

As for CERCLA, it exhibits what might be called an "interstice" on the issues of allocation arising out of liability for Superfund costs and damages. Although the federal common law that can be expected to address these issues will surely be indebted to

older common law principles of allocation as applied by state courts in comparable pollution cases, it will also undoubtedly reflect a judicially ascertained federal policy on the matters of joint and several liability and contribution.

#### REFERENCES

1. The major House and Senate reports accompanying the bill that became CERCLA are found in 5 United States Code Congressional and Administrative News 6119 (1980). CERCLA's legislative history is summarized in Eckhardt, "The Unfinished Business of Hazardous Waste Control", 33 Baylor L. Rev. 253 (1981), and in Grad, "A Legislative History of the Comprehensive Environmental Response, Compensation and Liability ("Superfund") Act of 1980", 8 Columbia J. Env. L. 1 (1982).
2. See, e.g., Garrett, "Issues Relating to the Implementation of Superfund", 14 Nat. Res. Law Newsl. 5 (1982); Macbeth, "Superfund: The Comprehensive Environmental Response, Compensation and Liability Act of 1980", *Expanding Liability in Environmental Law* (Harcourt Brace Jovanovich, 1981); Marnell, "Superfund: Conscripting Industry Support for Environmental Cleanup", 9 Ecology L.Q. 524 (1981); Rodberg and Percell, "Joint and Several Liability in Hazardous Waste Litigation", 3 Chem & Rad. Waste Lit. Rep. 448 (1982).
3. For a history of the principles of allocation described above, see W. Prosser, *The Law of Torts* Ch. 8 (4th ed. 1971). The current state of the law is summarized in the Restatement (Second) of Torts, §§433A and B, and in Rodberg and Percell, cited *supra* in reference number 2.
4. See Restatement (Second) of Torts, Section 433A, comment h, "Exceptional Cases".
5. For an analysis of the law of contribution more detailed than the one given in the text below, see Rodberg and Percell, "Contribution Among Defendants in Hazardous Waste Litigation", 3 Chem. & Rad. Waste Lit. Rep. 591 (1982).
6. Rodberg and Percell, "Joint and Several Liability in Hazardous Waste Litigation", *supra* at pp. 459-460.
7. See articles cited *supra* in reference number 1 for a description of the bills preceding S. 1480.
8. See remarks of Senator Randolph in 126 Cong. Rec. S14964 (daily ed. Nov. 24, 1980), and remarks of Representative Florio in 126 Cong. Rec. H11773 (daily ed. Dec. 3, 1980), explaining that Stafford's bill preserved the standard of strict liability.
9. See, e.g., *Burgess v. M/V Tamano*, 564 F.2d 964 (1st Cir. 1977); *United States v. Tex-Tow Inc.*, 589 F.2d 1310 (7th Cir. 1978); *Stewart Transportation Co. v. Allied Towing Corp.*, 590 F.2d 609 (4th Cir. 1979); *United States v. LeBoeuf Brothers Towing Co.*, 621 F.2d 787 (5th Cir. 1980).
10. Remarks of Senator Helms, 126 Cong. Rec. S15004 (daily ed. Nov. 24, 1980).
11. Remarks of Representative Florio, 126 Cong. Rec. H11787 (daily ed. Dec. 3, 1980).
12. Remarks of Senator Randolph, 126 Cong. Rec. S14964 (daily ed. Nov. 24, 1980).
13. 126 Cong. Rec. H11788-89 (daily ed. Dec. 3, 1980).
14. *Ibid.*
15. See *United States v. M/V Big Sam*, 505 F. Supp. 1029 (E.D. Louisiana 1981), which rejected the government's position that third party liability under Section 311 should be read as joint and several: "We read the statute as being in the disjunctive and giving a choice of parties, depending on the existing facts." *Id.* at p.1033.
16. *Illinois v. Outboard Marine Corporation*, 619 F.2d 623, 630 (7th Cir. 1980). See also Friendly, "In Praise of Erie and of the New Federal Common Law", 39 N.Y.U.L.R. 383 (1964), and *Clearfield Trust Company v. United States*, 318 U.S. 363 (1943), and its progeny.
17. See *Textile Workers v. Lincoln Mills*, 353 U.S. 448 (1957); *D'Oench, Duhme & Co. v. Federal Deposit Insurance Company*, 315 U.S. 447 (1942).
18. See *United States v. Solvents Recovery Service*, 14 ERC 2010, 2020, 496 F. Supp. 1127 (D. Conn. 1980); *Illinois v. Milwaukee*, 406 U.S. 91 (1972).

5. CERCLA Section 113(b) provides that the United States District Courts have jurisdiction over all cases arising under the Act. The action may be brought in the district in which the release or damages occurred or where the defendant resides, may be found, or has his principal office.

# PROTECTION FROM LONG-TERM LIABILITY AS A RESULT OF SUPERFUND REMEDIAL ACTIONS

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## FEDERAL EPA STANCE

The potential for civil litigation as a result of accidental discharges by a contractor of wastes secured under Superfund is a very valid concern, and one that is being addressed at both the Federal and state levels at this time. The USEPA generally provides indemnification for contractors in its two Superfund Technical Support Zone Contracts and in its Technical Assistance Team contract. They are providing this indemnification in order to encourage maximum competition for the contracts. The reasoning for indemnification is that a number of contractors expressed concern about the possibility that they will be liable to third parties for damages arising out of their remedial response performance for USEPA. These contractors stressed that the activities conducted under these contracts may involve significant risk of injury to third parties, the effects of which may not be evident for years. They expressed reluctance to compete for contracts where they might be held liable for these long term risks.

USEPA realized that insurance against the risk of such liability would be extremely costly, a cost that USEPA would ultimately bear. Moreover, insurance against certain extraordinary risks appears to be difficult or impossible to obtain, and even where such insurance is available, some insurers insist on limiting coverage to a period of time, perhaps three years. Thus, although the Federal Tort Claims Act does not require or prohibit indemnification for contractors, USEPA felt indemnification would be the most effective method available to ensure best use of the fund and maximum competition for the contract.

Authority to indemnify is limited by the Anti-Deficiency Act.<sup>1,2</sup> USEPA believes, however, that agencies may agree to indemnify contractors if it is as "necessary expense," if adequate competition could not be otherwise obtained, or if the agency were faced with the certainty of reimbursing a large amount of insurance costs, as contrasted with the possibility of large indemnity payments being required.<sup>2,3</sup>

There are two types of indemnity agreements, unqualified and qualified.<sup>4</sup>

### Unqualified Indemnity Agreements

To create an unqualified obligation to indemnify consistent with the Anti-Deficiency Act, an agreement must either: (1) provide that the duty to indemnify applies only to loss or damage to specified property (in which case the total indemnity could not exceed the value of the property); or (2) establish a ceiling on the amount the government is obliged to pay for third-party liability. The problem with an unqualified indemnity agreement is that it is necessary to establish a reserve of funds to cover the contingency. The Comptroller General has stated that: "Where circumstances are such as to indicate some likelihood of payment being required, an appropriate reserve or obligation would, of course, have to be established to assure the availability of funds."<sup>5</sup>

## Qualified Indemnity Agreements

In a qualified indemnity agreement, any contract providing for assumption of risk by the Government for contractor owned property must clearly provide that: (1) in the event the government has to pay for losses, such payments will not entail expenditures which exceed appropriations available at the time of the losses; and (2) nothing in the contract may be considered as implying that the Congress will, at a later date, appropriate funds sufficient to meet deficiencies.<sup>6</sup> Without inclusion of provisions along these lines, legislative exemption from the application of the statutory prohibitions against obligations exceeding appropriations would have to be obtained.

The application of this requirement to an agreement to indemnify for third party liability has been addressed by USEPA. The phrase "available at the time of the losses" has been interpreted to mean that funds must be available at the time the obligation becomes certain as to amount.

USEPA has chosen the "Qualified Indemnity Agreement" approach in the language for the Technical Support Zone contracts. The agency has modified the standard "Insurance-Liability to Third Persons" clause of 41 C.F.R. 1-7.204-5 to make clear that reimbursement for liabilities to third persons for loss of or damage to property, or for death or bodily injury as the result of contractor activities shall not exceed appropriations available at the time such liabilities are represented by final judgements or by settlements approved in writing by the government. The language also makes clear that an agreement to reimburse the Contractor for certain liabilities to third persons shall not be interpreted as implying that the Congress will, at a later date, appropriate funds sufficient to meet deficiencies.

The USEPA Office of General Counsel (OGC) expressed concern that the language for the Zone Contracts does not make clear that the "appropriations available" would come from the Superfund. This raises the possibility of the necessity for creation of a separate fund for liability payments, which was not the intention of the Agency. This point will be clarified in future language to make it clear that "appropriations available" must come from Superfund.<sup>7</sup> Still, a question may remain as to whether general substantive limitations in Superfund on third party claims are applicable to similar claims arising out of contractor malfeasance.

The question then arises about liability when the cleanup is performed under a State/USEPA Cooperative Agreement. USEPA's advice is that Cooperative Agreements, which are required when the state has lead responsibility for the activity and funds are transferred to the state, and Grants fall under the same liability requirements, even though grants may be less complicated than many Cooperative Agreements. (For example, under some Cooperative Agreements, USEPA may do part of the work; i.e., the design or the feasibility study, while the state and/or state contractor performs the remainder of the remedial action.) However, 40 C.F.R. Part 30, the Grant Regulations, holds that normally

USEPA has no liability after funds are given to the grantee. The USEPA OGC's position is that USEPA will also not indemnify the state under a Cooperative Agreement.<sup>8</sup>

The USEPA OGC also is of the opinion that Section 107(d) of Superfund probably does not protect either contractors or the government against claims by third parties. Their interpretation of 107(d) is that it is a limitation on the liability to the government of contractors and others for cleanup costs under Title I of the Act, and probably does not limit private rights under ordinary tort principles.<sup>9</sup>

However, OGC also stressed that in the event the contractor is held liable to third parties for damages arising out of Superfund remedial response activities, and money was not available to pay an indemnity, the contractor could seek a private bill in Congress.

## STATE STANCE

A number of states have awarded contracts for remedial activities on Superfund sites. Only two of the states which were contacted for this study, New Jersey and California, are using or are planning to use language in their contracts which partially or totally indemnifies the state from liability for third party claims, thereby placing the responsibility on the contractor. Both of these states are also very specific about the types of insurance which the contractor must carry to cover remedial action activities.

In New Jersey's contracts, indemnification is addressed through the following language:

"The Contractor shall be solely responsible for and shall keep, save, and hold harmless the State of New Jersey and its employees from and against any and all claims, demands, suits, actions, recoveries, judgments, and costs and expenses in connection therewith on account of the loss of life, property, or injury or damage to the person, body, or property of any person, agency, corporation, or government entity, which shall arise from or result directly or indirectly from the work and/or materials supplied by or arising out of the performance of this contract. The Contractor's liability under this contract shall continue after the termination of the contract with respect to any liability, loss, expense or damage resulting from acts occurring prior to termination. This indemnification obligation is not limited by, but is in addition to the insurance obligation contained in this agreement."<sup>10</sup>

New Jersey requires contractors to maintain insurance in accordance with the following language from a contract:<sup>11</sup>

"The Contractor shall secure and maintain in force for the term of the contract the following minimum insurance coverages. The contractor shall provide the State of New Jersey with current Certificates of Insurance certifying coverage and containing the provision that the insurance shall not be cancelled for any reason except after 30 days written notice to be directed to the State of New Jersey, Director, Division of Purchase and Property.

"Comprehensive General Liability Insurance as broad as the standard coverage form currently in use in the State of New Jersey which shall not be circumscribed by any endorsements limiting the breadth of coverage. The policy shall include an endorsement (broad form) for contractual liability, an endorsement for completed operations liability, and shall include the State of New Jersey as an additional insured. Limits of bodily injury liability and not less than one million dollars per occurrence for property damage liability."

"Comprehensive Automobile Liability Insurance covering owned, non-owned, and hired vehicles with minimum limits of one million dollars per occurrence for bodily injury and property damage liability combined.

"Workers Compensation Insurance applicable to the laws of the State of New Jersey and any other state where the contractor will be active under this contract, and Employers Liability Insurance with a limit of not less than \$250,000. The policy

shall be endorsed to include coverage under the United States Longshoremen's and Harbor Workers Compensation Act and any other Federal Workers Compensation Law which may apply to the Contractor's operations."

The State of California protects itself from liability in three ways.<sup>12</sup> First, they use a standard indemnification clause which indemnifies the state generally against contractor malfeasance. Second, the state has developed a specific indemnification clause for hazardous waste sites. This clause requires the employer to:

- Carry specified insurance
- Notify state and contractor employees of the hazards present at the site
- Notify the state of any spills

Third, the State Tort Act provides that there must be a showing of gross criminal negligence on the part of the state before any state entity can be prosecuted. There is also another section in the State Tort Act which protects the contractor unless gross negligence on the part of the contractor can be proved.

Both New Jersey and California stated that they do not believe competition for the contracts was reduced by the provision that the contractor assumes the long term liability for the remedial actions. Both states did, however, indicate that they believe there may be health problems in the future which the liability language and insurance requirements will not cover.<sup>13</sup>

The State of Washington includes language in their contracts which provides protection from claims by the contractor against the State, but has not addressed the issue of protection from long term liability.

The State of Michigan did not address this issue in the Superfund pre-implementation contract which they have already awarded. They do, however, plan to include language in future contracts that will include provisions to hold the contractor liable if engineering work fails, while the State will be liable if failure is the result of remedial design.<sup>14</sup> Louisiana is also drafting an Article which will address the issue of long term liability for remedial actions.

The State of Colorado, which awarded a contract for work on the Denver radium sites, included language which indemnified the Federal government and the state. They required their architect/engineer contractor to indemnify itself for one year after the work is completed. However, the contract reads that the State and Federal government, through the contractor, will "attempt to reduce the radiation levels". It does not provide any guarantee to what value the radiations levels will be reduced. This, the state believes, will help prevent a basis for third party liability claims.<sup>15</sup>

The other five states which were contacted have not yet addressed the issue of long term liability, but realize they will need to in the near future.

The experience of selected states indicates several potential bases for determining indemnification rules. These are:

- Design versus construction.* (Michigan) This pinpoints responsibility for remedial design failures versus responsibility for remedial construction failures.
- Standard of care.* (California) The standards used are:
  - Negligence, where the failure is fairly commonplace
  - Gross Negligence, where the failure is of such magnitude that careful attention should have prevented it
  - Knowledge where the contractor had knowledge of the problem, but took no corrective action
- Monitoring and Disclosure.* (California) The contractor must agree to disclose information and keep the State informed on the status of activities at the site.
- Remedial Action.* This considers the question of responsibility for the remedial action itself. For example, the government may assume third-party liability, while holding the contractor responsible for redoing a remedial action which fails. Insurance is an important consideration in this area of negotiation in order to ensure site integrity and compensation for damages.

•*Insurance.* (California) This involves specifying what insurance is carried by which entity, and determining the distribution of insurance payments across time. A damage ceiling is an important point to consider when determining insurance requirements.

•*Damage Ceiling.* Here, exposure of the contractor is limited to a fixed sum.

•*Types of Damages.* These include:

- Remedial Action
- Remedial Costs
- Personal Injury
- Damage to Property
- Environmental Damage

•*Site Specific versus General Rule.* Contract provisions can be site specific, depending on such factors as the degree of hazard of the site, rather than providing a general rule for all sites.

Obviously, these contractual determinants are not mutually exclusive. Accordingly, a state can select any combination of these determinants to modify existing contractual provisions for the clean-up of hazardous waste sites.

## CONCLUSIONS

There appears to be significant disagreement between USEPA and the states on the degree to which long term liability rules can potentially affect contractor competition. It is easy to imagine instances where the choice of an indemnification rule could significantly affect competition. For example, the standard of care (e.g., negligence versus gross negligence) may help determine the pool of qualified contractors. Also, the imposition of broad long term liability on contractors may have a differential impact on larger, more established firms and smaller, more financially marginal firms. Consequently, the competition issue should be carefully considered at the time an indemnification rule is established.

Finally, the states should establish a clear-cut contractual rule determining the entity responsible for additional remedial action in the event the original remedial action fails. This is important because Superfund terminates in September, 1985. Thus, appropriations available from Superfund to respond to any liability suits may be significantly reduced or non-existent after this time.

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# LIABILITY AND INSURANCE ASPECTS OF CLEANUP OF UNCONTROLLED HAZARDOUS WASTE SITES

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## INTRODUCTION

Cleanup operations at uncontrolled hazardous waste sites can complicate an already complex terrain of legal liability and insurance. Rather than review the underlying common law and statutory liabilities of responsible parties, the author's focus in this paper is on how the cleanup operations themselves generate an independent set of liabilities and how that risk can be reallocated through various contractual agreements.

Because legal outcomes depend very heavily on the facts of specific situations, a treatise would be required to adequately discuss the myriad of potential situations that could arise as a result of cleanup operations at uncontrolled hazardous waste sites. The author can only present in this paper the broad outlines of typical situations and applicable legal doctrines. It is also impossible for the author to analyze and report here the many variations in applicable state laws.

This paper has three major parts: (1) an overview of what occurs during cleanup operations and what can go wrong is presented, (2) potential types of resulting liability are discussed, and (3) the use of private agreements to shift financial responsibility for liability claims is surveyed. Given the complexity of this subject matter, the author's goal is to clarify basic terms and relationships for the general professional reader.

## CLEANUP ACTIVITIES AND POTENTIAL DAMAGES

Uncontrolled waste disposal sites include: landfills containing loose or containerized waste, open dumps of unidentified barrels and drums, contaminated structures, contaminated river or lake sediments, and unstabilized surface impoundments. Hazardous wastes may include flammable, explosive, radioactive, carcinogenic, and infectious materials; pesticides, heavy metals, organic solvents, waste oils, inorganic acids, etc. Among the key hazards are explosion and fires, release of toxic fumes, contamination of private real estate, groundwater, and surface water supplies.

Contractors will play a key role in the cleanup of uncontrolled hazardous waste sites, usually under the supervision of federal and/or state government personnel. Often, a prime contractor will use the services of one or more subcontractors for different aspects of the cleanup operation. There are several aspects of operations at uncontrolled hazardous waste sites that contribute to the dangerousness of the activity but the lack of knowledge of the nature and amount of hazardous substances present and their disposition is the major factor.

Contractors are likely to perform some or all of the following activities as part of a cleanup effort:

- On-site investigation (preliminary assessments, site inspections, remedial investigations)
- Remedial action planning and design
- Selection of subcontractors including transporters, disposal sites, etc.
- Technical services including construction of fences, dikes, berms, or waste impoundments
- Removal and disposal of wastes, decontamination of structures and equipment
- Temporary provision of alternate water supplies

- Cleanup and restoration or replacement of affected natural resources (including groundwater)

Contractors may face liability exposure to the extent that damage proximately results from any of these activities.

## On-Site Investigation

The contractor may be called upon to perform site investigations and develop characterizations of the hazardous substances present, pollutant dispersal pathways, types of receptors, and site management practices. Where damage results that would otherwise have not occurred had site investigation been properly performed, liability could attach.

The major concern of the contractor should be the proper identification of the wastes, particularly those that may be explosive, reactive, or incompatible. In addition, careful identification and location of nearby sources of drinking water is necessary. Any plan for protecting the safety of workers and nearby residents will only be as good as the data it is based on. The uncontrolled nature of the waste site heightens the risks involved.

## Remedial Planning, Design, and Construction

The remedial action phase is critical to cleanup operations. It may include erecting dikes, constructing trenches or ditches, installing a clay cover or synthetic liners, segregation of reactive wastes, dredging or excavations, repair or replacement of leaking containers, collection of leachate and run-off, physical cleanup of hazardous substances or their neutralization, treatment and incineration.

While planning is an essential management function, the concept of proximate cause requires that execution take precedence over planning when assessing legal causality. Poor planning by itself is rarely the cause of damages and claimants will face a formidable burden of proof in this regard. A cleanup contractor has a strong self-interest in selecting subcontractors with care and in ensuring proper performance on the part of all subcontractors since a prime contractor may be liable for harms caused by the actions or omissions of its subcontractors.

Design and construction, however, is a major area of concern. Improper design and/or construction may result in waste containment structures that do not work. Breach of an impoundment, liner, or cover due to poor design and construction could result in damage claims brought against the contractor.

Cleanup contractors need to exercise special care in designing or selecting underground storage tanks, leachate collection systems, gas collection systems, liners, and the like. In the construction field, architects are frequently sued for negligence in specifying some new product without adequate testing; cleanup contractors may face similar suits.

## What Can Go Wrong

During the cleanup of an uncontrolled hazardous waste site, the following damages typically could occur:

- Injury or death to a person on-site, such as a cleanup contractor employee or a government employee due to explosion of a 55 gal drum during earth moving

- Property damage resulting from a fire which starts on-site and spreads to surrounding property
- Spill of hazardous wastes during transport for off-site disposal
- Release of toxic fumes into surrounding community causing minor injuries due to acute reactions and exposure to potentially carcinogenic compounds
- Continued community exposure to contaminants due to improper design or construction of waste containment systems
- Injury or death of an emergency response professional such as a fireman
- Increased cleanup costs or harm to natural resources.

From a legal point of view, it is essential to know why these damages occurred. It can make a significant difference if the damages resulted due to: (1) negligence, (2) an intentional act (e.g., arson), or (3) due to no one's fault in particular. In addition, if an intentional or negligent act is involved, the identity of the actor is important. Among the possibilities are: (1) the prime contractor and its employees, (2) subcontractors and their employees, (3) trespassers, (4) bystanders, (5) residents, or, (6) government personnel (federal, state, or local). The possible scenarios are numerous.

### LIABILITIES RESULTING FROM CLEANUP

Liability has a variety of meanings, even in the law. At its broadest, the term can refer to any obligation. As the term is used in this paper, it has a narrower focus. By liability, the author means a legally enforceable responsibility to take action or provide money for particular kinds of losses, damages, or costs.

There are many sources of legal liability. It can arise under federal and/or state law, both through statutes promulgated by legislative bodies and through judicially-developed common law. Liability can be civil or criminal. In a legal proceeding, a claimant will name as many alternative theories of liability as possible in support of its case.

Liability may also arise through contractual agreements. The most familiar instance of this is the liability created for an insurer through the contract of insurance. An indemnification agreement likewise can create liability. This type of liability is sometimes referred to as "secondary" or "derivative" to distinguish it from liability imposed directly, without reference to private agreements.

Liability always needs to be defined in terms of whose liability, to whom, and for what. This is in addition to specifying whether the liability is federal or state, statutory or common law.

Whose liability refers to the class or classes of legal persons to whom the liability can legally attach. For example, sovereign immunity protects state and federal governments from certain types of liability. Waste generators may be treated differently from common carriers transporting waste. Likewise, liability may depend on what class of legal persons is the claimant. Because of state workers' compensation statutes, employees may have more limited options if injured as a result of cleanup activities than do bystanders or residents. Common law similarly restricts certain causes of action to certain persons, and injuries outside the "scope of the risk" may not receive preferential judicial treatment. Finally, liability may only exist for certain kinds of damages or for certain kinds of conduct.

For the purposes of this paper, several sources of liability need to be addressed: (1) the federal Comprehensive Environmental Response, Compensation and Liability Act ("CERCLA" or Superfund), (2) state common and statutory law, and (3) the doctrine of vicarious liability known as respondeat superior. Liability for damages resulting from cleanup operations will also be affected by the legal concept of proximate causation which will be discussed at the end of this part of the paper.

### CERCLA and Liability for Damages

Section 107 of CERCLA contains most of the key liability provisions of the legislation. In addition to establishing liability for response costs and natural resource damages, Section 107 of the

Comprehensive Environmental Response, Compensation and Liability Act also addresses liability for damages resulting from remedial and response cleanup actions. The statutory language reads as follows:

"No person shall be liable under this title for damages as a result of actions taken or omitted in the course of rendering care, assistance, or advice in accordance with the national contingency plan or at the direction of an onscene coordinator appointed under such plan, with respect to an incident creating a danger to public health or welfare or the environment as a result of any release of a hazardous substance or the threat thereof. This subsection shall not preclude liability for damages as the result of gross negligence or intentional misconduct on the part of such person. For the purposes of the preceding sentence, reckless, willful, or wanton misconduct shall constitute gross negligence." (Section 107(d))

This section only addresses CERCLA liability for response costs and natural resource damages. It says nothing about third party damages resulting from cleanup activities. Third party damage provisions were dropped from CERCLA prior to its enactment in 1980. Section 114(a) makes it clear that CERCLA does not preempt any state from imposing statutory liability for third-party damages from the release of hazardous substances.

Although the language of CERCLA is essentially silent on the third party damage liability issues of greatest concern to cleanup contractors, the legislative history of the Act does address this matter in part. The Senate Report on S. 1480 (Report No. 96-848), the Senate bill that eventually became CERCLA, discusses third party property damages resulting from authorized response actions. It states on page 82:

"It should be clear, as under section 311 [of the Clean Water Act], if an innocent third party's property is damaged pursuant to authorized removal or remedial operations those damages are part of the cost of removal or remedial payable from the fund and chargeable to the owner or operator."

This suggests that, at least with regard to property damages, contractors are not liable but, rather, the originally responsible party is. It is also possible that other third party damages resulting from response actions could be dealt with this way, i.e., by defining them as response costs that are payable by the Response Fund and chargeable to the owner or operator. Regardless of whether the legislative history extends to third party damages beyond property, there is a larger issue: to what extent is legislative history operationally useful in protecting potentially liable contractors? The question of personal injury damages has not come up under Section 311 of the Clean Water Act. The Congressional intent is not clear, nor is the statutory language.

Because CERCLA is silent on third party liability, state statutory and common law will control with respect to third party damages incurred as a result of both the uncontrolled disposal of hazardous waste and damages resulting from cleanup operations. Section 107(d) quoted above offers no definite protection to cleanup contractors outside of CERCLA's narrow focus on cleanup costs and natural resources damages.

CERCLA addresses secondary or derivative liability in Section 107(e). This section, at first, seems to contradict itself, but in fact it does not:

"(e)(1) No indemnification, hold harmless, or similar agreement or conveyance shall be effective to transfer from the owner or operator of any vessel or facility or from any person who may be liable for a release or threat of release under this section, to any other person the liability imposed under this section. Nothing in this subsection shall bar any agreement to insure, hold harmless, or indemnify a party to such agreement for any liability under this section.

(2) Nothing in this title, including the provisions of paragraph (1) of this subsection, shall bar a cause of action that an owner or operator or any other person subject to liability under this

section, or a guarantor, has or would have, by reason of subrogation or otherwise against any person."

This is a complex provision that accomplishes several goals. First, Section 107(e)(1) prevents any shift of primary liability away from responsible parties. Thus, a generator whose standard waste disposal contracts include agreements by the disposer to indemnify the generator for any damages would not be able to thereby avoid the joint and several liability created by CERCLA. Second, CERCLA maximizes the number of possible "deep pockets" for payment of claims by not barring private insurance or indemnity arrangements—these contractual provisions act to create a secondary liability on the part of the insurer or indemnifier and to assure that certain sums will be available to pay claims. Third, paragraph (2) fosters the negotiation of private risk sharing arrangements by making explicit that CERCLA is not to be construed as barring insurers, indemnifiers, or guarantors from suing responsible parties for reimbursement pursuant to subrogation clauses.<sup>1</sup>

### State Law

State statutory and common law are key sources of liability that may apply to cleanup operations at uncontrolled hazardous waste sites. There is much variation in the types and language of existing state statutes and there is often conflict among the holdings of state common law.

**Statutory Law.** Within the past 15 years, an increasing number of states have promulgated laws imposing liability for harms caused by releases of hazardous substances.<sup>2</sup> The goal of this legislation has often been to create "strict" (i.e., no fault) liability on the part of responsible parties to answer for damages caused by releases. Whether or when a cleanup contractor becomes a responsible party under the terms of these laws is usually not addressed. It should not be assumed that these laws will not apply to remedial and removal actions.

Many state statutes have been enacted for the protection of employees against occupational disease and injury. Violation of statutory requirements generally constitutes actionable negligence. In addition, statutes adopted in many jurisdictions, such as employers' liability acts, workmen's compensation acts, and similar statutes have altered, limited, abolished, or supplanted common law rules regarding the liability of an employer for injuries to an employee. These statutes do not address third parties.

In general, workers' compensation acts provide no-fault protection, i.e., a right to compensation for all injuries incident to the employment, with certain exceptions, is given. Where such acts are compulsory, not elective, they supercede existing laws and an employee cannot recover at common law for an injury which is compensable under the acts. This is known as the exclusivity doctrine.

**Common Law.** In many instances, injured parties will base their claims for recovery under applicable state common law. Typically, negligence, strict liability, nuisance, or trespass will be asserted as the basis for recovery. The strengths and limits of these doctrines have been adequately explored elsewhere and need not be repeated here.<sup>3</sup> These doctrines are generally used by residents and bystanders with damage claims but may also be asserted by employees in certain contexts.

In many instances, cleanup contractors may also be manufacturers, sellers, or suppliers, which renders them vulnerable to products liability suits. It is now generally accepted that the liability of a construction contractor is the same as that imposed upon a manufacturer for injuries resulting from defective products. Under this view, a contractor is held to a standard of reasonable care for the protection of third parties who may foreseeably be endangered by his negligence, even after acceptance of the work by the contractee. Breach of the duty of proper performance which results in injury is actionable. The plaintiff must still prove, of course, the contractor's negligence, that such negligence is the proximate cause of the injury, and that the plaintiff came within the scope of the risk. The liability of an employer as a manufacturer is distinct from

its liability as an employer and may be asserted successfully as the grounds for a claim by an injured employee.

If the negligence of a contractor causes injury to other contractors or other employees, to his own employees or employees of his principal, or to some third person for whose protection the contractor is bound to exercise due care, the contractor may be directly liable for the injury under state common law.

With respect to its employees, it is the general duty of the employer to provide a reasonably safe place of work and to furnish suitable and safe instrumentalities with which to work. The employer's liability to provide a safe place of work is severely compromised when cleanup operations at uncontrolled waste sites are involved. Nevertheless, the standard of care to be exercised must be commensurate to the dangers of the business. This means that the employer must warn the employee of conditions under which he is employed which may engender disease. The employer may be held directly liable for occupational diseases which can be traceable to some negligence on its part. The employer must also furnish suitable protection from the danger (e.g., respirators), provided he is in a position to have greater knowledge of the existence of the danger than the employee.

Where the harm was caused by the negligence of a subcontractor, the prime contractor may be liable under the theory that the firm selected the subcontractor without satisfying the necessary standard of care and is thus itself liable. The alleged negligent selection of subcontractors theory would most likely arise in a suit naming a "deep pocket" prime contractor for damages due to personal injury from explosion, fire, or significant release of fumes or material during on-site operations (including removal for off-site disposal). The claimant could be an employee of a subcontractor, or a third party bystander or resident, or even an emergency response professional. All these parties could, of course, proceed against the negligent subcontractor itself.

### Vicarious Liability

This type of common law liability is based on a relationship between parties, though not through a contract or indemnification agreement. Rather, vicarious liability is based on social policy considerations under which it is determined that irrespective of fault, a party should be held to be liable for the acts of another. Thus, there need be no negligent act or omission of the party held vicariously liable. The application of vicarious liability to employers or contractors occurs through the doctrine of *respondet superior*, discussed below.

It is universally recognized that an employer is civilly liable for injuries to the person or property of third persons caused by the torts, negligence, frauds, deceptions, concealments, misrepresentations, and other malfeasances or misfeasances of the employee which are within the scope of his employment. This rule of vicarious liability is one of long standing. Among the showings required to establish liability is proximate cause. Of course, if the employer has been held liable by a third party victim, he has a right to be indemnified by the wrongdoer employee.

An employer may be vicariously liable for tortious acts of their employees and may also be vicariously liable for injuries to employees, even if caused by third persons. An initial question is always whether the person either injured or causing the injury is, in fact, an employee. Whether a person is an employee or an independent contractor depends upon the power of control which the employer is entitled to exercise over the person in question, regardless of the existence of written subcontracts. A "cost plus" contract is not itself determinative.

To a large extent, the difference between an employee and an independent subcontractor disappears when the nature of the work being performed is inherently dangerous—as is the case with cleanup operations at uncontrolled hazardous waste sites. The general rule of law prevents an employer from using independent contractors as a shield against liability for harms. Injuries resulting from excavation, blasting, and demolition work are frequently handled in this manner. If the injury that occurs might have been antici-

pated as a probable consequence of the execution of work assigned to an independent contractor, the employer as well as the subcontractor may be held liable.

Where the "inherently dangerous activity" doctrine is applicable, the law invokes the theory of *respondeat superior*, even though an employer has attempted to escape liability by employing an independent contractor. There is much variation in the specific application of this theory. In many cases, recovery is limited to physical harm only and presupposes that the subcontractor acted negligently by failing to take suitable precautions.<sup>4</sup> Additionally, there is a conflict of opinion as to whether this doctrine of *respondeat superior* can be invoked by employees of the employer or is only available to third parties (e.g., bystanders, subcontractor employees). In all cases, the employer itself need not have been negligent or otherwise at fault.

Cleanup operations would clearly seem to be inherently dangerous activities because it is an activity which can only be safely carried on by the exercise of special skill and care and which involves a grave risk of serious harm if unskillfully and carelessly done. If the nature of the work is classified as "ultrahazardous"—work which necessarily involves a serious risk of harm to others which cannot be eliminated by the exercise of the utmost care and which is not a matter of common usage—then vicarious liability is not contingent on proof of negligence on the part of the subcontractor but is absolute.

### Proximate Causation

Another key issue in determining liability for third party damages resulting from cleanup actions relates to causation. The law requires a showing of "proximate cause" as a precondition to the attachment of liability.<sup>5</sup> Generators, other responsible parties such as transporters, and their insurers will take the position that once cleanups begin, the chain of causation is interrupted and any "new" damages are the responsibility of the cleanup contractor and involved government agencies. Conversely, in certain instances, a cleanup contractor or government agency may want to implead one or more of the originally responsible parties under the theory that those parties are legally liable for all the adverse consequences associated with the waste site, including those associated with cleanup. The question is one of proximate causation.

The key legal question is whether the cleanup actions are to be considered "intervening causes" which relieve the waste generators, site owners, or other originally responsible parties of liability. Alternatively, these actions can be viewed as the natural and probable consequences of the original wrongful act (i.e., the uncontrolled disposal of hazardous wastes). It is only when causes are totally independent of each other that the nearest in time and space becomes the proximate cause. The law recognizes that a wrongful act can set in motion a chain of events leading to injury. The fact that the actual consequence was one that rarely follows from the particular act or omission does not afford a defense; it is not necessary that the injury should be the usual, necessary, or inevitable result of the negligence for proximate cause to be found.

Natural phenomena (winds, rains) of a usual and ordinary kind are not regarded as independent intervening agencies which will break the chain of causation. A rainstorm somewhat greater than usual is not so totally unforeseeable as to act as a superceding cause.<sup>6</sup>

These issues have been most thoroughly explored in the law with respect to personal injury cases. Where injuries have been aggravated by medical or surgical treatment (i.e., a remedial response), the original tort-feasor may be liable for damages resulting from the treatment itself where the person injured (or a third party) has used reasonable care in selecting the physician or surgeon. The negligence or malpractice of a physician or surgeon, selected with reasonable care, who aggravates or fails to minimize injuries, is regarded as a consequence reasonably to be anticipated. The law regards the wrong of the one who caused the original injury as the proximate cause of the damages and holds him liable.

Of course, negligent selection of a physician—or, analogously, a cleanup contractor—acts as an intervening cause; the original tort-feasor is not generally held liable for the consequences of such negligence.

Thus, a wrongdoer—whether waste generator, transporter, or cleanup contractor—is responsible for the natural and probable consequences of a wrongful act or omission and this rule of law applies both in contract and in tort. However, the application of this rule to the circumstances of particular cases is often difficult and each case will be decided largely on its own specific facts. Normally, the question of "proximate cause" is one of fact to be determined by a jury (or other trier of fact) although in some cases the court may, as a matter of law, instruct the jury that damages are too remote to be considered. Finally, the question of whether resulting damage is direct and proximate does not depend on the anticipation, knowledge, or lack of knowledge of the wrongdoer.

Because cleanup activities have potential third party liabilities, it will be important for cleanup contractors to shift that risk either through insurance or indemnification agreements, if possible.

### SHIFT OF FINANCIAL RESPONSIBILITY FOR LIABILITY CLAIMS

Given the potential liabilities associated with cleanup operations at uncontrolled hazardous waste sites, cleanup contractors have an incentive to reallocate financial responsibility through private agreements. Two types of private agreements are of most relevance: (1) indemnification agreements with the contracting authority (federal, state, or local governments) and with subcontractors, and (2) insurance agreements with insurance companies.

#### Indemnification Agreements

Indemnification operates like insurance and is similarly created by a contract. Commonly, an indemnification clause is used in a contract as a means of reallocating risk; the indemnifier is not in the regular or primary business of underwriting insurance but agrees to compensate the other party for any loss or liability it incurs. This is also known as a hold harmless agreement.

In drafting contracts for investigation or cleanup of uncontrolled hazardous waste sites, government agencies and private contractors can agree to various provisions relating to liability. The options include the following:

- Contractor agrees to indemnify government
- Government agrees to indemnify contractor
- Contractor agrees to obtain insurance

Which option is selected will depend on the procurement procedures in effect and different states are likely to use different procedures.

Federal government procurement regulations have long required contractual language requiring the contractor to procure and maintain insurance for ordinary risks such as workers compensation and occupational disease insurance as required by state law, employer's liability insurance, comprehensive general liability insurance, and automobile liability insurance (1 CFR§1-7.204-5). These requirements were reflected in the contract provisions for WA 82-HO71, the USEPA Hazardous Site Remedial Response RFP contract.

USEPA's Article LI addresses insurance and liability to third persons. It directs the contractor to obtain liability coverage as required by the Agency and allows reasonable costs of insurance as a reimbursable contract expense. Subpart H adds that if required or approved insurance coverage is reduced without the USEPA Contracting Officer's approval, the liability of the government will not be increased as a result.

Subpart E, however, is the crucial section of Article LI. It constitutes a broad indemnification agreement whereby the Government agrees to reimburse the contractor for liability in excess of that compensated by required insurance. It reads as follows:

"The Government will hold harmless and indemnify the Contractor against claims (including expenses of litigation or settle-

ment) by third persons (including employees of the Contractor) for death, bodily injury, or loss of or damage to property arising out of performance of this contract, to the extent that such a claim is not compensated by insurance or otherwise. Any such claim within deductible amounts of the Contractor's insurance will not be covered under this article. Reimbursement for such liabilities to third persons will not cover liabilities for which the Contractor has failed to insure as required or to maintain insurance as approved by the Contracting Officer."

This broad agreement applies even to the claims contractor employees may bring against the cleanup contractor itself—thus placing employees on a par with third parties as defined traditionally. This is particularly good protection in view of the increasing breaches of the exclusive remedy interpretation of workers compensation statutes, discussed earlier. The clause does protect the Government, however, against failure by the contractor to get and maintain required insurance. Deductibles are not covered, nor any losses compensated by insurance or otherwise. This indemnity is analogous to a layer of "excess risk" insurance.

In contrast to the indemnification of the contractor by the federal USEPA, it has been reported that some state governments require cleanup contractors to agree to fully or partial indemnify the state from liability for third party claims.<sup>7</sup> Language such as the following would accomplish that purpose:

"In connection with the services to be furnished hereunder, the Contractor agrees to be responsible for and to indemnify and hold the Government harmless for any recovery of damages resulting from death, personal injury, property damages, or other loss incurred by the Contractor's Agents or employees, or third persons, including within the latter group, Government employees, regardless of whether they are directly or indirectly associated with the performance of services to be rendered pursuant to the Terms of this Contract."

Under such an arrangement, the contractor assumes financial liability for damages the government may be liable for in addition to its own underlying liabilities for damage claims. Thus, financial responsibility for cleanup liabilities can be shifted in this direction as well.

A prime contractor may also have indemnification agreements with its subcontractors, with the burden to indemnify going in either direction. There is an important limit on this, however. Many state and federal statutes (e.g., Federal Employers' Liability Act) expressly invalidate any contract which attempts to exempt an employer from liability for injury negligently inflicted on an employee. According to a number of cases, agreements between employer and employee (or employer and subcontractor) attempting to exonerate the employer from liability for future negligence (whether of himself or of his employees) are void as against public policy.

### Types of Insurance Coverage

Insurance is a contractual agreement whereby an insurer agrees to pay certain amounts to the insured if certain events occur. Businesses typically purchase insurance to protect themselves against the financial impact of: (1) losses directly suffered (e.g., loss of a pesticide plant in a fire), and (2) liability for losses suffered by others (e.g., fire damage to neighboring properties). The latter is termed liability insurance and applies to specific types of liabilities up to specified dollar limits.

Insurance in the hazardous waste context has become very important this past year because of the RCRA financial responsibility regulations. While those regulations do not apply to cleanup activities at uncontrolled hazardous waste sites, the Apr. 16, 1982 regulations (effective July 16, 1982)<sup>8</sup> have had an impact on the market for pollution insurance or environmental impairment liability (EIL) insurance.

Insurance coverage is available in a variety of forms to owners or operators of hazardous waste facilities to cover liability due to

sudden and/or nonsudden accidents involving hazardous substances. Nonsudden refers to gradual pollution such as from boiler or incinerator emissions, contamination of groundwater from leachate, and similar situations. Depending on the specific fact situation, a cleanup contractor may want to procure nonsudden coverage. Sudden coverage is advisable, particularly where explosions or fires or release of fumes or impoundments may occur.

There are several different types of insurance coverage that may be triggered by damage resulting from cleanup operations:

- Comprehensive general liability (CGL) coverage
- Worker's compensation or employer's liability coverage
- Design and construction liability coverage
- Environmental impairment liability (EIL) coverage

Which type of coverage is involved will depend on the specific type of damage and the parties damaged.

### Comprehensive General Liability

Referred to as CGL, this policy form is designed to provide an "all hazards" scope of protection, subject to certain exclusions and conditions specified in the policy form. Nearly all businesses carry this type of insurance. Since 1970, CGL insurance has contained a Pollution Exclusion Clause which excludes coverage for bodily injury or property damage arising out of the:

"discharge, dispersal, release or escape of smoke vapors, soot, fumes, acids, alkalis, toxic chemicals, liquids or gases, waste materials or other irritants, contaminants, or pollutants into or upon land, the atmosphere or any water course or body of water."

This exclusion does not apply, however, if the discharge, dispersal, release or escape is sudden and accidental. Thus, companies with CGL insurance are covered for all risks apart from non-sudden or gradual environmental impairment. This latter exposure is relevant only where the remedial action involves on-site land disposal of wastes with the attendant risks of leachate contamination of groundwater, etc.

### Worker's Compensation Coverage

While discussion of the many different types of state worker's compensation systems is beyond the scope of this paper, one important point must be made: a key premise of worker's compensation has been that in exchange for the benefits of participating in the system, covered workers gave up all other rights against the employer for seeking compensation for injuries. This "exclusive remedy" doctrine was upheld as constitutional in 1917 by the Supreme Court.<sup>9</sup> However, this doctrine is being eroded through a series of court decisions finding employers liable on a number of different theories: dual capacity, manufacturer liability, intentional misconduct, etc. Thus, participation in a worker's compensation program should not necessarily be viewed as adequate protection against employee claims for compensation.

### Employer's Liability Coverage

Employer's liability insurance complements workers compensation protection. There are two situations where employer's liability coverage is commonly used: (1) for employees exempt from workers' compensation, such as agricultural workers, and (2) in states where workers compensation can be accepted or rejected. Only liability for the death of or injury to employees is covered; such a policy does not cover injury to employees of independent contractors or to other third parties. The policy may cover the employer's liability at common law as well as his liability under workmen's compensation acts.

In quite a few cases, the question has arisen as to whether an occupational disease is within the scope of the coverage when the policy does not specifically address this issue. Coverage depends on whether the courts view the occupational disease as an "accident" or not.<sup>10</sup>

### Design and Construction Defect Coverage

Liability policies are commonly issued to contractors insuring them against liability for damages or injuries occurring in connection with the performance of their contracts. This type of coverage is analogous to CGL coverage but does not necessarily provide protection against later claims based on design and construction defects. Court decisions have generally depended on the presence or absence of specific policy provisions dealing with such contingencies.<sup>11</sup>

Recently, construction-defect coverage has been made available to design-build firms to protect them against liability for construction defects.<sup>12</sup> Previously, liability coverage has been available only for design defects, not construction defects. Common policies for design professionals' liability totally exclude construction errors or omissions. Because the construction defects liability coverage is relatively new, it is not clear whether it will be provided for firms doing remedial design and construction work at uncontrolled hazardous waste sites.

About ten companies now offer policies to protect architectural and engineering firms from professional liability claims. This market first opened up in the late 1950s and shows signs of further expansion because of increasing court victories against state statutes of limitation that were enacted in the 1960s to protect design professionals.

### Environmental Impairment Liability

A cleanup contractor may want, or be required, to purchase pollution liability insurance for financial protection against bodily injury, property damage, and environmental impairment resulting from the discharge, dispersal, release, escape, or seepage of toxic substances into the environment. This type of insurance coverage is designed to protect the insured from claims resulting from pollution or environmental damage losses. Typically, policies cover both sudden and nonsudden events.

In order to cover the pollution exclusion clause of CGL coverage, EIL policies provide a very broad definition of environmental damage or gradual pollution. The usefulness of EIL coverage for nonsudden events is vitiated by the fact that currently only "claims made" policies are available. Under this type of policy, coverage is triggered only when claims are made during the policy period. The period coverage may be expanded or restricted somewhat by incorporation (i.e., purchase) of "Discovery Period" or "retroactive Period" provisions. The purpose of claims made coverage is to protect insurers from "trailing" liability for diseases which manifest after lengthy induction and latency periods. Previous types of insurance—called "occurrence-based"—have been held to cover claims based on whether the causal event occurred during the policy period; this coverage is not available for gradual pollution

occurrences at the present time. Eight firms presently offer pollution coverage, and the market is seen as a growing one.

### CONCLUSION

Cleanup operations at uncontrolled hazardous waste sites pose many risks, not the least of which are legal risks of being directly, vicariously, or secondarily liable for the costs of damages resulting either during operations or, in the case of gradual damage, many years later. Legal uncertainties abound. Firms which plan or hope to have "deep pockets" should strive to protect their assets through the purchase of appropriate insurance coverage or the negotiation of protective contract provisions.

### FOOTNOTES

1. Subrogation may be defined as the right of one person to stand in the place of another with respect to legal rights. Conventional subrogation arises through contract. The doctrine of subrogation is universally applied on behalf of a surety (e.g., insurer) who has been compelled to pay on behalf of its principal (e.g., the insured).
2. See, generally, *Survey of State Liability Provisions* (ICF Incorporated, 1982).
3. See Grad *et al.*, *Injuries and Damages From Hazardous Wastes—Analysis and Improvement of Legal Remedies* (1982), especially p. 81-115.
4. See Restatement of Torts, 2d §427.
5. *Corpus Juris Secundum* provides the following definition of proximate cause: "[P]roximate cause is any cause which in natural and continuous sequence, unbroken by any efficient intervening cause, produces the result complained of and without which the result would not have occurred, and from which it ought to have been foreseen or reasonably anticipated by a person of ordinary prudence in the exercise of ordinary care that the injury complained of, or some similar injury, would result therefrom as a natural and probable consequence." 65 C.J.S. pp. 1129-30.
6. See *Southern Pacific Co. v. City of Los Angeles*, 55 P.2d 847; *Ely v. Bottini*, 3 Cal. Rptr. 756.
7. Sanders, "Liability for Remedial Cleanup Failures," *Waste Age*, June, 1982, p. 102-3.
8. See 47 FR 16544 (Apr. 16, 1982).
9. *New York Central Railroad v. White*, 243 U.S. 188 (1917).
10. See *Belleville Enameling and Stamping Co. v. United States Casualty Co.*, 266 Ill. App. 586; *United States Radium Corp. v. Globe Indem. Co.*, 178 A. 271, aff'd 182 A. 626.
11. See *Koch v. Ocean Acci. and Guaranty Corp.*, 230 S.W. 2d 893 (later damages covered); *Berger Bros. Electric Motors v. New Amsterdam Casualty Co.*, 58 N.E. 2d 717 (later damages not covered).
12. See *ENR*, July 1, 1982, p. 88.



# NEGOTIATING SUPERFUND SETTLEMENT AGREEMENTS

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## INTRODUCTION

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, (CERCLA),<sup>1</sup> more popularly known as "Superfund," represents a new approach in environmental law. CERCLA does not provide a statutory framework for the establishment of standards or permits to regulate industry as do most other major pieces of environmental legislation passed in the last decade. Rather, CERCLA provides EPA with broad authority for achieving clean-up at hazardous waste sites and imposing liability for the costs on the responsible parties. Thus, through its liability provisions, the statute provides an incentive for greater diligence and concern in the handling and disposal of hazardous substances as well as incentives for potentially responsible parties to resolve their liabilities for past operations which resulted in environmental contamination through the negotiation of settlement agreements.

Potentially, CERCLA provides a strong arsenal of legal theories for the USEPA to use in its pursuit against parties responsible for environmental contamination. At Superfund sites throughout the country, the USEPA is pursuing its enforcement options, and in many of these cases settlement negotiations are already underway. These negotiations must, of necessity, take place without the benefit of Superfund case law as there has not yet been a full trial of a Superfund case. This lack of precedent makes the negotiation of Superfund settlement agreements particularly difficult.

The following paper outlines the general liability scheme of CERCLA and discusses major issues likely to arise in the course of settlement negotiations. In addition, this paper will also examine how these issues were confronted and resolved in the resolution of one party's liability for the Superfund site in Woburn, Massachusetts.

## LIABILITY PROVISIONS OF CERCLA

Sections 104,<sup>2</sup> 106,<sup>3</sup> and 107<sup>4</sup> of CERCLA provide the underpinnings for USEPA's enforcement scheme.

Section 104(a)(1) provides that the President is authorized to act,<sup>5</sup> consistent with the national contingency plan,<sup>6</sup> whenever:

(A) any hazardous substance<sup>7</sup> is released or there is a substantial threat of such a release into the environment, or

(B) there is a release or substantial threat of release into the environment of any pollutant or contaminant<sup>8</sup> which may present an imminent and substantial danger to the public health or welfare.

The crucial exception to this authority to take action is if the President determines that such action will be done properly by a responsible party. Hence, federal remedial response is predicated on the inability or unwillingness of the responsible parties to act.

Section 106(a) provides that, upon determining that there may be an imminent and substantial endangerment due to an actual or threatened release of a hazardous substance, the President may require the Attorney General to secure such relief as necessary to

abate the danger or threat. The President is also authorized to take other actions, including the issuance of administrative orders, to compel necessary action.

Section 107 sets forth four categories of parties responsible for any incurrence of response costs consistent with the national contingency plan, including all costs of removal or remedial action incurred by the United States Government. Broadly speaking, these categories are:

- Owners and operators of a facility (or other source of release)
- Owners or operators of the facility at the time of disposal
- Generators or any other person who arranged for the disposal or treatment of hazardous substances
- Transporters of hazardous substances to the site at which the release occurred

Section 107(c)(3) of CERCLA allows the United States to seek up to three times the costs incurred by the Fund if a liable party fails, without sufficient cause, to comply with an order issued pursuant to sections 104 or 106 of CERCLA.

With certain limited exceptions, the functions vested by CERCLA in the President were delegated to the Administrator of USEPA by Executive Order 12316 of August 14, 1981.<sup>9</sup>

## INITIATING THE SUPERFUND ENFORCEMENT PROCESS

Consistent with the intent of Section 104, USEPA policy<sup>10</sup> is that USEPA should attempt to secure cleanup by the responsible parties, rather than the Trust Fund established under CERCLA,<sup>11</sup> whenever such clean-up can be accomplished properly and in a timely manner. Therefore, prior to the expenditure of government funds at a Superfund site, notice will generally be sent to responsible parties.<sup>12</sup>

However, that it is the position of USEPA that a notice letter is not a legal pre-condition for a subsequent lawsuit by EPA to seek cost recovery against a responsible party if Fund money is spent.<sup>13</sup> There may be a number of reasons why a notice letter does not issue prior to the expenditure of Fund money. For example, USEPA may be involved in on-going negotiations with a responsible party or there may have been no evidence which linked the responsible party to the site known to USEPA at the time Fund money was spent.

Implicit in the notice letter process is the concept that such a letter will set into motion an opportunity to resolve informally the problems at the site, thereby eliminating the need to initiate court action or to issue a unilateral administrative order; where an agreement is reached prior to litigation, the agreement will be reduced to writing via an administrative order on consent. Hence, in most cases where responsible parties are identified, former legal action at a site will be preceded by a period of time in which informal settlement negotiations will occur. The mere existence, however, of a responsible party will not prevent the agency from moving forward with the expenditure of Fund money or formal legal action if such responsible party is not willing to address the problems at the site in a proper and timely manner.<sup>14</sup>



## ADVANTAGES OF SETTLEMENT

Both the government and the responsible parties have much to gain if the problems at a site can be resolved through negotiations. From the government's perspective, the statutory objective is achieved if a responsible party undertakes the clean-up obligations. Fund money is preserved for those sites which will not be addressed by a responsible party. In addition, because of the intricacies of federal contracting and the CERCLA statutory requirements relative to state participation, it is likely that the site will be cleaned up more quickly if the responsible party agrees to do so voluntarily. Finally, while negotiations themselves can be very resource-intensive for USEPA, resolution of a case through settlement will invariably take much less time and resources than if the case were actually litigated.

There are also numerous advantages to settlement for the responsible party. CERCLA provides USEPA with a broad delegation of authority as to what are appropriate actions for which the government can recover costs. In addition, the potential exists for the recovery of triple the actual costs expended by virtue of the punitive damages section. Further, the potential application of a strict liability standard places a significantly greater burden on the responsible party in actual litigation. A responsible party avoids these problems by settling, and gains the additional benefit of participating in the decisions and final terms relative to the scope of its involvement in the resolution of the problems at the site.

Another concern to a responsible party at a Superfund site is cost; a party considering a settlement must balance the projected costs of a negotiated cleanup against the substantial legal fees necessary to fight, and possibly lose, a law suit. Even if a responsible party thinks his legal defenses to a law suit will prevail in a court of law, it is necessary to take into account the enormous costs of litigating hazardous wastes cases due to the substantial time needed to prepare legal arguments and expert witnesses. The limited number of hazardous waste cases that have actually been litigated to date indicate that such trials can take months.<sup>15</sup>

Finally, a responsible party, particularly in the chemical industry, may find there are public relations advantages to settling. Rather than being portrayed as an irresponsible party that caused a pollution problem and refused to help clean it up, a corporation has the opportunity to be a "good corporate citizen" that volunteers to rectify an environmental problem.

## MAJOR ISSUES IN SETTLEMENT NEGOTIATIONS

### The Woburn, Massachusetts Settlement

On May 25, 1982, USEPA, pursuant to the statutory authority of section 106 of CERCLA, issued an order on consent to the Stauffer Chemical Company for the investigative study, cleanup, and future monitoring of the Superfund site in Woburn, Massachusetts. This site was listed by the Administrator of USEPA as one of the top ten Superfund sites in the country.<sup>16</sup> The Commonwealth of Massachusetts, through its Department of Environmental Quality Engineering (DEQE), participated in the settlement negotiations and was a party to the agreement. The settlement marked the first use of CERCLA's section 106 administrative order authority at a listed Superfund site.

The settlement negotiations at this site presented the regulatory agencies with a number of difficult problems that had to be resolved before the parties could enter into a consent order. Many of the issues confronted are ones likely to arise in the context of most settlement negotiations at other sites. Successful resolution of these issues requires a careful understanding and balance of various USEPA policies relevant to the implementation of CERCLA, the technical needs of the site, the motivations and interests of the negotiating responsible party, and the concerns of the affected community.

### Joint and Several Liability

Joint and several liability is a legal theory which, if applicable in a given fact situation, can result in any one of a number of

responsible parties being held responsible for all of the damages. The issue of joint and several liability only arises where the acts of more than one party produce a single harm.<sup>17</sup>

In a hazardous waste context, a basic example of joint and several liability is the multiple generator situation where a number of companies have shipped barrels of a single type of hazardous waste to a site, little or no evidence exists relative to the amounts of the substance shipped by each company, and all of the barrels leak into and result in the contamination of the groundwater. Under these circumstances, each of the generators may be held responsible on the theory that the harm to the groundwater caused by one of the generators is indistinguishable from the harm caused by any of the others; therefore one, or all, may be held fully liable. The concept is best summarized as follows:

Where the tortious acts of two or more wrongdoers join to produce an indivisible injury, that is, an injury which from its nature cannot be apportioned with reasonable certainty to the individual wrongdoers, all of the wrongdoers will be held jointly and severally liable for the entire damages and the injured party may proceed to judgment against any one separately or against all in one suit.<sup>18</sup>

How joint and several liability will be applied by a court in the Superfund context is not known at this time. While USEPA and the Department of Justice will argue the applicability of joint and several liability where the facts warrant,<sup>19</sup> industry strongly maintains that the theory is not applicable in a CERCLA lawsuit. Actual resolution of the controversy will not occur until the issue has been fully litigated, and even then case law may vary depending on the particular fact situation before the court.

As a practical matter, most successful negotiations will result in some type of apportionment. In most cases there would be little economic incentive for a responsible party to be willing to cooperate with the federal government unless some apportionment of liability is recognized. USEPA's willingness, therefore, to apportion liability in a negotiated agreement where the facts are appropriate should not be viewed as a rejection of the applicability of the joint and several liability theory to the site at hand, but rather a practical recognition that the apportioning of liability is an important aspect of encouraging settlements.

Apportionment of liability was a major issue in the Woburn Consent Order. Stauffer and companies it acquired had manufactured glue at the site; Stauffer was willing to assume responsibility for those wastes generated by the glue manufacturing process. Other wastes found at the site resulted from the manufacturing activities of the other known responsible party. Some of the wastes from all prior operations had been commingled, due to the land development activities of one of the present property owners.

The apportionment issue was resolved as follows: Stauffer agreed to undertake the full investigative study and to participate in the cleanup of Stauffer-generated wastes. After the conclusion of the investigative study, USEPA and the state will determine the proportionate responsibility, pursuant to a formula set forth in the agreement, for the contamination at the site which will then be the basis for apportioning the costs incurred in implementing the investigative study. Stauffer may then choose whatever legal means it deems appropriate to recover those funds it expended on the study beyond its proportionate share. In addition, because the apportionment determination will be made prior to the implementation of the clean-up, Stauffer's participation in the clean-up will be limited to its determined proportionate responsibility.

### Handling Indefinite Commitments by Agreement

A comprehensive settlement agreement requires fully addressing at the outset the scope of the investigative study, the cleanup and subsequent monitoring commitments, and the release provision. However, these commitments are being made at a time when there is frequently little information available to quantify the extent of the problem being addressed or the adequacy of the intended actions.

Because of the difficulties such a situation imposes, a responsible party may only be willing to negotiate its involvement in the investigative study, leaving its cleanup liability for resolution at a later date. Even if USEPA were to be responsive to a proposal for a partial settlement, the negotiating party would obviously not be able to benefit from a release provision relative to its cleanup liability, thereby leaving unresolved a major aspect of its liability and a major motivating factor for entering into negotiations at the outset. In addition, the resolution of the total problem remains unresolved. It seems, therefore, to be in the best interests of the responsible party and USEPA to enter into comprehensive settlements which address all aspects of the site, rather than piece-meal agreements in which only portions of the problem are resolved at a time.

The Woburn agreement provides an illustration of how indefinite commitments were made relative to future actions and expenditures unknown at the time of negotiations. In general, a "checks and balance" system was developed; adequate controls were built into each commitment made by the parties, such that each party had a self-interest in fulfilling its responsibilities. For example, in regard to the investigative study commitments, Stauffer agreed to a phased approach: phase I of the study is specific in its commitments, thereby allowing Stauffer the opportunity to project its costs for this phase of the investigation. Phase II is a more open-ended commitment which provides for additional study as needed pursuant to stated criteria. This second phase provides the flexibility needed to insure that the site is adequately studied.

Following the investigative study, Stauffer will propose a recommended remedial action which EPA and the state may accept or reject; a period of time for negotiation is provided. If accepted, Stauffer is obligated to participate as directed in accordance with its determined proportionate share. If the proposal is rejected, Stauffer has no further obligations under the agreement, now, however, is Stauffer released from liability. Thus, both parties have a strong interest in seeing that an acceptable remedial action is implemented: USEPA wants the site cleaned up; Stauffer wants its release from liability.

### Releases

The release provision is an issue of great concern to a party entering settlement negotiations. Most responsible parties enter negotiations with the expectation that, if the case is successfully resolved through settlement, their potential liability at that site will be ended.

Although the scope of the release will vary with each fact situation, there are certain general principles which the negotiating parties should recognize at the outset:

- The releases run to the settlement of civil claims only; the USEPA cannot settle criminal liability.<sup>20</sup>
- The scope of the release should be commensurate with the scope of the cleanup; a total release should not be granted if the party is not undertaking its total share of the study and cleanup.<sup>21</sup>
- The release should be conditioned upon the timely and satisfactory completion of all of the party's obligations under the agreement.<sup>22</sup>
- USEPA cannot bind other federal agencies. Therefore, USEPA should not attempt to bind the "United States" or waive claims which may be asserted by other federal agencies.<sup>23</sup>
- USEPA should be very careful to protect its future rights against other responsible parties who are not participating in the settlement.<sup>24</sup>

Stauffer's release provision was conditioned on Stauffer fulfilling all the commitments made in the Consent Order. Specifically, one of the issues raised was the statutes under which Stauffer's release would be effective. USEPA's position was that the releases would correspond to the jurisdictional authority of the consent order. Therefore, since the consent order was issued pursuant to CERCLA and Section 7003 of the Resource Conservation and

Recovery Act (RCRA),<sup>25</sup> and since Stauffer agreed to assume full responsibility for its own wastes, the release stated that fulfillment of Stauffer's commitments in the agreement constituted full satisfaction of USEPA's civil claims pursuant to CERCLA and RCRA. To protect the rights of the parties entering into the consent order against other, nonsettling parties, a provision was inserted in the agreement, consistent with Massachusetts law, clearly stating that the release to Stauffer in no way affects the liability of any other responsible party.

### Citizen Participation

The presence of a hazardous waste site can cause significant fear and concern in the local community. Particularly frightening for the affected citizens are the unknown health impacts such a site may have. It is, therefore, important to provide as much knowledge as possible to the local community and keep the citizenry informed regarding the activities occurring at the site.

The National Contingency Plan recognizes the affected locality by stating that response personnel should be "sensitive to local community concerns in accordance with applicable guidance."<sup>26</sup> This includes the establishment of an effective community relations program at each site. The goal of this program is to set forth the various ways in which the agency in charge of the response plans will communicate with the citizens through public forums, press releases, and meetings.

When the negotiations with Stauffer began in Woburn, a local Citizens Advisory Committee (CAC) was already in existence and was meeting twice a month to participate in and track developments relative to the hazardous waste site. State and federal regulatory officials attended most meetings of the CAC. During the lengthy period of time the group had been meeting, the members developed a comprehensive understanding of all issues surrounding the site.

Throughout the course of the negotiations with Stauffer the regulatory agencies made a substantial effort to keep the CAC informed and to seek their input. Stauffer was very cooperative in this endeavor. For example, prior to presenting an investigative study proposal, representatives of Stauffer attended a meeting of the CAC to hear the specific concerns of the citizens. They also attended other meetings of the CAC to present their study proposal and to accept comments. The citizens brought forward a very reasoned approach and the company was willing to listen to and address their concerns. By maintaining regular communication, the actual issuance of the consent order was not viewed by the community with suspicion; rather, it was viewed as an opportunity to finally see the problems of the site addressed.

### Federal-State Relations

Most states have their own panoply of environmental laws which are often similar to their federal counterparts, although few states have a statute with the breadth of authority as CERCLA. Therefore, in addition to its federal liability, a responsible party may face the risk of being the recipient of a state enforcement action pursuant to state law. For this reason, it is in the best interests of the responsible party to attempt to resolve its liability with both USEPA and the state in which the hazardous waste site is located. USEPA encourages the involvement of the state in the negotiation of these agreements.

The Woburn negotiations were marked by a close working relationship between USEPA and the state's DEQE. The result was the issuance of one document to which EPA, the state, and Stauffer were parties. This resulted in the most efficient use of the agencies' resources. In addition, the fact that there is only one document offers greater assurance that consistency and uniformity in the implementation of the consent order will result.

### CONCLUSIONS

Resolving problems at Superfund sites through negotiated agreements is a difficult and complex undertaking. However, there

are significant benefits to both the responsible parties and the USEPA by settling these cases. Upon entering negotiations, the parties should be willing to consider all aspects of the issues in controversy and to develop fair and reasonable solutions that accommodate each other's concerns without sacrificing the technical needs of the site. In addition, the concerns of the local community must be addressed in a meaningful way. Approached this way, significant headway will be made in the clean-up of the nation's many hazardous waste sites.

## REFERENCES

1. 42 U.S.C. §9601 *et seq.*
2. 43 U.S.C. §9604.
3. 42 U.S.A. §9606.
4. 42 U.S.C. §9607.
5. Such acts include authorization "to remove or arrange for the removal of, and provide for remedial action relating to such hazardous substance, pollutant or contaminant at any time...or take any other response measure consistent with the national contingency plan which the President deems necessary to protect the public health or welfare or the environment..."
6. Section 105, 42 U.S.C. §9605, requires the publication of a National Hazardous Substance Response Plan to establish procedures and standards for responding to releases of hazardous substances, pollutants, and contaminants. This document was recently published at 47 Fed. Reg. 31180 (July 16, 1982).
7. Hazardous substances are defined in section 101(14) of CERCLA, 42 U.S.C. §9601(14).
8. "Pollutant or contaminant" is defined in section 104(a)(2) of cercla, 42 U.S.C. §9604(a)(2).
9. "Responses to Environmental Damage," Executive Order, No. 12316, 46 Fed. Reg. 42237 (August 20, 1981).
10. February 23, 1982 Memorandum from Christopher J. Capper, Acting Assistant Administrator for Office of Solid Waste and Emergency Response, and William A. Sullivan, Jr., Enforcement Counsel, to the Regional Administrators, entitled: "Hazardous Waste Compliance and Enforcement Program Guidance," at 5.
11. 42 U.S.C. §9631 establishes a 1.6 billion dollar Hazardous Substance Response Trust Fund for federally-financed responses at designated sites.
12. *supra*, note 10 at 5.
13. November 25, 1981 Memorandum from Sullivan and Capper to Regional Administrators, et al., entitled: "Coordination of Superfund Enforcement and Fund-Financed Clean-Up Activities," at 10.
14. *supra*, note 10 at 7.
15. *e.g.*, *Village of Wilsonville, Ill. v. SCA Service, Inc.*, No. 52885 (Ill. Sup. Ct., May 22, 1981), 2 CHEMICAL and RADIATION WASTE LIT. REP. 288 (1981)—length of trial was over 100 days; *State Department of Environmental Protection v. Ventron Corp.*, Nos. A-1395-79,-1432-79,-1446-79,-1545-79 (N.J. Super. Ct. App. Div., Dec. 9, 1981)—length of trial was 55 days.
16. On October 23, 1981, the Administrator of USEPA released an interim national priority list of 115 sites, pursuant to Section 105(8)(B) of CERCLA, 42 U.S.C. §9605(8)(B).
17. 74 Am. Jur. 2d §62.
18. *Landers v. East Texas Salt Water Disposal Co.*, 248 S.W. 2d 731 (Tex. S. Ct., 1952) at 734.
19. There is significant legislative history in CERCLA which provides a basis for USEPA's position that joint and several liability was deleted from the legislation in order to leave the issue to resolution by the courts pursuant to the common law. For example, see: Senator Randolph, Chairman, Senate Environmental and Public Works Committee and Floor Sponsor, Congressional Record, November 24, 1980 (S. 14964); Congressman Florio, Chairman of House Subcommittee on Transportation of House Commerce Committee and Floor Sponsor, Congressional Record, December 3, 1980 (H. 11787).
20. December 18, 1981 Memorandum from Sullivan to Regional Counsels, et al., entitled: "Guidance on Hazardous Waste Site Settlement Negotiations," at 4.
21. *id.*
22. *id.*
23. *id.*
24. *id.*
25. 42 U.S.C. §6973.
26. 47 Fed. Reg. 31214, (July 16, 1982).

# **HAZARDOUS WASTE AND THE REAL ESTATE TRANSACTION: A PRACTICAL AND THEORETICAL GUIDE FOR THE TECHNICAL CONSULTANT, REAL ESTATE ATTORNEY, BUSINESS PERSON, INVESTOR, OR ANYONE INVOLVED IN BUYING AND SELLING LAND**

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## **INTRODUCTION**

Statutory schemes and common law tort liability expose past and present owners of land containing hazardous waste materials to enormous potential liability. Consequently, all those who deal with real property transactions need to be apprised of the nature and scope of the problem. A combined technical and legal approach addresses these questions: Where does the law place liability? What are the "red flags" of a potential problem? How, and at what cost, is technical evaluation of a site made? What types of remedial action are available? How will a problem affect the value and uses of the land? Is insurance a solution?

## **SOURCES OF LIABILITY: THE SCOPE OF THE PROBLEM**

Like termites or zoning laws, hazardous wastes are a fact of life which may profoundly affect the value of real property and expose parties involved in a real estate transaction of significant liability. As a result, all those who deal with real property transactions must be apprised of the nature and scope of the problem.

Legal liability for hazardous waste is imposed upon past and present owners of real property by federal statutes and regulations, state statutes and regulations and common law principles. The major sources of federal liability are found in (1) the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 ("Superfund"), 42 USC Sec. 9601 *et seq.*, which deals with cleanup and containment of hazardous wastes which have been disposed of accidentally; (2) the Resource Conservation and Recovery Act ("RCRA"), 42 USC Sec. 6901 *et seq.*, which regulates the generation, treatment, storage, disposal and transportation of hazardous wastes; and (3) the Toxic Wastes Substances Control Act ("TOSCA"), 15 USC Sec. 2601 *et seq.*, which regulated management of toxic substances, including PCBs (which until recently were commonly used in the oil contained in transformers and capacitors).

States have enacted legislation and promulgated regulations specifically directed at hazardous wastes. For example, Massachusetts has enacted the Waste Management Act, M.G.L.c. 21C, and the Massachusetts Hazardous Waste Regulations of July 1, 1982, 310 CMR 30.000. Other state laws directed at protecting various parts of the environment such as waterways or wetlands, may also effectively impose liability for improper handling of hazardous wastes. By federal statute, whenever federal and state laws diverge, the stricter standard controls.

Common law theories, including nuisance, trespass, negligence, and strict liability may be the basis of public or private actions for damages or injunctive relief from harm stemming from hazardous wastes.

The sources of liability are extensively discussed elsewhere. The salient point for the purposes of this article is that statutory liability for damages and remedial efforts rests with both past and present owners and operators of facilities where there has been improper generation, treatment, storage or transportation of hazardous wastes. Statutory liability is joint and several.

Thus, whether an enforcement agency compels a cleanup action, or seeks reimbursement for costs of an agency conducted effort, it may seek satisfaction from past and present owners and operators in any order it deems appropriate. The agency need not exhaust the resources of one party before proceeding against the other. While not absolutely clear, it also appears likely that any liability predicted on common law theories would also be joint and several, so that an injured plaintiff could proceed against any one of a number of possible defendants.

Cleanup efforts can be enormously expensive. For example, typical costs for excavating, transporting and disposing of contaminated soil are on the order of \$200 per ton. Other remedial measures, such as capping, may provide a less expensive alternative in some instances, but the cost is still great. Remedial measures are usually developed in consultation with enforcement authorities; in some cases they may be sufficiently broad as to include relocation of parties endangered by contamination.

Joint and several liability means that while it is easy to buy a hazardous waste problem, it is extremely difficult to sell one: a conveyance out does not relieve the seller of potential liability. This being so, sale of contaminated land to an irresponsible buyer who improperly disposes of waste can result in liability that will come back to haunt the seller. The chain of liability can be extended back as far as the first party responsible for introducing the hazardous waste onto the land.

At the present time, hazardous waste insurance is of only limited utility to property owners and does not eliminate or significantly reduce the problem of potential liability. Policies typically cover off-site accidental personal and property damage. On-site prophylactic cleanup may be covered upon the insurer's prior written consent when there is an imminent threat of a pollution incident. Exclusions are numerous. Bodily injury, property damage or environmental damage which is expected or intended from the standpoint of the insured is not covered; nor are damages resulting directly or indirectly from failure to comply with all applicable laws. Premiums are very high, and before a policy is written, an extensive site inspection is conducted.

Thus, the nature of potential liability forces all prudent parties to a real estate transaction to concern themselves with hazardous wastes and their proper management. Knowledge, together with a well-conceived plan for compliance with the law, is the best strategy for avoiding or mitigating liability. The technical expert is crucial to achievement of this end.

## **THE ROLE OF THE ENVIRONMENTAL PROFESSIONAL**

An environmental professional provides necessary information to the parties involved in the real property transaction based upon his or her training and experience, and the results of a site-specific environmental liability assessment. The purpose of professional consultation is to avoid the need for guarding against or negotiating around the unknown. On industrial/commercial sites the unknown can be potentially hazardous contamination of air, build-

ings, soil, groundwater or surface water. Other potentially restrictive conditions are proximity to wetlands, coastal zones or drinking water supplies. It is also possible that the site is already subject to regulatory compliance. The information gathered and interpreted by the technical professional provides a greater level of confidence for making decisions and adopting negotiating postures in the transaction. Technical information can provide the basis for specific language in legal documents, and can help define the characteristics of an industrial/commercial site that require detailed legal attention. Most important, the informed party gains assurance that "surprises" do not exist, and consequently he or she can proceed without fear of the unknown.

## THE TECHNICAL APPROACH TO ENVIRONMENTAL LIABILITY ASSESSMENT

A phased or incremental approach to technical assessment of environmental liability provides the greatest amount of specifically directed information in the most cost effective manner. The phased approach consists of gathering and interpreting information in discrete steps. The information from one step helps determine whether the next phase is necessary, and forms the basis for planning and executing the next phase of investigation in an efficient manner.

### Phase I

The first phase of a technical environmental liability assessment may not, at the outset, require the services of an environmental professional. An informed party engaged in a real property transaction can start the process by running through a check list such as that set forth in Table 1. In this table, typical, but by no means comprehensive, examples of conditions commonly encountered on active or inactive commercial/industrial properties which are "red flags" of potential environmental liability are provided. Should these or similar conditions exist at the site under consideration, it is prudent to seek professional assessment of the condition. These conditions may not indicate actual liability, but still may require consideration as the sale is negotiated. The better the site conditions are defined, the better informed the negotiators will be.

If no "red flags" are evident, it should not be taken as an indication that the site is problem-free. A site may be covered with tall grass and bordered by sturdy trees; rabbits may bound across it, and hawks may wheel overhead, but it is not impossible that several decades' worth of industrial waste sludge lies buried below the grass and wildflowers. In the scene just described, past disposal practices and the resulting liability may only come to light through investigation of the site history. Detailed review of the site history is the most important part of the initial site assessment process, and should be among the first activities pursued.

"Red flags" of environmental liability are not peculiar to sites of heavy industrial activity. The careful party should go through the initial check list for seemingly benign structures, such as apartment houses that might have old transformers in the basement, or a dwelling where overly liberal use of a pesticide like chlordane may have resulted in potentially hazardous accumulations.

The alert party should be aware of site conditions, and site history. He or she should be suspicious. Review of noted site conditions with an environmental professional at this point may serve to confirm his or her own observations and conclusions, or to raise further relevant questions.

### Phase II and Beyond

Beyond the do-it-yourself check-list phase of environmental assessment, a technical specialist is required. The technical consultant is best suited by training and experience to employ appropriate investigative techniques, interpret data, and formulate recommendations which will most effectively satisfy the client's needs. The environmental professional's involvement starts with a thorough discussion of the client's requirements so that an appropriate level of investigation can be designed and executed. The level of effort is governed primarily by the value of the transaction and magnitude of potential liability.

**Table 1.**  
**Check List of "Red Flags" of Potential Environmental Liability.**

This list provides a summary of conditions sometimes found on active or inactive industrial/commercial property. These conditions can be "red flags" or strong indications of potential liability.

- Odorous or visible particulate air emissions
- Use, storage or transport of known hazardous materials
- Waste disposal areas: this includes disposal of all types of waste in end dumped piles, lagoons, barrels, swamps, wells, etc.
- Leaking pipes, electrical gear, containers, tanks, barrels, or stockpiles
- "Stories" of accidents, spills, explosions or dumping; complaints by neighbors
- Fouled surface water standing on-site or flowing off-site
- Odorous or turbid water from a well
- Odorous or stained soil
- Proximity to flood plains, wetlands, coastal zones, or surface-water bodies
- Proximity to an existing or planned public or private drinking water supply; this includes surface water and groundwater sources
- Regulatory compliance status

Generally, the technical investigation starts with gathering and reviewing all available pertinent information about the site history and conditions, including published information regarding soil, groundwater, surface water, and air quality conditions, aerial photographs, past engineering and construction reports, and oral information from the client and client's attorney. Published company histories which chronicle activities at the site may be particularly helpful.

Armed with this information, the technical consultant undertakes a first-hand inspection of the property under consideration. The investigator, a trained and experienced observer, uses a detailed check-list approach somewhat similar to that undertaken in Phase I. This directed reconnaissance phase may also include preliminary air, soil, groundwater, surface water or materials sampling. Further analyses may be ordered based on the likelihood of the presence of particular constituents.

Based on analysis and interpretation of the information gained from review of existing information and the site reconnaissance, the technical consultant determines whether further investigation is necessary, and if so, what activities should be pursued. A review of case histories that are representative of varying potential liability and transaction values is most instructive of what may lie beyond the do-it-yourself check-list and initial technical reconnaissance.

## CASE HISTORIES

The following case histories represent orders of magnitude differences in liability, value of transaction, and cost of investigation. The first case history involves a straightforward low-level investigation of a site undertaken at the outset of a sales transaction. The second case history describes a "late-in-the-game" investigation which was undertaken too late to prevent significant losses. The last case history demonstrates the severe penalties of not having undertaken an environmental assessment prior to sale of the property.

### Case History 1

The first case history involves the assessment of a 200 acre quarry and bituminous concrete plant on behalf of a potential purchaser. The purchaser's attorney provided site history information, aerial photographs and appropriate details on the proposed use of the site as they influenced the extent and nature of environmental liability assessment. Public agencies were contacted for information on existing or planned downgradient drinking water supplies. Further topographic, geologic and hydrologic information was obtained to determine the most likely conduits for potential off-site migration of contaminants.

An on-site inspection was conducted that consisted of a thorough on-foot traverse of the entire site in the company of the quarry manager. In this manner, the environmental professional

made a first-hand inspection of the land, surface water bodies, buildings, equipment, and processes while he interviewed a long-time employee. The plant manager was able to explain the current operations and past practices. He could also recall past problems and complaints. The reconnaissance and interview provided: (1) a confirmation and an augmentation of the site history, (2) an inventory of past and present operations, (3) an inventory of hazardous materials handling, use and disposal practices, (4) waste handling and disposal practices, (5) indication of gross air and surface water quality, (6) areas of potential concern, and (7) a basis for recommendations of further action.

By discussing the findings of the reconnaissance, the buyer's attorney and the technical consultant decided that it would be prudent to analyze the groundwater from an on-site well that is used for process water. The analysis was recommended because several thousand cubic yards of waste bituminous-concrete were piled on-site. Fuel oil, asphalt and solvents were also stored and used. Although there were no indications of spills or disposal of hazardous constituents evident at the surface, testing the groundwater provided an inexpensive way to investigate for past spills or disposal. Limited analyses for solvent and petroleum constituents did not reveal any contamination.

This level of technical investigation did not indicate any source of environmental liability. Based on the technical investigation, the attorney was able to include specific contingencies in the purchase and sale agreement. The cost of the investigation, including meetings, analytical fees and a formal written report, was \$2,000.

### Case History 2

This case history illustrates the possible penalties for not seeking qualified assistance in a timely manner. In this case the client was engaged in the purchase of a 60 year old, 15,000 ft<sup>2</sup> electroplating facility that was to be converted to office and warehouse space. The client had pursued standard purchasing procedures, including a structural inspection of the building. A purchase and sale agreement had been signed and a \$20,000 deposit had been made. Within one week of the scheduled closing, an alert employee of the purchaser called attention to the presence of sludge in the crawl space under the building. A technical consultant was hastily retained and a fast paced investigation was undertaken.

In order to determine whether or not the sludge constituted a hazardous waste, the following steps were taken: sampling and analyzing the process materials and waste, determining the regulatory compliance status of the current waste disposal practices, sampling and analyzing (by EP toxicity and mass analysis methods) the sludge and underlying soil for cyanide and selected metals included in the primary drinking water standards, and sampling and analyzing the groundwater from an on-site well that was used for process water. Also, the reactivity of the sludge was analyzed by subjecting the sludge to acid and analyzing for the release of hydrogen cyanide gas.

The analyses revealed that the leachate from the EP toxicity tests on the sludge were enriched in the metals analyzed for, but that the concentrations in all cases were below the hazardous waste characterization criteria. The sludge did, however, satisfy the hazardous waste characterization criteria of reactivity by virtue of its evolving hydrogen cyanide gas in the presence of acid. The well water did not manifest any enrichment of the constituents analyzed for.

The results of this "late-in-the-game" investigation were complex, and the resulting costs were high. The purchaser backed out of the transaction and risked loss of the \$20,000 deposit because there was no pertinent contingency clause in the purchase and sale agreement. The owner subsequently contracted for removal and disposal of the sludge for an approximate cost of \$50,000. The fee for the investigation, analyses, and report was approximately \$5,000.

### Case History 3

This case history is unusual because of the magnitude of costs involved. It is worth discussion, however, because it emphasizes the need for investigating and confronting environmental liabilities before conveying land. The site is a 30-acre grassy field bordered by trees. This large open expanse on a river bank in a residential/industrial neighborhood appeared to be an attractive site for a municipal park, and the owner donated the land to a municipal agency for that purpose. Shortly after donation of the property, construction of the park facilities began.

Construction of the park included earthwork for foot paths, roads, and parking areas. Trenches were excavated for utilities and sewage, and several structures were erected. During the excavation and earthwork, waste disposal trenches were breached that contained sludges, slag, minor amounts of off-specification pesticides and other industrial wastes. Construction workers complained of various systems while they were working on the site.

The municipal agency retained a consultant to investigate. His limited investigation revealed the severe conditions at the site which included, among other characteristics, the presence and migration of various toxic constituents of the buried sludges. He also identified pesticides in the waste. As a result of this investigation, the former owner purchased the site back for an amount equal to the cost of park construction, which by that time amounted to approximately \$3,000,000.

The owner then hired its own consultant and undertook an extensive site investigation. The investigation started with a detailed reconstruction of the site history from interviews with employees of companies which had disposed of waste on site, published and unpublished documents, and aerial photographs. Review of the aerial photographs was critical. Their coverage ranged back to the 1940s when the site was a picturesque asparagus farm. Photographs from ensuing years allowed compilation of waste-type and waste-pit location maps. Initial review of existing information and waste-history mapping formed the basis for planning, and gave specific direction to the field investigation.

The field investigation included installation of 26 groundwater monitoring wells, 46 gas driven groundwater samplers, 3 real time groundwater level sensors and transmitting gear, drilling and logging 74 borings, and excavating and logging 26 test pits. Fifty soil or waste samples and approximately 200 groundwater samples were chemically analyzed. In addition, grain size analyses, scanning electron microscopy, ultimate analyses and other analytical work was performed. Reduction and interpretation of the field data produced a thorough site characterization, and quantified the amount of potentially hazardous constituents migrating off-site.

The recommended remedial action included securing the site from unauthorized trespass, periodic groundwater sampling and analysis for selected parameters, and covering and protecting some exposed waste. One barrel of pesticide encountered during test pit excavation was excavated and disposed of at a secure landfill. This relatively low level of remedial action was acceptable to the regulatory agencies because the amounts of potentially hazardous constituents that were moving off-site were extremely small. The off-site migration was less than the discharges from neighboring industries. Further remedial action may entail excavation and incineration of the sludges. The pits would then be back-filled with material of predictable bearing capacity.

The direct costs to the owner to date are on the order of 4.7 million dollars, including the \$3,000,000 repurchase price and \$1,700,000 for site characterization and initial remedial action. It does not include the costs of potential liability associated with continued ownership or the costs of bad publicity.

Hindsight indicates that an initial environmental assessment carried out prior to any transfer activities would have saved at least the \$3,000,000 repurchase price.



## ROLE DEPENDENT APPLICATIONS

Let us consider how each party to a real estate transaction may wish to incorporate consideration of hazardous wastes into his or her individual strategy.

The prospective buyer's position is the most straightforward. Not yet committed to purchase, the buyer will want a thorough assessment of the nature and extent of any hazardous waste problem which may exist, for such a problem could significantly alter, or even defeat, the contemplated use of the property. Accordingly, the buyer will want to include a hazardous waste inspection clause into the purchase and sale agreement if there are threshold indications that trouble may exist. In addition to the "red flags" discussed above, the buyer should be alert to an Order of Condition or other problem markers which may appear in a routine title run-down.

The inspection clause should take into account who is to bear the cost of inspection, who will select the technical consultant and have access to the results, and what options will be available to the parties when the tests are completed and the results have been evaluated. The buyer will want to have the option of terminating or renegotiating the deal when he or she has evaluated the information gained in light of the planned use of the property.

While the buyer will want to have as much information as possible about the potential risks associated with the site, and may be motivated to develop a "worst-case" picture in order to gain negotiating strength, the buyer must nevertheless see that the investigation is conducted with discretion. In the event that a deal is consummated, the buyer will have to live with the site evaluation. Moreover, accurate rather than sensational information is essential to making a sound business judgment about the economic effects of the hazardous waste problem upon the usefulness of the property. Objective, fair investigation thus will serve the buyer best.

The seller's position is more complex. Because potential statutory (and perhaps common law) liability is joint and several, the seller cannot realistically hope to sell the problem to a naive buyer and walk away from it forever. It is always possible that a problem may develop in the future, and the seller, as a former owner, will be answerable to enforcement agencies or other third parties. In some situations, for example if the buyer is a large corporation with extensive assets, and the seller is planning to dissolve its interests or move out of the United States, the seller may find it an acceptable risk to convey with little attention to solution of a hazardous waste problem. In most cases, however, a seller cannot hope to evade a hazardous waste problem and possible liability by transferring the property to an unsuspecting buyer.

Indeed, in most instances the liability imposed by the state and federal statutes forces the seller to be very particular about the buyer's identity. For example, if the site is contaminated, the seller must be wary of conveying to a buyer who is undercapitalized, or notoriously irresponsible, or both, because it is possible that such a party will aggravate any problems, but be financially unable to assume the consequential liability.

The fact of the statutory liability scheme, taken together with the unlikelihood that the question of hazardous wastes will simply be overlooked by a sophisticated buyer in a sizable transaction, may lead the seller to initiate hazardous waste evaluation prior to the sale. By taking the initiative, the seller can select the technical consultants, actively participate in designing the investigation strategy, and have complete access to test results. Based on evaluation of test results, the seller can consider remedial measures and incorporate them into a marketing strategy. If the seller possesses and controls information about the problems which exist, it will be easier to resist possible unfair "scare" tactics which a potential buyer may try to use.

A seller is in the best position to give an honest and complete site history to consultants. With good information, the consultants can

efficiently select locations for sampling, and do laboratory tests only for relevant materials. Guess work, dead ends, and surprises are reduced; better results are achieved at less cost.

Based on test results, remedial measure and possible uses for the parcel can be coordinated. For example, a portion of a lot might be able to accommodate significant new construction only at prohibitive cost because of the necessity of removing contaminated soil. The same problem area, however, might be capped or otherwise contained and used for parking or as open space at far less cost. The seller, together with technical advisors, may be able to devise and market to the prospective buyer plans which are both remedial and developmental. If worked out in consultation with enforcement agencies, such plans may serve as a basis to limit future liability.

Thus, the informed seller has the advantage of being able to acknowledge the existence of a problem, and suggest ways of coping with it. Because such a seller knows what remedial measures are available and what they are likely to cost, the hazardous waste problem becomes simply another fact about the property. It is no longer a club in the hands of a potential buyer who has commissioned an inspection, and quotes astronomical figures based on a radical "worst-case" remedial scheme in order to win the advantage in price negotiation.

The prepared seller also gains time. The seller can make hazardous waste information readily available to a serious potential buyer rather than wait for the buyer to initiate tests. Moreover, the knowledgeable seller can negotiate the purchase and sale agreement and final sales contract to meet his or her own needs. It may be possible to bargain over who should undertake remedial work, what standards of performance must be observed in remedial work, and so forth. The seller may reserve the right to terminate dealings with a buyer who proves to be financially weak or otherwise irresponsible. The seller may wish to prevent inappropriate uses of portions of the land by restrictive covenants, exception deeds or other mechanisms designed to isolate problem areas. Armed with knowledge of the site, the seller may be able to limit future liability through indemnification agreements.

If nothing else, the seller may hope to limit future liability by preserving a "picture" of the status of the site. Test results create a record of which wastes were associated with the seller's use and reduce the likelihood that the seller will be charged with responsibility for wastes he or she did not generate.

The potential mortgagee must also be concerned with the possibility of hazardous waste contamination. A prudent mortgagee will incorporate threshold inquiry into its routine questionnaire for borrowers. Obviously, property subject to an enormous cleanup liability is not good loan security. The mortgagee must also be wary of becoming an "owner" subject to full liability in the event that it becomes a mortgagee in possession. To reduce risk, lender's counsel may wish to demand a hazardous waste opinion from borrower's counsel.

Contractors who bid on work connected with renovation of a site or its adaptation to a new use must also exercise caution. In the course of construction activities a contractor may become "transporter" of hazardous wastes subject to appropriate licensing and management procedures, and will be exposed to liability if it fails to comply with those standards.

A real estate broker must consider the possibility that deliberate concealment of information about hazardous waste problems could be construed as a misrepresentation of material facts.

Counsel for any of the parties to a real estate transaction should, of course, be prepared to provide in depth advice regarding the client's particular situation. Indeed, prudent counsel will routinely open inquiry on the subject of hazardous wastes with his or her client before participating in the conveyance of land. Routine inquiry, plus consultation with technical experts should it be indicated, may save a deal, and prevent economic disaster.