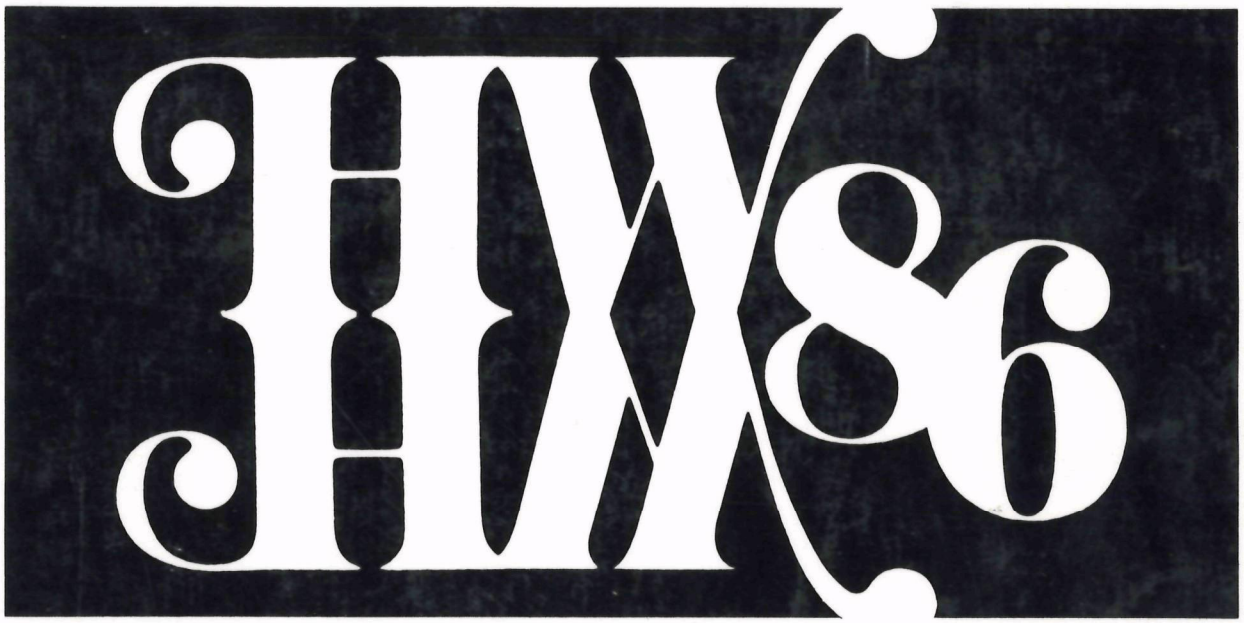
Hazardous Wastes



and Hazardous Materials

Formerly Hazardous Wastes and Environmental Emergencies

Site Remediation • On-Site Treatment • Risk Assessment
• Contaminated Groundwater Control • Permitting • Monitoring • Incineration
• Underground Leak Detection • Fixation • Cost/Economics

PROCEEDINGS OF THE
NATIONAL CONFERENCE ON

HAZARDOUS WASTES AND HAZARDOUS MATERIALS

Site Remediation • On-Site Treatment • Risk Assessment • Contaminated Groundwater Control • Permitting • Monitoring • Incineration • Underground Leak Detection • Fixation • Cost/Economics

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National Lime Association

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The National Conference and Exhibition on Hazardous Wastes and Hazardous Materials: Site Remediation • On-Site Treatment • Risk Assessment • Contaminated Groundwater Control • Permitting • Monitoring • Incineration • Underground Leak Detection • Fixation • Cost/Economics required dedication and talent from many individuals and commitment from a number of organizations. We gratefully express our thanks and appreciation to the following conference affiliates for all their contributions to a successful conference.

U.S. Environmental Protection Agency
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Agency for Toxic Substances and Disease Registry
Portland Cement Association
National Environmental Health Association
National Lime Association

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Preface

The RCRA Amendments of 1984 (the new RCRA) have radically changed hazardous waste management throughout the country and considerably improved the control of hazardous wastes. Whereas it was estimated that the old RCRA provisions would cost the regulated industry between $1 billion and $3 billion per year, the new RCRA amendments, when completely implemented and fully in effect, may cost as high as $20 billion per year.

The new RCRA includes 58 congressionally mandated statutory deadlines that go into effect by 1987 or early 1988. Congress wrote, into the statute, provisions that are detailed and directive. The bill does not wait for EPA to write regulations or issue guidance; provisions go into effect automatically on prescribed dates.

Land Application Management

The law establishes a hierarchy of management practices. There is a very strong presumption against the disposal of hazardous wastes on the land and a very strong preference for treatment and destruction of hazardous wastes.

Site Remediation

The bill provides EPA with "corrective action authority" at existing hazardous waste facilities which are very similar to the enforcement authorities under Superfund. The bill also closes the gap in the existing program by expanding the regulated community.

Leaking Underground Tanks

A major new subtitle of the legislation dealing with leaking underground storage tanks went into effect on May 8, 1985. This section probably affects two to five million underground tanks across the U.S. including tanks storing petroleum products and gasoline as well as very complex tank storage systems storing hazardous chemicals.

As of May 8, 1985, there is a ban on new tanks that are not designed to prevent releases due to corrosion or structural failure. An estimated 100,000 new tanks must meet these requirements. By May 1986, a nationwide registration program will require state notification of the age, size, type and location of the tank, as well as its uses.

Burning Hazardous Wastes

The provision concerning burning hazardous wastes and the blending of hazardous wastes into fuel requires notification of the fuel user that they are receiving hazardous waste. Some cannot be burned in residential and commercial boilers.

RCRA Permit Program

The bill makes permitting of a hazardous waste facility far more difficult than it has been. Permit applicants must now submit exposure information on the potential for public exposure to hazardous substances from landfills and surface impoundments. This exposure information will be used to write new permit conditions. EPA has the authority to write any permit condition necessary to protect human health in the environment, independent of whether or not regulations are in place for that purpose.

Congress has also set some very strict deadlines for the issuance of permits. By November 1985, all applications for land disposal facility permits must have been submitted to EPA or an authorized state. Final determination on these land disposal permit applications must be made by November 1988.

By November 1986, all incinerator applications must be submitted and EPA must make final decision on these by November 1989. All remaining applications have to be in by November 1988, and EPA must make a decision on these by November 1992.

Small Quantity Generators

The first small quantity generator (SQG) requirement went into effect in August 1985. Any SQG that ships wastes offsite must do so by using the Uniform National Manifest Form. Effective in April 1986, SQGs must send their wastes to fully regulated hazardous waste facilities. These requirements will have a tremendous impact on small generators; costs for their waste management will be considerably greater.

Other RCRA Amendments

There are many other provisions of the new RCRA. There is a set of provisions that deal with non-hazardous solid waste and small quantity generator wastes disposed of in landfills and surface impoundments. The bill also provides for federal enforcement of the requirements for lagoons. There are a series of waste minimization requirements for generators to certify that they are doing everything economically feasible to reduce the amount of wastes generated. There are requirements for listing additional hazardous wastes. Delisting of wastes is much more difficult and complex under the new bill. New tests for ascertaining toxicity are included in the new RCRA.

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Equipment for Data Collection at Hazardous Waste Sites—An Overview for Environmental Management Professionals

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INTRODUCTION

Industry and government are in the process of cleaning up America. Industry is becoming increasingly concerned with questions of environmental liability. Regulatory agencies are actively protecting public health and the environment. Future liability can be minimized by the use of environmental audits. Present liabilities, however, must be thoroughly understood in order to develop cost-effective liability management plans that meet the goals and objectives set for environmental cleanup.

This understanding generally is gained through environmental investigations at individual sites or facilities. CERCLA, RCRA and other statutes require regulatory compliance. In some cases, the buyer or seller of a property may run into unforeseen environmental liabilities. Some states have recently passed legislation that requires environmental conditions be defined and problems investigated prior to real estate transactions. In cases of corporate mergers or other processes where ownership of a facility changes, new owners or sellers may be held accountable for the environmental liability at a facility. While the government agencies ensure that cleanups are effective, industries which finance the cleanups can encounter huge expenditures. Businessmen and legal professionals handling environmental affairs stay close to technical events, carefully monitoring costs and cleanup strategies. These environmental management professionals are sometimes unfamiliar with techniques for data collection and the creative use of equipment used for data collection activities. This paper is directed toward business, legal and environmental management professionals seeking knowledge of various types of equipment available for environmental data collection. An understanding of the use of this equipment will help in the development of cleanup strategies for a proper, complete and cost-effective cleanup.

While each site investigation is unique and requires a certain degree of site-specific modification, there is a logical sequence of events that is followed in order to collect the desired information. While the purpose of this paper is to discuss the field equipment available to perform the investigation, it is important to understand the sequence of events in order to define the situations in which the equipment should be used.

The first phase of the investigation should be devoted to collecting enough background data on site conditions as possible. While there may not be much data available on actual site conditions, there is usually a certain amount of regional information available. Data can be obtained from local health departments, state and federal environmental and geological agencies and universities. This information is important in defining the general environmental setting of the site.

The second phase of the investigation should be devoted to understanding the source of the potential contamination. At this point, certain indirect techniques such as surface geophysical instruments or portable analytical instruments are very useful. They can be used to define the possible horizontal extent of the source, detect buried objects and initially determine the general types of contaminants. Soil borings and soil sampling techniques also are used to collect actual waste or contaminated soils for chemical analysis to further define the characteristics of the contaminant.

Once it has been determined that there is a contaminant source, the question arises as to whether the contaminants are migrating. This usually requires more extensive sampling of surface water, sediment, soils and groundwater. Normally, groundwater is an important issue and becomes the focus of further investigations. Wells usually are installed adjacent to the source to determine the subsurface conditions as well as to detect any immediate migration. Proper soil sampling and well drilling techniques are essential to the adequate completion of this task. Downhole investigative equipment becomes useful in defining subsurface geology. Water levels are measured in wells to define flow directions. As the scope of the potential problem develops, additional wells may be required at further distances to define long-term migration pathways.

The final component is the data evaluation and risk analysis. This phase is as important as the field effort. The data must be properly organized and the actual risks correctly established in order to arrive at a cost-effective remedial solution.

SURFACE GEOPHYSICAL TECHNIQUES

Surface Geophysical Techniques have been used for years to give indications of subsurface rock and soil conditions. These techniques vary greatly in theory and technology, resulting in very specific conditions where their use is warranted. In recent years, these techniques have been applied successfully to investigations at hazardous waste sites.

Surface geophysical surveys are performed as indirect techniques to provide information to investigators in advance of direct sursurface investigatory techniques such as test pitting, test borings or well drilling activities. At hazardous waste sites, these techniques generally are used in three different ways. First, some methods can be employed to provide information about subsurface conditions such as depth to bedrock, depth to the water table or thickness of certain soil units. Next, some methods can be employed to examine the migration of contamination in groundwater. Finally, some techniques can be utilized to search for buried metal, specifically containerized wastes such as drums or tanks which could act as ongoing sources of contamination.

Magnetometry

Magnetrometry has been used successfully in the past to identify trends in regional geology. More recently, it has been applied to search for buried metals at hazardous waste sites. The proton precession magnetometer measures the total intensity of the earth's magnetic field at one point. The earth's magnetic field, which is fairly constant over a small site area, is affected by ferrous metals. Ferrous metal objects create their own magnetic fields which change the intensity of the magnetic field over a site. Using the magnetometer, these ferrous metal objects can be located.

Several key steps in a magnetometry survey must be observed to obtain quality data. First, all measurements must be referenced to a grid system. Second, a point free of magnetic inferences must be located, known as a reference point. The magnetic field of the earth changes throughout the day. These changes are known as diurnal changes. A full record of diurnal changes must be kept for corrections of the intensity measurements taken at grid points during the day. Often it is necessary to have a base station magnetometer dedicated to this task. These measurements also can guard against the collection of poor quality data such as that collected during magnetic storms.

Once correct data are plotted, it is sometimes possible to model the depth, mass, shape and angle of orientation of an object. Theoretically, that degree of data interpretation is possible only under ideal conditions.

Variations on this technique are possible. Gradiometers can be used to measure the point changes in a field, instruments can be hand held, sensors can be placed on staffs and instruments may be towed along traverse lines for continuous readings.

Limitations are critical to this type of survey. Magnetic induction caused by alternating current in power lines will affect readings. In this case, or in the case of extensive surface metal interference, surveys should not be performed. Additionally, it is preferable to have a map of shallow buried surface metal from a metal detection survey to aid in data interpretation. With these precautions in mind, magnetometry can be a useful tool to indicate the presence of buried ferromagnetic objects.

Metal Detention

Metal detention has been used for years to locate pipes and other buried metal objects. It relies on the effects of a conductive metal object or a radio signal which it broadcasts and receives. The effective depth of penetration is only a few feet, but it can be used very accurately to locate shallow buried metal targets.

Electromagnetic Conductivity

Electromagnetic conductance, generally referred to as "EM," also responds to the conductive properties of materials. EM, also called terrain conductivity, usually is used to indicate the presence of a conductive contaminant plume.

EM does not require ground contact. The EM transmitter coil radiates an electromagnetic field which induces eddy currents in the earth. Each of these eddy current loops, in turn, generates a secondary electromagnetic field which is intercepted by the receiver coil. An output voltage fis produced which is linearly related to subsurface conductivity.

Continuous survey instruments are available with transmitter and receiver fixed in the same instrument, but their use is limited to shallow depths. Instruments are available with separate transmitter and receiver coils for deeper surveys. Initially, several EM soundings are made by varying the intercoil spacing at each location. After a determination of background conductivity and appropriate intercoil spacing, EM profiles can be completed along previously surveyed transverse lines.

Electrical Resistivity

Electrical Resistivity (ER) allows a measurement of subsurface resistivities in soil, rock and groundwater. Application of the method requires that an electrical current be introduced into the ground through a pair of surface electrodes. The resulting potential field is measured at the surface between a second pair of electrodes. The electrodes can be arranged into several different configurations.

Initially, several ER soundings can be made to establish subsurface background conditions and determine the appropriate electrode ("A") spacing for the ER profile lines. The sounding data will be collected by establishing a central reference point and varying the spacing between the current and potential electrodes.

ER profiles then can be assembled to indicate areas of low resistance, indicating the presence of potential contaminant plumes. Areas of low resistivity also could indicate perched water zones or low lying topographic areas.

ER is best used, as with most geophysical techniques, in conjunction with other indirect testing. Soundings always should be done to determine the depth to the water table and depth of any clay layers that might be present. ER is a quick and inexpensive technique generally available for site investigations.

Ground Penetrating Radar

Ground penetrating radar (GPR) is a reflection technique in which high frequency radio waves are radiated downward into the subsurface and then reflected back to a receiving antenna. Variations in the return signals occur when subsurface materials have different electrical properties. An interface between two layers having sufficiently different electrical properties will show up in the radar profile. The effectiveness of GPR can be limited by the penetration depth of the radio waves. The effective penetration is highly site specific and dependent upon subsurface boundaries, water content and clay content.

The radar system electronics usually are mounted in a van, with the antenna towed behind. An impulse radar transmits electromagnetic pulses of short duration into the ground from a broadband antenna. Pulses from the antenna are reflected from various interfaces in the subsurface and then are picked up by the receiver section of the antenna.

Unfortunately, GPR systems are very expensive and usually are used to locate contaminant plumes which are lighter than water.

PORTABLE ANALYTICAL INSTRUMENTS

Hazardous materials emergency response has spawned the design of many field analytical instruments due to the added safety requirements inherent in the performance of such dangerous work. Many of these instruments have been readily adapted for use in site investigations to collect data which can be used in the assessment of a site. These instruments can be used either to gather data directly or as a screening technique to indicate where further investigation is needed. This section of the paper discusses the more common types of instruments which can be used to gather field data and their uses and limitations.

Organic Vapor Analyzers

Two general types of instruments are currently used to analyze for the presence of volatile organic compounds. Both detectors rely on the ionization potential of the organic compounds. Flame ionization detectors (FID) rely on a flame which burns compounds to break chemical bonds to release energy. Photoionization detectors (PIDs) rely on ultraviolet light which is capable of breaking the chemical bonds to release energy. The major difference in their application is that methane and some very light or-

ganic compounds cannot be ionized by ultraviolet light. As a result, PIDs can be used only if methane concentration is not a concern. If qualification of methane is a concern, a flame ionization detector should be used to measure its presence.

PIDs, such as the HNU portable photoionizer, and FIDs, such as the Century Systems (Foxboro) Organic Vapor Analyzer (OVA), have been used in hazardous waste site investigations to survey for the presence of organic compounds. Since compound separation and identification are not possible, total concentrations are measured as the benzene response equivalent. When used in the survey mode, the OVA is an efficient and accurate indicator of total organic compound concentrations on a continuous sampling basis with a response time of one to two seconds. If instantaneous information is required on the presence of methane and non-methane hydrocarbons, both instruments can be used in tandem. An example of this application is a methane-vinylchloride gas mixture which can be common at landfill vents.

In cases where compounds identification or quantification is required, portable gas chromatographs can be used. The Model 128 OVA is a portable FID gas chromatograph. The OVA has an injection port which enables a sample to be injected from the air intake line or by a syringe. As an initial approach to sample evaluation, this technique can quantify the amount of volative organics in a particular sample. This technique is useful when screening soil or water samples to select screen placement or selecting worst case samples for laboratory analyses. This type of field screening can lead to significant savings. If a gas chromatograph (GC) column is present, separation of each of the individual components in a mixture is possible for identification and quantification. The OVA provides data in the 1 ppm concentration range.

Low ppb concentrations can be measured with a Photovac portable PID gas chromatograph. Several Photovac models currently are available. The most advanced is the model 10S70 which has two columns, is fully programmable, has a 100-compound memory with computer peak search and integration and an interface to allow communications with a home-base computer. This type of instrument can separate non-methane organic compounds, identify them and perform integration to provide accurate concentrations. When used with prepared standards and laboratory analytical checks, the Photovac can provide confident analytical analysis on-site in a matter of minutes without the expense of an on-site laboratory.

Applications of Portable Analytical Instruments

Portable analytical instruments typically are employed in several different approaches during site investigations. One approach is an investigation of the lateral of extent of shallow volatile organic soil contamination. This is commonly done by opening a hole in the ground with a slam-bar or other tool and inserting the probe of a survey instrument to measure the concentration of total organics. If measurements are referenced to a grid, they can provide an indication of areas to be sampled for analytical analyses or remediation.

Another common use is to screen samples taken during an investigation. To prevent costly analyses of every sample, only certain samples are sent to the laboratory based on the sample screening. A small amount of sample is placed in a VOA vial and heated to volatilize the organics into the air, or "headspace," in the vial. An aliquot of air is removed by a syringe and injected into a GC column for analysis. This technique can also be used to assist site geologists in deciding the depths at which to finish wells designed to monitor for volatile organic contamination.

The photovac is gaining widespread use as a quantitative analytical tool to monitor drilling discharge water to prevent releases of contaminants into the environment.

Portable units to scan for concentrations of trace metals are expensive and relatively insensitive. They can be useful for sites with widespread metals contamination in the 100 ppm and up range. The Colombia X-Met 700 portable x-ray fluorescence (XRF) spectrophotometer recently has been used successfully for this application. Although it is expensive, the portable XRF currently is gaining acceptance as a field analytical tool.

Other direct-reading instruments which could be adapted from safety-oriented tasks to portable analytical data gathering tools include scintillometers, mercury vapor analyzers and Hydrogen Sulfide indicators.

In addition to safety related instrumentation, some field analytical tools have been adapted from the laboratory and have been around for some years. They include pH meters, conductivity meters, specific ion probes for the measurement of dissolved metals and colorimetric test kits for indicator parameters such as chlorides and COD.

The advantages of using these techniques are time and cost savings. Field analyses provide data rapidly and allow data to be factored into an investigation while work is still taking place. Plans can be developed concurrently for further investigation. The number of field analyses need not be limited in these situations. A limited number of samples can be selected and analyzed by the laboratory for confirmation of contamination, saving expensive laboratory time and reducing lab costs. Scheduling and costs are crucial on any project but are paramount at sites requiring hydrogeologic investigations or soil investigation and excavation projects.

SUBSURFACE SAMPLING EQUIPMENT

A large portion of the effort devoted to any site investigation should be toward understanding the geologic and hydrologic properties of the soils or rock, the extent of soil contamination and the potential for contaminant migration through the unsaturated zones. Since most hazardous waste site investigations involve surface or near surface disposal of liquid and solid materials, one of the primary questions that needs to be answered is how much of the material remains in the soil and how much continues to leach. Source investigations involve the combined application of surface geophysics and direct soil sampling.

Additionally, contaminant migration potentials within the unsaturated zone and upper water table are important issues to be addressed. This determination requires the collection and analysis of subsurface soil and rock samples. Many methods are available for advancing boreholes to obtain samples or details of strata; the selection of a method is dependent on the extent of potential contamination, the complexity of the site geologic conditions and the risk of contaminant migration. The principal methods in use are: hand augers, power augers and rotary core drilling methods.

Augers

The auger technique is useful as a tool to collect preliminary samples, to use with an OVA, HNU or Photovac in a soil gas survey or to collect near surface waste samples. At least six types of light portable augers are available for sampling soft to stiff rolls.

Hand augers may be used by one or two people. The hole is advanced by pressing down on the cross bar as the tool is rotated. Once the auger is full or has collected sufficient material, it is brought back to the surface and the soil is removed. The most commonly used augers are the post hole, the helical and the spiral augers.

Hand augering usage is commonly limited to 3 to 7 ft. In tills or clays that contain gravels or cobbles, hand augering may be impossible. In uncemented sands or gravels, it will not be possible to advance the hole below the water table since the hole will continually collapse. Only samples of very limited size can be obtained from the hole.

In addition to collecting shallow subsoil samples, hand augers also are used to create small diameter holes for a soil gas survey. The holes are installed based on a grid system and the probe of an OVA, HNU or Photovac is inserted into the hole. A sample of the gas is collected and analyzed. This technique is a useful initial method to define the extent of soil contamination by volatile organic compounds.

Because hand augers are limited by soil conditions, depth of penetration, quantity of sample, size of borehole and thickness of the unsaturated zone, they usually are confined to preliminary surveys intended to generally define the limits of the contamination.

Power Augers

The most common power augering procedures used at hazardous waste site investigations are the continuous flight solid stem and hollow stem augers. Another type of augering technique is the bucket auger. This procedure uses open-topped cylinders with base plates which have one or two slots reinforced with cutting teeth which break up the soil and allow it to enter the bucket as it is rotated. However, because of the limited depth of penetration and the expense involved with operating a bucket auger rig, it is rarely used.

Solid stem augers drill much deeper holes with fewer problems. However, this technique presents a serious problem when subsurface soil samples are required. To obtain the sample, the auger string must be pulled from the borehole. Unless the soils are stiff clays or silts above the water table, the borehole is likely to collapse and any sample obtained would not be representative of the stratum.

Hollow stem augers consist of 3- to 6-in. diameter pipe with continuous flights attached to the outside. Auger tailings are removed from the hole by traveling up the flights and emerging at the surface. When samples of the soil in advance of the augers are required, the drilling is stopped and a sampling device is inserted into the pipe. The device is gently lowered to the bottom of the hole and then either driven or pressed into the soil ahead of the augers. Hollow stem augers allow drilling and sampling below the water table, the acquisition of samples without pulling the drill stem and the collection of "undisturbed" samples.

Auger rigs are mounted on four wheel drive trucks and all terrain vehicles, allowing access to most locations. Auger rigs will not drill through rock and certain cobbly or till soils. Augers usually are restricted to 200 or 250 ft in depth and still require casing if the hole is to remain after auger removal.

Rotary Core Drilling

The most common use of rotary drilling in site investigations is to obtain intact samples of rock. To do this, a "core-barrel" fitted with a "core-bit" at its lower end is rotated and grinds away an annulus of rock. The stick of rock in the center of the annulus passes up into the core-barrel and is subsequently removed from the borehole when the core-barrel is full. The length of core drilled before it becomes necessary to remove and empty the core-barrel is termed a "run."

In its simplest form, the core-barrel consists of a single tube with an abrasive lower edge which is rotated against the rock while fluid is passed under pressure. However, most rock drilling in the United States utilized the double tube swivel type core-barrel. The importance of this tool is that it contains an inner barrel connected to the outer tube at the top via a swivel which allows the inner barrel to remain stationary while the outer barrel is rotated. The rock core "rides up" into the inner barrel.

Double tube rock core barrels normally obtain a core between 5 and 10 ft long. Rock cores should be at least 2 1/8 in. diameter or larger. In soft to moderately hard rock, cores 12 in. in diameter or larger can be taken. A core barrel that collects a 2 1/8-in. diameter rock core will produce a 3-in. borehole.

Deep rock coring can be expedited with the use of the "wireline" technique. A wireline can produce rock cores without the removal of drill rods on the outside core barrel. The inside core barrel is retrievable as a separate unit with the use of a method cable, or "wireline." An empty barrel can be sent down on a messenger to continue coring. This type of technique saves time and money for deep continuous coring operations.

Core barrels should be held horizontally while the cores are extracted onto a rigid surface. The core should be properly tagged and then placed in a core-box. Wooden spacer blocks should indicate the top and bottom of each run.

Soil Sampling Devices

The primary purpose of soil augering is to collect subsurface samples for visual examination and chemical and physical tests. In unconsolidated material capable of being drilled with an auger, an important component of any investigation should be the collection of soil samples ahead of the drill bit. Hollow stem augers are the most common drilling technique, but soil samples also can be collected ahead of drilling while using hydraulic rotary methods.

A large number of samplers are available, most adapted from geotechnical or soil survey investigations. However, the most common device used in conjunction with hollow stem augering is the split spoon sampler. In this device, the sampler barrel is split longitudinally into two halves. The device is lowered into the inner space of the hollow stem auger and driven into the soil by repeated blows of a 140 lb hammer falling through 30 in. During driving, the longitudinal halves are held together by the shoe and head which are screwed into each other. The split barrel allows easy examination and extraction of soil samples.

Soil obtained with the split barrel sampler can be subject to a wide variety of field and laboratory tests. Samples can be field screened with an OVA to determine presence of volatile organic compounds. Soil should be logged by describing its texture, color, grain size distribution, moisture content and odor. If the split spoon has been properly decontaminated before sampling, soil can be obtained for chemical analysis.

Occasionally, large diameter "undisturbed" soil samples are required for complex physical tests such as hydraulic conductivity determinations. Shelby or push tube samplers often are used to obtain undisturbed samples of medium to stiff consistency cohesive soils. The sampler is pressed into the soil. Care should be taken because the sampler can be damaged, either by buckling or blunting or tearing the cutting edge, when driven into very stiff, hard or stony soils. Undisturbed samples of soft or loose soils must be taken with a piston sampler. Undisturbed samples containing much gravel or soft rock must be obtained with a Denison sampler.

SURFACE WATER/SEDIMENT SAMPLING

One of the primary waste migration pathways is via surface runoff to rivers, streams and lakes. The contaminant may move as a dissolved constituent in the runoff or attached to entrained soil particles. One of the most cost-effective means of determining the extent of waste migration is to sample surface water and sediment.

Surface Water Sampling Techniques

Surface water sampling locations are selected on the basis of their probability for showing contaminants migrating from the site. Prior to sampling, the surface water drainage in and around the site must be characterized using all available background maps, topographic maps, serial photographs, river basin surveys and other sources.

Either grab or composite samples may be collected. Grab samples are collected at one particular point and at one time. Flow or time-weighted composited samples are composed of more than one specific aliquot collected at various sampling sites and/or at different points in time. Because of the unknown safety risks, as well as the changes in chemical nature of the sample that may occur through compositing, samples containing hazardous materials at significant concentrations shall not be composited.

If it is necessary to enter the water to obtain the sample, it should be done carefully to leave the bottom sediments undisturbed. If the water is moving, a grab sample should be obtained by pointing the open end of the container into the direction of the flow. An attempt should be made to obtain the sample in the middle of the stream and at mid-depth.

The choice of a particular sampling device is dependent upon the size of the water body, the purpose of the sample and the types and concentrations of wastes anticipated to be in the water body. The types of samplers available include open tube, pond sampler, manual hand pump, weighted bottle sampler, kemmerer sampler and extended bottle sampler. Of these, the pond sampler and weighted bottle are used most often.

The pond or dip sampler consists of a container attached to the end of a long pole by an adjustable clamp. The pole can be of any non-reactive materials such as wood, plastic or metal. The sample is collected in a jar or beaker made of stainless steel, glass or non-reactive plastic. Preferably, a disposable beaker which can be replaced at each station should be used.

The weighted bottle sampler consists of a glass bottle, a weight sinker, a bottle stopper and a line that is used to open the bottle and to lower and raise the sampler during sampling. The sampler can be either fabricated or purchased. This sampler is used to take discrete samples at predetermined intervals. The pond sampler can be used to develop composite samples from a single location by collecting individual samples at regular intervals.

Sediment Sampling Techniques

Sediment samples are valuable for locating pollutants of low water solubility and high soil binding affinity. Heavy metals and high molecular-weight halogenated hydrocarbons are examples of contaminant groups which might be found in greater concentrations in sediment. A background sediment sample should be obtained from sediments upstream from the suspected source for comparison. This is especially important if contamination with heavy metals is suspected, because they occur naturally.

Very simple techniques usually are employed for sediment sampling. Most samples will be grab samples from one particular locations although, for preliminary studies, several locations may be composited to reduce the analytical requirements. Suggested techniques include:

- In small, low-flowing streams or near the shore of a pond or lake, the sample container (typically an 8-ounce wide-mouth glass jar) may be used to scoop up the sediments.
- To obtain sediments from larger streams or farther from the shore of a pond or lake, a Teflon beaker attached to a telescoping aluminum pole by means of a clamp may be used to dredge sediments.
- To obtain sediments from rivers or in deeper lakes and ponds, a spring-loaded sediment dredge or benthic sampler may be used by lowering the sampler to the appropriate depth with a rope. The sediments thus obtained are then placed into the sample container.

DOWNHOLE TECHNIQUES

Geophysical borehole logging has been used for oil, coal and mineral exploration for years. Recently, these techniques have gained widespread acceptance in the performance of hydrogeologic investigations. There are many different techniques available. Lithologic logging can be used to measure properties of the rock or soil in a borehole or well. Hydrologic logging can be used to measure the properties of the fluids in a borehole. Downhole television also can be used to examine downhole conditions. A review of these techniques and their applications is presented below.

Lithologic Logging

Lithologic logging is used to measure the properties of downhole soils and rock. As with all logging techniques, it is first advisable to log at least one hole by physical examination of either split spoon samples from soils or rock core samples for bedrock. Rock core samples are more useful than chips because fracture occurrence and widths (which are important conduits of groundwater flow in bedrock) can be determined. Once lithology of at least one hole is known, the information can be correlated to other holes.

The simplest of the lithologic techniques is caliper logging. The caliper tool measures the diameter of a rock borehole using three spring loaded prongs. As the tool is pulled up the hole, the prongs spread out indicating the width of the borehole. Results ared recorded electrically at the surface. The caliper method indicates the relative hardness of rock units. Caliper logging also can indicate fracture location and occurrence. Caliper logging can be the best tool to examine the presence of bedding plane fractures.

Spontaneous Potential Logging

Spontaneous potential logging is one form of electric logging. It serves to measure the natural electrical potential that develops between the formation and the borehole fluids. This logging technique must be performed in an open borehole filled with fluid. The logging device consists of a surface electrode and a borehole electrode with a voltmeter to measure potential.

Generally, SP logs are read in terms of positive and negative deflections from an arbitrary base line which might correlate either with permeable or impermeable zones. Information regarding zones of higher permeability will indicate likely contaminant pathways that may require further investigation. The rate at which the particular logging tool is lowered into the borehole is another important criterion in the data evaluation. The rate should be sufficient to detail specifics of the geology and possibly detect isolated zones of contamination or likely contaminant pathways.

Resistivity Logging

Resistivity logging is another electric logging technique. Two types of resistivity logging techniques are commonly employed in downhole methods. The single point resistance log is the simplest form of electric log. In this method, a single electrode is lowered into the hole and the return path for the current flow is furnished by the ground electrode. The single point resistance log measures the total resistance of earth materials.

The second type of resistivity logging involves measurements taken in the borehole in a similar manner as surface resistivities investigations. In this system, four electrodes are commonly employed, two for emitting current (I) and two for potential measurement (P). A number of different electrode configurations can be used in resistivity logging to provide specific information. The short normal spacing indicates the resistivity of the zone close to the borehole where the drilling fluid might be an influence. The long normal spacing has more distance between the electrodes and thus measures the resistivity further away from the borehole, presumably beyond the influence of the drilling fluid. Both configurations, short and long-normal, measure a greater radius of influence than the single point resistance.

A third configuration involving lateral devices utilizes widely spaced electrodes for measuring zones that are far from the borehole. Because of the wide spacings, lateral devices will not detect thin beds of different resistivity. Boundaries of formations having different resistivities are located most readily with short electrode spacing, whereas information on fluids (e.g., contaminated groundwater) in permeable formations can be obtained best with long spacings.

Density Logging Techniques

Many downhole techniques are available to measure the density of rock units. Natural gamma ray logging is perhaps the most common. Natural gamma logging measures the quantity of gamma rays naturally emitted by radioisotopes contained in clay minerals. The higher the clay content of a rock, the more gamma rays will be emitted. This information is useful in indicating the permeability of rock units, since lower permeability units generally contain more clay size particles.

Other techniques which can be used to indicate density are high resistivity density, gamma-gamma density and neutron logging. As with natural gamma ray logging, these techniques can be run in cased boreholes. In other words, if the geology at a well needs to be investigated and no records exist, a cased hole can be logged to gather qualitative information. Natural gamma ray logging can be especially useful to locate the depth and thicknesses of bentonite seals on grout packs in monitor wells.

Vertical Seismic Profiling

Recently, some success has been met utilizing vertical seismic profiling, or "cross-hole seismic." This technique utilizes an array of detectors set in a borehole to produce a three-dimensional image of subsurface structures such as fractures. A seismic source is used on the surface at some distance from the borehole to create the seismic movement measured by the detectors. Although this technique is still under investigation, it shows promise for hydrogeologic investigation in the area of the development of three-dimensional data.

Hydrologic Logging Techniques

The two most common hydrologic borehole logging techniques are fluid conductivity and temperature logging. These open borehole techniques examine the properties of fluids within a borehole and can provide important information on the natural circulation of fluids in a borehole or the presence of contamination.

These two probes are commonly available together and can be run as a hydrologic suite. Fluid conductivity logs provide a continuous record of the conductivity or resistivity of fluid in the borehole, which may be related to the conductivity of fluids in the adjacent formation. A temperature log made simultaneously with a fluid conductivity log allows the most accurate conversion to specific conductance and also may identify contaminated or more permeable zones in the formation.

Fluid conditions in the boreholes should stabilize prior to implementing this technique. The longer the period of time between the drilling of the borehole and the logging of the hole, the more accurate the results will be. Hydrologic logging can detect geothermal gradients in groundwater in holes on the order of 100 ft thick. Fractures contributing to groundwater movement sometimes can be noted by changes in the geothermal gradient. Changes in temperature or conductivity also may be an indication of contamination.

Downhole Television

Downhole television has been utilized successfully to gather in-situ information on boreholes and wells in several groundwater monitoring programs. Borehole television surveys are a viable alternative to other downhole instruments in the subsurface investigation stages of a groundwater monitoring program.

Miniature borehole television cameras, developed for use in the examination of nuclear reactor cores, have been modified for use in borehole investigations. The lens attachments are capable of looking sideward or downward and include built-in lighting assemblies.

The in situ characterization of fractures that can provide pathways for contaminant migration is critical in some investigations. Borehole television inspection can provide information on the frequency, size and orientation of these fractures. Vertical correlations of rock cores in areas where voids are present (i.e., deep mining or karst topography) also can be simplified by this technique. Borehole television can be used to check monitoring well integrity. Casing inspections are especially useful for construction inspections when construction details are not known. Well screens may be inspected in place to determine if rusting has enlarged the screen openings or if screens have been damaged during emplacement or well development operations. This information may be invaluable in the decision to decommission a well. This technique is quick, inexpensive and creates a permanent record for potential court cases.

Packer Assemblies

Downhole packers were developed for in situ measurements of permeability in geotechnical investigations such as dam building where data are critical. The packer assembly consists of two sets of packers, upper and lower, separated by a perforated pipe. Each packer is surrounded by a rubber seal which is fastened to the assembly. Packers are inflated with compressed air from the surface to seal against the sides of the borehole. Particular zones then can be isolated for testing.

For in situ permeability testing, water is pumped in at a low and constant pressure, creating a constant artificial head. Operating pressures are stabilized with a gate valve until they remain constant. Pressures then are checked with a pressure gauge and recorded for later use in permeability calculations. Each zone is tested for a defined period of time, and the amount of water received by the zone is recorded with a standard water meter.

Another recent development is the insertion of electric or bladder pumps inside the assembly to remove water from the borehole. A particular zone can be isolated and tested with a portable GC for identification of zones carrying volatile organic contamination. Screens then can be set at optional levels for the study of groundwater contaminant migration.

SPECIAL EQUIPMENT

Equipment which was not discussed in this manuscript includes air sampling equipment. Generally, air sampling programs are highly specific. Particulates such as asbestos can be collected on filters by high volume air samplers, while organics can be collected in packed tubes for thermal desorption by the use of low

volume air samples. Air investigations generally include the use of continuously reading portable meteorologic stations.

Air sampling technology recently has been extended to plume tracking through the analyses of soil gas. Tubes are placed in the ground, usually for several days. Organic compounds which volatilize from groundwater or soil travel upward over time in the unsaturated zone of the soil and collect a trace levels in the tubes. The tubes then are removed, thermally desorbed and analyzed for volatile organics. The technique is not yet accepted as a standard methodology, but has been useful in many cases and currently is gaining wide acceptance.

Groundwater pumps continue to be refined, especially dedicated systems. These systems include small diameter electric submersible pumps and bladder pumps. Materials used in the pumps are being researched. Many bladder pumps currently available for purchase are built almost completely of Teflon.

Technological developments continue in the area of continuous measurement devices for groundwater levels in monitor wells. These devices range from single well units with solid-state memories to full-scale 16-channel devices. Some multi-channel devices can be operated up to one mile away from a well, making them useful for aquifer tests. Some actually have built-in computers, disk drives, monitors and printers and can analyze aquifer test data, keep records on each well and even generate reports.

CONCLUSIONS

The general structure of an investigation requires an analysis of data gaps, particularly with regard to source definition, pathway examination and assessment of potential for contaminant migration. Cost and time constraints involved in collecting certain types of data can be balanced against the usefulness of the results. For instance, it sometimes may be less expensive to install additional wells than to use a costly indirect geophysical technique.

Investigations generally rely on indirect investigatory techniques to start, followed by necessary confirmation steps. Specifically, a technique such as magnetometry can be used to search for buried containerized wastes, but this generally is confirmed through test pitting and subsurface waste analyses. It is important to note, however, that the limitations inherent in some techniques may preclude their use in certain situations. A knowledge of these limitations is critical to cost-effective investigations and proper cleanup strategies.

Knowledge of indirect measurement techniques and field analytical equipment is critical to the collection of proper data and the control of costs. Innovative technologies constantly are being considered for their usefulness in these investigations. Use of this type of equipment to paint a complete picture of site conditions can help the environmental management professional reduce long-term liability and provide useful data for risk assessments and feasibility studies. We hope that we have provided a basic overview of the equipment, its limitations and its usefulness to environmental site investigations.

A Statistician's View of Groundwater Monitoring

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ABSTRACT

Owners and operators of hazardous waste facilities are required to monitor the groundwater around the hazardous waste facility and perform prescribed statistical tests on the resulting data to detect the existence, if any, of groundwater contamination. The statistical test prescribed by the U.S. EPA, which is referred to as Cochran's Approximation to the Behran's-Fisher Student's t-test, has received increasing criticism as being inappropriate and resulting in the allegation of groundwater contamination when, in fact, contamination did not occur. In addition, its specified application requires the existence of a well that clearly monitors groundwater upgradient of the site. The U.S. EPA recognized these problems. In publication of its regulations for owners and operators of permitted waste facilities, the U.S. EPA indicates the admissibility of statistical procedures alternate to the Student's t-test.

The inadequacy of the Student's t-test is in part due to the lack of recognition that background groundwater quality varies both spatially and temporally. This paper describes a statistical model appropriate for describing spatially and temporally varying background water quality. An alternate statistical test procedure for assessing groundwater contamination as a deviation from this background model is proposed. Use of this test procedure permits the owner/operator to control the risk of "false positive" test results to a small specified probability. Thus, the risk of unfairly being required to conduct an expensive groundwater quality assessment program is controlled while assuring protection against groundwater degradation.

CURRENT GROUNDWATER MONITORING PROCEDURE

A sampling program to determine whether a particular hazardous waste facility is contaminating groundwater should be designed so that any contribution from the particular facility can be distinguished from other sources. These other sources, which may be both anthropogenic and natural, provide what is loosely referred to as the background. The design of a sampling program to distinguish the contribution of the site of interest from the background is complicated by temporal and spatial variations in the background.

Temporal variations in groundwater may, in part, be explained by recharge rates which are weather related. Spatial variations among wells may be due to a variety of reasons. Some of this variability may be reduced by ensuring that the wells monitoring the aquifer beneath a particular waste disposal site are located relatively close together and drilled to the same depth. Nevertheless, spatial variations may occur even if there is no contribution from the site being monitored. The variations might be expected to be horizontal gradients across the site.

The Behrens-Fisher Student's t-test recommended by the U.S. EPA for monitoring the groundwater near possible sources of contamination[1,2] has increasingly become the topic of critical reviews.[3,4,5] The U.S. EPA procedure is based on establishment of a background level before the disposal facility is put into operation and is, therefore, insensitive to spatial and temporal variations in the background. It can be used, however, if variations in the background levels are taken into account.

Considering the hypothetical situation in which measurements of groundwater quality are obtained without sampling or measurement error, the sample variance of upgradient well measurements, S_B^2, reflects only real background variations. Measurements on subsamples from the sample taken from a downgradient well all have the same value X_m. The test statistic given by U.S. EPA, which is referred to as Cochran's approximation to the Behrens-Fisher Student's t-test,[2] reduced to:

$$(X_m - X_B)/(S_B^2/N_B)^{1/2} \qquad (1)$$

where X_B is the mean of the background values and N_B is the number of background values. This test is inappropriate because in the absence of contamination, X_m can vary as widely as the background values. The test is appropriate for the inappropriate null hypothesis that X_m equals the mean of the background values. The appropriate null hypothesis for testing is that X_m is a member of the same population as the background values. The appropriate statistic for this test is:

$$(X_m \quad X_B)/(S_B^2+S_B^2/N_B)^{1/2} \qquad (2)$$

Compared to the first test statistic, the estimate of the standard deviation used in the second is considerably larger. Therefore, for many sets of measurements, while the first test statistic may erroneously indicate that there is contamination, the second test statistic may indicate the opposite.

The U.S. EPA has recognized this problem. In publication of its regulations for owners and operators of permitted waste facilities, the U.S. EPA acknowledges the admissibility of statistical procedures alternate to the Students t-test.[2] An alternate statistical procedure is described below.

PROPOSED ALTERNATE MONITORING DATA EVALUATION PROCEDURE

Although the background quality of groundwater varies both spatially and temporally, temporal variations in background at

nearby points are expected to be related. Extending this assumption, temporal variations (apart from sampling and measurement error) are the same at nearby points. This procedure leads to the expression of a mathematical model for the background quality of groundwater around a waste disposal site. In this model, the background quality is given by the sum of a general mean (μ), a spatial effect (W_i) and a temporal effect (T_j).

If contamination of the groundwater occurs from the waste disposal facility, and if the monitoring wells surround the site so that they are located both upgradient and downgradient from the site, then contamination is unlikely to change the levels of a constituent in all wells by the same amount. Thus, contamination from a disposal site represents a deviation from the background model, and such a deviation can be detected.

Monitoring groundwater quality around a disposal site is an experiment with two factors: a spatial factor (or well factor) and a temporal factor. In conducting such an experiment, samples are collected and measurements made at each well at each sampling time. If the background model holds, these measurements, denoted by Y_{ij}, can be represented by:

$$Y_{ij} = \mu + W_i + T_j + E_{ij} \qquad (3)$$
$$i = 1 \ldots N$$
$$j = 1 \ldots M$$

where N is the number of wells, M is the number of sampling times and E_{ij} represents the random sampling and measurement error. The measurements can be arranged in a two-way table and can be analyzed by a two-way analysis of variance.[6]

Estimates of μ, W_i and T_j may be obtained from the data. Denoting these estimated by m, w_i and t_j, respectively, they are given by:

$$m = \frac{\sum_i \sum_j y_{ij}}{nm} \qquad (4)$$

$$w_i = \frac{\sum_j y_{ij}}{m} - m \qquad (5)$$

$$t_j = \frac{\sum_i y_{ij}}{n} - m \qquad (6)$$

The differences between the observed values, y_{ij}, and the values predicted by the model are the residuals

$$r_{ij} = y_{ij} - w_i - t_j - m \qquad (7)$$

As mentioned above, the contamination of groundwater by a waste disposal site will result in a deviation from the background model. Therefore, it is the residuals which contain the answer to the question of whether the site is contaminating the groundwater. However, the residuals also are affected by the sampling and measurement error. Because the assumed background model does not indicate whether the residuals occur as a result of sampling and measurement error or are indicative of contamination, the model is incomplete.

The analysis of groundwater data can proceed no further because there is no way to decide whether the residuals from the background model can be attributed solely to sampling and measurement error. The solution to this problem is the collection of replicate samples. Replicate samples differ from each other only because they each contain an independent replicate of the sampling and measurement error. For example, a sampling design for groundwater monitoring might specify collection of two replicate samples from each well at each sampling time. Replicates are important in environmental sampling because the adequacy of environmental models is always in question.[7] Replicates allow the variations unexplained by the model to be compared with the variations caused by sampling and measurement so that model inadequacies can be detected.

The exact specification of the replicates that are needed is a complex process since it depends on the environmental model. For this reason, replicate laboratory measurements obtained by splitting samples are rarely adequate because they do not reflect sampling error. Specification of replicates often involves choosing the time period between successive replicate samples. The model should account for variations over long time spans with the term T_j. Sampling error usually accounts for local and short-term variations.

Assume that true replicate samples can be obtained by resampling the wells after a specific short time period. Consider a sampling program design which requires L replicate samples from each well at each occasion that the wells are sampled. In most cases, two (L = 2) replicates seem reasonable. The measurements on the samples may then be described by the following model:

$$Y_{ijk} = \mu + W_i + T_j + (WT)_{ij} + E_{ijk} \qquad (8)$$

where, as before,

i = 1 ... N (number of wells)
j = 1 ... M (number of sampling periods)
k = 1 ... L (number of replicates)

This model is the same as Model (3) except that another subscript has been added to index the replicates and a term $(WT)_{ij}$ has been added to account for the various changes that occur when the site is contaminating the groundwater. This term is referred to as the well by period interaction and describes changes in the relative relationship of the wells between time periods.

If the sampling and measurement errors E_{ijk} are statistically independent and normally distributed with the same variance, then measurements obtained under this model can be analyzed by the two-way analysis of variance appropriate for models with replicate sampling.[6] Estimates of μ, W_i, T_j and $(WT)_{ij}$, which are denoted by m, w_i, t_j and r_{ij}, can be obtained as before with y_{ij} replaced by:

$$y_{ij\cdot} = \frac{\sum_k y_{ijk}}{L}$$

The appropriate analysis of variance (ANOV) table is given in Table 1.

The crucial comparison of the interaction with sampling error which is indicative of groundwater contamination is made using the F-statistic.[6] The value of this statistic is given by:

$$F = \frac{NT(L-1)}{(N-1)(T-1)} \frac{L\sum\sum r_{ij}^2}{\sum\sum\sum (y_{ijk} - y_{ij\cdot})^2} \qquad (7)$$

If the interaction is found to be significantly greater than the sampling error, then one concludes that the wells do not vary in the same way over time, and thus there is local influence on the measured contamination.

True replicate samples can be obtained by sampling the same well after a fixed period. The duration of this period may be as short as hours or as long as days. The determination of this period can be established for a given well system with an initial sampling experiment. Such an experiment has been conducted on the monitoring wells of a major industrial facility.

DETERMINATION OF REPLICATE SAMPLES

The need for determining what constitutes a replicate sample has been discussed above. It also was indicated that replicate analyses of the same sample do not provide for the determination of sampling variability. To determine true replicate sampling for the monitoring wells, a sampling experiment was conducted over a four-day period. This experiment required the sampling of each well once a day on each of the four days. The samples were col-

Table 1
Appropriate Analysis of Variance (ANOV) for Groundwater Monitoring

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUM OF SQUARES
Between Wells	N-1	$LT\sum_i w_i^2$
Between Sampling Periods	T-1	$LN\sum_j t_j^2$
Interaction	(N-1)(T-1)	$L\sum_{ij} r_{ij}^2$
Sampling Error	NT(L-1)	$\sum_{ijk} (y_{ijk} - y_{ij.})^2$
Total	NTL-1	$\sum_{ijk} (y_{ijk} - m)^2$

Table 2
Groundwater Monitoring Study pH (Standard Units)

DAY	ANALYSES	WELL B1	B2	B3	B4
1	1	7.00	7.00	7.30	6.50
	2	7.00	7.00	7.30	6.50
	3	7.00	7.00	7.40	6.60
	4	7.00	7.10	7.40	6.60
2	1	6.50	6.90	7.30	6.50
	2	6.60	6.90	7.30	6.50
	3	6.60	6.90	7.40	6.60
	4	6.70	7.00	7.40	6.60
3	1	6.60	6.90	7.30	6.50
	2	6.60	6.90	7.40	6.50
	3	6.70	6.90	7.40	6.60
	4	6.80	7.00	7.40	6.60
4	1	6.60	6.90	7.30	6.50
	2	6.60	6.90	7.40	6.50
	3	6.60	6.90	7.40	6.50
	4	6.60	7.00	7.40	6.60

Table 3
Groundwater Monitoring Study Conductivity (μMHOS @ 25°C)

DAY	ANALYSES	WELL B1	B2	B3	B4
1	1	1039.00	913.00	599.00	1355.00
	2	1037.00	904.00	587.00	1353.00
	3	1012.00	911.00	592.00	1265.00
	4	1021.00	917.00	599.00	1352.00
2	1	1062.00	1097.00	688.00	1339.00
	2	1074.00	1090.00	683.00	1332.00
	3	1068.00	1087.00	686.00	1337.00
	4	1041.00	1087.00	672.00	1341.00
3	1	1080.00	1062.00	698.00	1339.00
	2	1067.00	1060.00	696.00	1341.00
	3	1071.00	1050.00	695.00	1339.00
	4	1064.00	1055.00	696.00	1340.00
4	1	1045.00	1011.00	712.00	1327.00
	2	1050.00	1027.00	712.00	1351.00
	3	1033.00	1005.00	712.00	1345.00
	4	1039.00	966.00	717.00	1356.00

Table 4
Groundwater Monitoring Study TOC (mg/l)

DAY	ANALYSES	WELL B1	B2	B3	B4
1	1	28.40	102.00	28.80	101.00
	2	27.80	98.80	29.30	97.90
	3	27.10	102.00	28.10	98.70
	4	27.90	98.50	31.30	98.20
2	1	37.60	72.60	44.70	103.00
	2	33.80	75.30	42.90	100.00
	3	36.80	75.80	42.70	106.00
	4	32.20	73.90	44.70	98.20
3	1	35.50	64.80	40.80	102.00
	2	33.40	64.80	40.30	100.00
	3	35.50	62.40	38.50	102.00
	4	33.90	64.00	40.50	103.00
4	1	32.20	64.60	38.90	93.40
	2	31.80	61.70	39.40	93.10
	3	32.40	61.30	38.20	97.30
	4	31.70	62.80	41.70	96.70

Table 5
Groundwater Monitoring Study TOX (μg/l)

DAY	ANALYSES	WELL B1	B2	B3	B4
1	1	21.00	29.00	<10.00	19.00
	2	21.00	21.00	<10.00	16.00
	3	22.00	32.00	<10.00	17.00
	4	18.00	29.00	<10.00	18.00
2	1	21.00	35.00	11.00	19.00
	2	21.00	36.00	<10.00	22.00
	3	23.00	33.00	<10.00	21.00
	4	21.00	34.00	<10.00	25.00
3	1	11.00	28.00	16.00	25.00
	2	10.00	31.00	16.00	22.00
	3	18.00	32.00	19.00	25.00
	4	16.00	31.00	17.00	27.00
4	1	12.00	26.00	<10.00	17.00
	2	10.00	27.00	<10.00	21.00
	3	11.00	31.00	<10.00	19.00
	4	12.00	28.00	<10.00	23.00

lected after three well volumes of water were removed from the well. Each sample was analyzed four times for pH, conductivity, total organic carbon (TOC) and total organic halogens (TOX). The data collected during this experiment are found in Tables 2 through 5.

The sampling plan was designed to compare the variability among samples from a given well taken within a relatively short time span (approximately 24 hr apart) to the variability among repeated analyses on the same sample. The sampling plan is, therefore, hierarchical, and the data were analyzed accordingly using the appropriate ANOV technique.[8] The results of these analyses are found in ANOV Tables 6 through 9.

The values of the F statistics shown in these tables are all greater than the tabulated critical values of F for the appropriate degrees of freedom.[9] They clearly indicate that highly significant variability exists in all the measured constituents among the wells and among samples from the same well during a comparatively short period of time. The significance of variability along the wells is as expected for reasons given above. The significance of

the variation among analyses of a given sample clearly illustrates that sampling variability is important.

To further illustrate this point, assume that the four samples taken from Well B1 describe the background groundwater quality for TOX. Thus, the background mean TOX is 16.19 μg/l, and standard deviation of the background TOX is 6.11 μg/l. Now assume that downgradient Well B4 was to be samples on one of the four days of this experiment chosen at random. The mean and standard deviation of the four repeated analyses for TOX of the daily samples is given in Table 10. Also presented in this table are the calculated and critical values of the Student's "t" statistic as prescribed by Appendix IV of 40 CFR 264.

Comparing the calculated and critical values of the Student's "t" statistic for these four consecutive days serves to illustrate the importance of the sampling variability. On two of the four days (Day 2 and Day 3), the calculated value of Student's "t" exceeds the critical value. Thus, a conclusion of groundwater degradation would be made. However, this is not true of the samples taken on Day 1 and Day 4. If the quarterly sampling day were picked at random from these four, there would be a 50% chance of concluding that groundwater degradation occurred solely due to random variation introduced by the act of sample collection.

Table 6
pH ANOV

VARIATION SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F STATISTIC	SIGNIFICANCE LEVEL
Wells	3	6.0162	2.0054	51.03	.999
Samples Within Well	12	0.4713	0.0393	12.61	.999
Analyses Within Sample	48	0.1500	0.0031		
TOTAL	63	6.6375			

Table 7
Conductivity ANOV

VARIATION SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F STATISTIC	SIGNIFICANCE LEVEL
Wells	3	3,578,628	1,192,876	127.81	.999
Samples Within Well	12	111,990	9,333	43.21	.999
Analyses Within Sample	48	10,348	216		
TOTAL	63	3,700,968			

Table 8
TOC ANOV

VARIATION SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F STATISTIC	SIGNIFICANCE LEVEL
Well	3	48,326	16108.70	44.22	.999
Samples Within Well	12	4,372	364.32	132.96	.999
Analyses Within Sample	48	132	2.74		
TOTAL	63	52,829			

Table 9
TOX ANOV

VARIATION SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F STATISTIC	SIGNIFICANCE LEVEL
Well	3	2,918	972.63	17.26	.999
Sample Within Well	12	676	56.36	12.44	.999
Analyses Within Sample	48	218	4.53		
TOTAL	63	3,811			

Table 10
TOX Concentration for Downgradient Well B4

DAY	MEAN µg/ℓ	STANDARD DEVIATION µg/ℓ	CALCULATED STUDENT'S "t"	CRITICAL STUDENT'S "t"
1	17.50	1.29	0.79	1.84
2	21.75	2.50	2.82	1.99
3	24.75	2.06	4.65	1.94
4	20.00	2.58	1.91	1.96

Table 11
Expected Mean Squares for Groundwater Monitoring

VARIATION SOURCE	EXPECTED MEAN SQUARES
Well	$\sigma_A^2 + 4\sigma_S^2 + 16W^2$
Samples Within Well	$\sigma_A^2 + 4\sigma_S^2$
Analyses Within Sample	σ_A^2

Table 12
Variance Components for Groundwater Monitoring Parameters

VARIATION SOURCE	pH	CONDUCTIVITY	TOC	TOX
Analyses, σ_A^2	0.003	215	2.74	4.53
Sampling, σ_S^2	0.009	2,279	90.39	12.95

The selection of a sampling plan for continued groundwater monitoring can be made with the information generated by the analysis of variance. By equating the mean squares estimated by the analysis of variance to their theoretical expectations, one can estimate the contribution of each component (e.g., sample collection or analysis) to the total variability of the measurement. If σ_A^2 and σ_S are used to symbolize the variability due to analysis and sample collection respectively, then the expected mean squares for the analysis of variance are given in Table 11.

In Table 11, W^2 symbolizes the natural background variation among wells. The resulting estimates of σ_S^2 and σ_A^2 are given in Table 12 for the indicator parameters observed.

The characterization of the contaminant concentration for a well undergoing quarterly monitoring is by the mean of the observations taken during the quarterly monitoring period. A sampling plan should be designed to minimize the variation in this mean. If S samples are taken during the quarterly monitoring period and A analyses are run on each sample, the variance of the quarter mean is given by:

$$\frac{\sigma_A^2}{SA} + \frac{\sigma_S^2}{S}$$

The effect on this variance of varying the number of samples, S, and analysis per sample, A, then can be investigated. If the analytical cost is constrained by requiring the $S + A \leq 4$, then the minimum variance, and hence maximum precision, of the quarterly mean value for the indicator parameters for a given well is obtained for the same analytical cost if the well is sampled four times each quarter approximately 24 hr apart and one analysis is performed on each sample. These results are given in Table 13. The information on the last line of the table indicates that the precision of the quarterly mean is approximately doubled (the variance halved) from the U.S. EPA recommended sampling scheme of one sample per quarter by sampling each well twice and analyzing each sample once. This reduction in analytical cost may be sufficient to compensate for increased sampling costs.

Table 13
Variance of Well Quarterly Mean

NUMBER OF SAMPLES	NUMBER OF ANALYSES PER SAMPLE	pH	CONDUCTIVITY	TOC	TOX
1	4	0.00975	2332.75	91.08	14.08
2	2	0.00525	1193.25	45.88	7.61
4	1	0.00300	623.50	23.28	4.37
2	1	0.00600	1247.00	46.56	8.74

CONCLUSIONS

The salient conclusions are summarized as follows:

- The portion of the total measurement variability due to the act of sampling is much greater than that due to repeated chemical analyses of the same sample. Thus, repeated chemical analyses of the same sample do not necessarily improve quarterly characterization of groundwater.
- Adequate replicate samples may be obtained by repeated sampling of each well approximately 24 hr apart.
- The precision of the quarterly measurement for groundwater contamination will be greatly improved from that specified in Federal Regulations if each well is sampled twice within a four-day time span and only one analysis is performed on each sample. This sampling scheme also will permit the use of the analysis of the variance statistical procedure to adequately test the hypothesis of groundwater contamination.
- Continued use of the statistical procedure specified in the Federal Regulations will, more than likely, yield results alleging that groundwater contamination has occurred when the application of adequate statistical procedures will conclude that there is not contamination.

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Data Evaluation in a Groundwater Study of Waste Management Practices in the Phosphate Processing Industry

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ABSTRACT

The phosphate processing industry has been the focus of several groundwater monitoring programs within the past several years. As a result of these studies, a relatively large data base has been assembled which, in addition to evaluating the characteristics of the various wastes generated by this industry, also includes groundwater monitoring data which were used to evaluate the impact of the industry on groundwater quality. The interpretation of the monitoring data involved the use of several different evaluation techniques which will be discussed.

Student's t-test is one traditional method of evaluation that was used. This method compares the average and standard deviation of a set of paired values. This method has been used extensively in hazardous waste-related groundwater studies and has been criticized for its lack of sensitivity.

Another traditional method of evaluation is the comparison of Stiff diagrams. These diagrams are graphical representations of the basic quality of a water sample. This method is very useful when dealing with the wastes from the phosphate industry, but the method is somewhat subjective.

Several newer methods also were used in the course of these projects. These methods included the calculation of ion indices and the use of cluster analysis.

The ion indices are calculated using basic water quality components such as sodium and chloride. Through the comparison of indices from impacted wells with indices from background wells, an evaluation of contamination and attenuation can be made.

Cluster analysis was used to identify any trends or relationships between monitoring wells. Cluster analysis is a collective term covering a variety of statistical techniques for delineating natural groups or clusters. Evaluations were made based upon the degree and the order in which the individual wells were clustered. This method proved to be quite useful in confirming trends which other methods also identified.

INTRODUCTION

Over the past several years, PEI Associates has been involved with evaluating the waste management practices in the phosphate industry. These evaluations have involved the installation of groundwater monitoring programs at phosphate processing facilities. In the course of these projects, eight different facilities with a total of 85 wells were monitored. Samples were collected from these wells at varying times; each well was sampled at least twice and analyzed for a wide variety of water quality parameters. The interpretation of the monitoring data involved the use of several evaluation techniques which will be discussed.

STUDENT'S T-TEST

Groundwater monitoring data collected for the purpose of fulfilling RCRA groundwater monitoring permit requirements have been evaluated using Student's t-test. The Student's t-test is the principal criterion for testing hypotheses concerning two population means. The t statistic is the deviation of a normal variable (X) from its mean (μ) measured in standard error units (S_x).

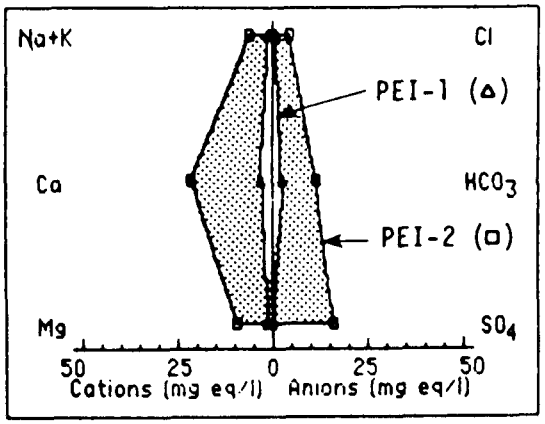
$$t = (X - \mu)/S_x \quad (1)$$

This test compares the average and standard deviation of the measurements for each parameter with the same parameter as measured in another well, usually the background well. This test was used on some of the data. However, it was not used on all the data since there were not enough replicates to make the test statistically valid. At least three or more replicates are required to make the test valid. Due to various constraints on the projects, only two sets of samples were collected at some of the sites. In addition to the lack of sufficient replicates, the Student's t-test has been shown to generate false positive results as has been documented in the *Federal Register*. Therefore, additional methods for evaluating the data were used.

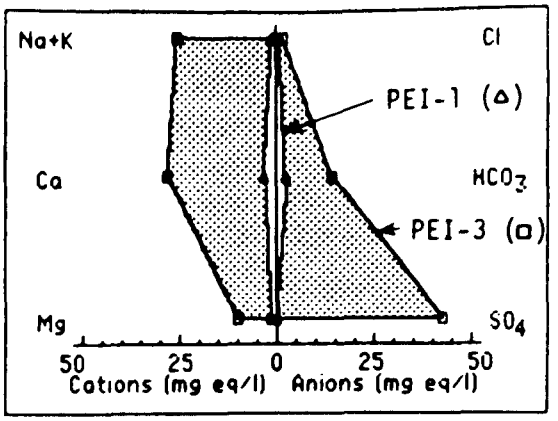
STIFF DIAGRAMS

Stiff diagrams are a traditional method of depicting the basic water types. Only the major cations and anions typically are used in the diagrams (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}, alkalinity and SO_4^{-2}). The concentrations of the ions are converted to milliequivalents/liter and then plotted on a Stiff diagram. The shape of the resulting polygon is indicative of the type of water being evaluated. For example, the Stiff diagram of a sodium carbonate water is distinctly different from a calcium sulfate water. Therefore the comparison of a Stiff diagram of a sample of liquid waste from a processing facility to the diagrams from monitor wells will enable one to graphically determine if there has been any impact on the groundwater from the liquid waste.

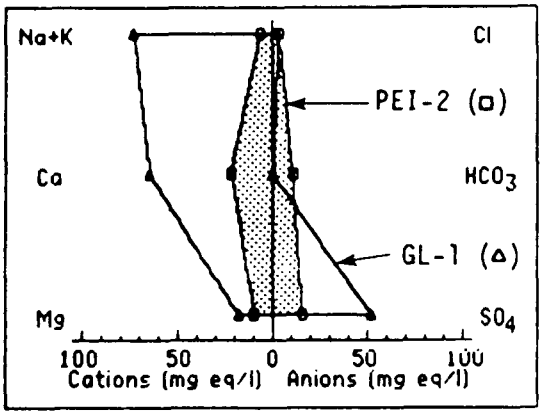
Figure 1 shows such a comparison for one of the test sites. The waste sample (GL-1) and the background well are compared to two different wells from the site (PEI-2 and PEI-3). Neither of the diagrams for PEI-2 or PEI-3 resemble the diagram for the background well, indicating that the water quality in these wells differs from background conditions. The Stiff diagram for PEI-3 bears a close resemblance to the diagram of the waste (GL-1), indicating that some contamination has occurred in this well. The Stiff diagram for PEI-2 does not resemble the diagram for GL-1 as closely as PEI-3, but is more similar to GL-1 than to the background well, and therefore, it can be concluded that PEI-2 is contaminated but not as severely as PEI-3.



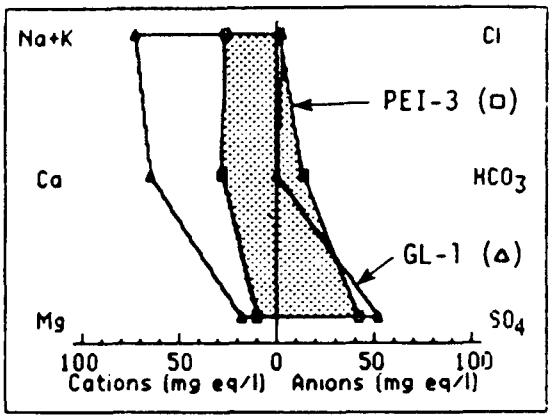
BACKGROUND vs. PEI-2



BACKGROUND vs. PEI-3



GYP LIQUID vs. PEI-2



GYP LIQUID vs. PEI-3

Figure 1
Stiff Diagrams from the Test Site

ION INDICES

Another method which has been used with some degree of success is the calculation of ion indices. These indices were developed by the U.S. Geological Survey during an evaluation of phosphate mining and processing in Florida.[1] The indices are a numerical evaluation of the concentration of the major anions and cations within a sample and in some cases the sample concentrations were compared to the concentrations in the background samples.

The two most useful indices are the index of Nonmineral Input (INMI) and the Percentage of Ion Increase (PII). The INMI measures the percentage increase in concentrations of sodium above chloride and calcium plus magnesium above sulfate plus alkalinity compared to the same parameters in the background samples.

$$INMI = \frac{[(Na-Na')-(Cl-Cl')]}{C' + A'} + \frac{[(Ca+Ca' + Mg-Mg')-(SO4-SO4'+Alk-Alk')]-[C-A]-[C'-A']}{C' + A'} \times 100 \quad (2)$$

where:

INMI = Index of Nonmineral Input, in percent above background
Alk = Alkalinity, in milliequivalents/l
C = Cation sums, in milliequivalents/l
A = Anion sums, in milliequivalents/l
' = Background conditions

The PII is used to evaluate the increase in ions above background concentrations and is based solely on the sum of selected cations and anions.

$$PII = \frac{(C+A) - (C'+A')}{(C'+A')} \times 100 \quad (3)$$

where:

PII = Percentage of Ion Increase, in percent above background
C = Cation sums, in milliequivalents/l
A = Anion sums, in milliequivalents/l
' = Background conditions

The senior author of the U.S. Geological Survey report[1] considered an INMI of approximately 5% to be above background levels for the groundwater systems in Florida and to reflect an impact from the waste management practices. The relationships between the INMI and PII also can be used to evaluate the extent of seepage and whether or not the soil is attenuating the seepage through ion exchange. For example, if the INMI and PII are both significantly elevated above background conditions, this probably indicates that the seepage has not been altered by ion exchange. If the INMI is low and the PII is high, then this result may indicate that the seepage is being altered through ion exchange with the soil or that another source of contamination is influencing the system.

At the test site previously mentioned, ion indices were calculated for each sampling period. Table 1 shows the indices (calculated with PEI-1 as background) for the second sampling round. As can be seen from the data, the conclusions concerning PEI-2 and PEI-3 are supported by the indices. These two wells have the highest indices for both INMI and PII. The lower INMI for PEI-2 indicates that more attenuation has taken place at PEI-2 than PEI-3, while the other wells show some degree of impact. The high INMI for PEI-5, the second background well, is most likely a result of it being completed in a different lithology than PEI-1, rather than it showing the effects of seepage.

Table 1
Ion Indices at the Test Site

INMI	---	32%	411%	32%	32%	0%
PII	---	695%	1332%	123%	5%	100%

These methods have proven to be quite useful for evaluations of the phosphate industry where the waste being studied consists mainly of calcium and sulfate, both of which are included in the Stiff diagrams and the indices. However, these methods would not be very useful in evaluating seepage from wastes which did not impact any of the major cations or anions, such as organic contamination, and these evaluations often may be subjective when there is not a great deal of dissimilarity in the diagrams or the indices.

CLUSTER ANALYSIS

The groundwater data collected during these projects also were analyzed by cluster analysis to identify any water quality trends or relationships between the monitoring wells and the waste samples. Cluster analysis is a collective term covering a wide variety of statistical techniques for delineating natural groups or clusters in data sets.[2] The objective of this type of analysis is progressive grouping of the variables into clusters according to their degree of statistical similarity.

The cluster procedure in the BMDP Statistical Software package was used for this analysis.[3] The exact procedure used was Cluster Analysis of Cases (Method 2M). This procedure uses a hierarchial approach to building the clusters. Initially, each case (an individual sample from a monitoring well or waste sample) is treated as a single member cluster; then, the two most closely related cases are combined into a new cluster and the "distances" between the new cluster and the remaining ones are computed.

The distance measure calculated is the Euclidean distance radius between the clusters. The general formula used for this calculation is as follows:

$$d_{jk} = [\Sigma_i(X_{ij} - X_{ik})^2]^{1/2} \quad (4)$$

where:

d_{jk} = distance between two cases of clusters j and k
X_{ij} = value of the ith variable in the jth case

This process continues until all the cases are combined into one large cluster. Figure 2 is a graphical representation of this process; the initial cases are placed on a line in an order that is determined by the program. Vertical lines then are drawn from each case until it joins with another. By using the computed distance between clusters as the vertical scale, the vertical location of each joint or cluster shows the dissimilarity of the joined groups. Therefore, clusters formed near the top represent homogeneous groups, whereas clusters formed further down represent clusters formed only because the process goes to its logical end of one large cluster.

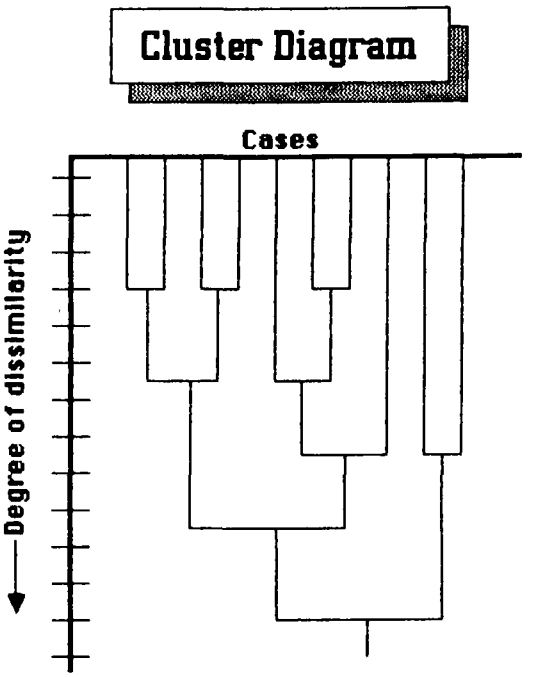


Figure 2
Example of Hierarchial Clustering

For the purposes of these studies, each sample from a monitoring well or waste sample was treated as one case, and all samples from a given sampling period were analyzed together; i.e., no clustering was conducted over the different sampling periods. The variables used in the analyses included the basic water quality parameters (Ca, Mg, Na, etc.) and several parameters chosen as a result of their concentrations in the waste (sulfate, fluoride, Ra-226, etc.).

The results of the cluster analysis were evaluated based on the criterion that any increase in distance between clusters that was twice the previous distance (a 100% increase) was considered to be a significant difference between clusters.

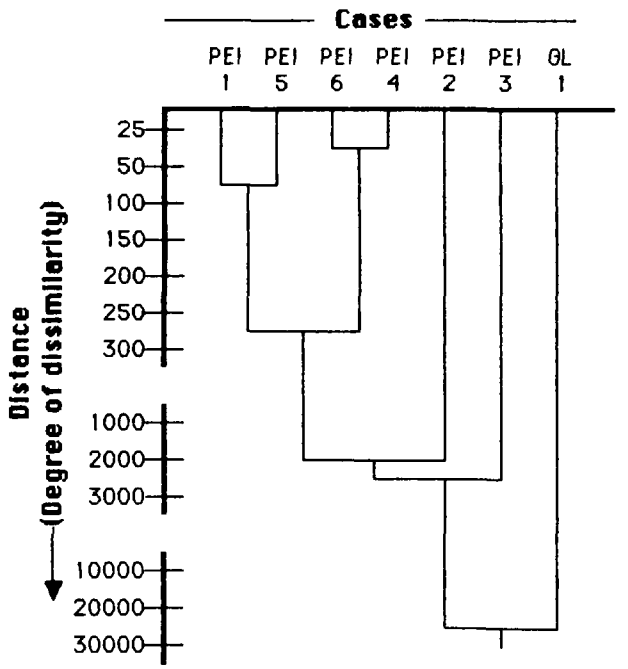


Figure 3
Test Site Cluster

The cluster analysis of the data represented previously in the Stiff diagrams supported the conclusions of the Stiff diagrams. As shown in Figure 3, the six wells analyzed showed definite clustering. The background wells (PEI-1 and PEI-5) were determined to be similar on the basis of the clusters, as were PEI-4 and PEI-6 (these wells were furthest downgradient from the waste source). Wells PEI-2 and PEI-3 also clustered together and were determined to be the least similar to the other well clusters and the most similar to the waste sample GL-1.

At this site, all the data evaluation methods provided the same conclusions as to which wells were being affected by the waste management practices. Cluster analysis is a worthwhile method to assist in the evaluation of data when traditional methods may not have the necessary statistical power to sort out all the variables.

The power of the cluster analysis may be increased if a factor analysis is performed on the data set prior to the cluster analysis. The factor analysis will identify which analytical parameters are responsible for the majority of the experimental variance. Use of factor analysis also will prevent the researcher from inadvertently weighting the cluster analysis by the inclusion of two or more parameters which represent the same effect. The primary variable should be identified by the factor analysis, and only those variables should be included in the cluster analysis.

CONCLUSIONS

As can be seen, there are a wide variety of methods available for the evaluation of groundwater monitoring data. The use of cluster analysis with or without factor analysis is a valuable technique which can help identify trends in the data that otherwise may not be recognized.

ACKNOWLEDGEMENTS

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Plant Cuticular and Dendrochronological Features as Indicators of Pollution

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ABSTRACT

In a highly industrialized world, it is imperative that scientists explore different methods of monitoring environmental contamination. One new field of environmental research, begun in recent years, may do this. This field is the study of leaf cuticle and annual growth rings in woody plants.

Several plant taxa growing in habitats characterized by varied levels of environmental contamination were studied by the author of this paper for dendrochronological and cuticular patterns. Growth rings, ring and porous wood, and related features were analyzed with a dendrochronograph. Cuticular patterns such as stomatal frequency, stomatal size and trichome frequency and type were studied in relation to environmental contamination in various habitats. Most plant populations under investigation were in the industrial areas of Nashville and Memphis, Tennessee—known for their high levels of environmental pollution.

Statistical analysis of the data revealed the significance of plant features as indicators of environmental pollution in the area. Growth rings were, for example, extremely narrow in highly polluted areas, while the plant populations exposed to relatively low levels of pollution exhibited fully developed annual increments. Growth rings tended to be unusually irregular in plants growing in highly polluted areas. Cuticular patterns such as trichome frequency and type were quite diagnostic for determining pollution levels in the environment.

With an increase in pollution level, the stomatal frequency decreased and the trichome frequency increased—possibly a response to offset the detrimental effects of pollutants on various metabolic reactions and reproductive strategies in plants. In addition, floral productivity seemed to be adversely affected in polluted areas. The results demonstrate that tree ring characteristics and leaf cuticular patterns can be used as monitors for evaluating the growth responses of a plant species to varied levels of environmental pollution.

Analysis of annual increment variation can be used to determine the degree of stress exerted by environmental pollution on plant growth. Results of several cuticular and experimental studies conducted by the author substantiate the findings reported herein. These results suggest that plants can be used as extremely reliable indicators of environmental pollution, including hazardous waste sites, provided long-term monitoring is done for a variety of plant species.

INTRODUCTION

Studies[3,5] have demonstrated the relationships between plants and the environment. Damaging effects of fluorides and sulfur dioxide on plants have been documented.[9]

In 1934, Chamberlin[1] determined that industrial pollutants of a large mid-western city in the United States were detrimental to coniferous flora of the area. He especially referred to the fatal effects of industrial pollution on *Pinus banksiana*. Hill and Thomas[3] observed that there was a decrease in alfalfa yield after exposure to sulfur dioxide. Pyatt[4] suggested lichens as possible indicators of air pollution in a steel-producing town in Wales. His studies revealed that thallus size decreased and the lichen flora decreased in the number of species present with increasing proximity of the pollution source.

While working in the forests of the northwestern United States, Scheffer and Hedgcock[5] found that sulfur dioxide from smelters produced a characteristic mottling of leaves. Coniferous plants were more affected than deciduous species.

Feder[2] reported that geranium and carnation plants had reduced branching and retarded floral productivity after exposure to low levels of oxidant-type pollutants. Although numerous plant taxa have been studies to determine the significance of various plant morphological features as indicators of environmental pollution, relatively little work has been done to establish relationships between cuticular dynamics and environmental pollution, especially hazardous waste sites. Recent studies[7,8] on the subject suggest the potential of leaf cuticular dynamics in environmental pollution research.

The purpose of this study was to collect data for three plant species in the relatively clean environment of Reelfoot Lake and to be compared to samples collected in the industrialized areas of Memphis and Nashville. The present investigation is, therefore, a continuation of a comprehensive study involving plant cuticular features as indicators of environmental pollution with special reference to hazardous waste sites.

MATERIALS AND METHODS

Plant populations of *Polygonum pensylvanicum* (smartweed), *Platanus occidentalis* (sycamore) and *Catalpa bignonoides* (catalpa) were studied; comparisons of samples taken from the relatively unpolluted sites of Reelfoot Lake and Martin in northwest Tennessee were made with ones collected from the contaminated sites in middle and northwest Tennessee—the latter sites were characterized by exposure to additional pollutants emitted by vehicular traffic and the industrial complex of the surrounding metropolitan areas.

Twenty-five randomly selected leaves were gathered from each plant species. Their lengths, widths, internodal lengths and length-width ratios were determined. Gross morphological meas-

urements were supplemented with cuticular data.

For cuticular studies, representative leaves were washed with a mild detergent and distilled water. After air-drying, the upper and lower surfaces of the leaves were coated with Duco-cement™.[10] Upon drying, fine layers of Duco-cement showing the cuticular or epidermal complex of leaves were removed; slides were prepared from the central portion of the layers for microscopic analysis. Cuticular dynamics representing in stomatal frequency stomatal size, epidermal wall undulation, trichome frequency, trichome length and type and subsidiary cell complex were recorded (N = 25) for the upper and lower surfaces representing upper and lower surfaces of leaves using 43x objective and 10x oculars.

Dendrochronological studies were conducted on the woody taxa by getting core samples in the two sets of habitats. Annual increments were recorded from the core samples. The entire data were analyzed by a computer.

RESULTS

Statistical analysis of the data revealed several significant differences in the gross morphological, cuticular and dendrochronological features of the two sets of samples (polluted versus relatively unpolluted). Plants growing in the contaminated areas had smaller leaves with both their length and width significantly reduced. In addition, internodal length also was reduced. Plants growing in the rural, Reelfoot Lake area were healthier and had larger leaves and longer internodes. These leaves were dark green, while the leaves of plants from the contaminated sites had yellowish, light green pigmentation. It is obvious that the photosynthetic productivity of the plants at the contaminated sites was adversely affected by the environmental pollution prevalent in the area.

A reduction in the total biomoass of plant populations in the contaminated areas was an additional evidence to suggest the detrimental effects of environmental degradation on plant growth. A reduction in metabolic activities, especially in photosynthesis, must mean reduced bimoass; this result was evident in all the populations of contaminated sites. Cuticular measurements revealed additional features affected by the environmental contamination of the sites under investigation. Stomatal frequency values of the lower leaf surfaces in all plants under study were high in the rural, less polluted habitats, while the plants from the contaminated sites exhibited extremely low stomatal frequency values.

In addition, trichomes on the leaf surfaces of plants from the latter sites had more numerous and much longer trichomes with large bases. Similar results have been found in earlier studies[6,7] in which affected plant populations were growing in sites characterized by heavy vehicular traffic. Stomatal size differences in the two sets of samples were not significant. Subsidiary cell complex remained unaffected by environmental contamination in all three plant taxa, and hence must be regarded as a reliable feature for identification purposes of the species.

The fact that some cuticular and morphological features of some plant species were different in the two habitats is indicative of the evolutionary trend exhibited by plants growing in areas exposed to various kinds of environmental contamination. Monitoring of these plant features over a long period of time is needed. This study is underway in order to determine if these morphological and cuticular trends are permanent. If so, these and similar plant species might be used as indicators of environmental complex, especially at contaminated sites.

Preliminary investigations of the core samples of woody taxa revealed a general decrease in the size of annual increment. Additional detailed studies are underway to determine the usefulness of plant features as monitors of environmental pollution, especially at hazardous waste sites. Such investigations might reveal plant species that are able to withstand specific contamination and hence be of significance for environmental and commercial considerations.

ACKNOWLEDGMENTS

Financial support for this work under the Research Grant Fund of The University of Tennessee at Martin is gratefully acknowledged.

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Detailed Stratigraphic and Structural Control: The Keys to Complete and Successful Geophysical Surveys of Hazardous Waste Sites

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ABSTRACT

Since the passage of RCRA and CERCLA legislation, countless geophysical surveys have been conducted at hazardous waste sites as part of site investigations in an attempt to delineate the horizontal and vertical extent of groundwater contamination as well as to delineate the limits of the sites. Of utmost importance during a geophysical survey is the identification of stratigraphic and structural control features which influence the potential migration of leachate away from a site.

Stratigraphic features such as sand zones, clay lenses, outwash valleys and top of rock zones are critical in the overall hydrogeological assessment of a site. Structural features such as faults and fractures are equally critical in the assessment of a site. Proper use and interpretations of geophysical data can result in a better understanding of a site's subsurface characteristics even before a drilling program begins.

The geophysical data interpretations explained in this paper, using the "Modified Wenner" method, are empirical and have resulted in the site-specific identification of subsurface details which have been reasonably accurate as compared to subsequent drilling results. The acquisition of detailed knowledge of a site's subsurface is the key to a complete and successful geophysical site survey.

INTRODUCTION

Geophysical surveys consist of surveying a site and its immediate vicinity utilizing one or more remote sensing techniques. The techniques may include earth resistivity, electromagnetics, magnetometry, seismic, metal detection and ground penetrating radar. Each technique has its own advantages and disadvantages at a particular site. When groundwater contamination is a suspected problem, either earth resistivity or electromagnetics normally is chosen as the technique in a geophysical survey.

Among the many methods utilized within the earth resistivity technique, the "Modified Wenner" method[1] has been reasonably accurate in terms of depth investigated as compared with subsequent drilling results. By utilizing the "Modified Wenner" method and empirical interpretations, site-specific identifications of stratigraphic and structural control features are possible. The identification of these features is the key to performing a complete and successful geophysical survey of a hazardous waste site.

STRATIGRAPHIC AND STRUCTURAL CONTROL

Stratigraphic and structural control is the understanding of a site's subsurface characteristics. When stratigraphic and structural control is understood, a site's geological characteristic can be understood. Furthermore, a site's hydrological characteristics can be understood better in terms of aquifers, confining layers and groundwater migration routes. Also, this control enables the investigator to more effectively perform resistivity profiles in an attempt to define the horizontal and vertical extent of identifiable contaminate plumes. By understanding the stratigraphic and structural control, the resistivity profile measurements can be effectively placed in the appropriate subsurface zones in which contaminant plumes are suspected.

Stratigraphic and structural control is normally established only after an exploratory drilling program, but the control can be established by the proper interpretation of resistivity soundings. Soundings are measurements of the earth's resistivity at various depths at a single land surface point.

RESISTIVITY SOUNDINGS

Resistivity soundings, utilizing the "Modified Wenner" method and empirical interpretations, have resulted in site-specific subsurface identifications which have correlated well with existing and/or subsequent drilling data. The key factor in the interpretations of "Modified Wenner" method soundings is that the potential or inner electrode spacing across the land surface very closely approximates the depth below the land surface at which a measurement is taken; or, in general terms, "electrode spacing equals depth below ground."

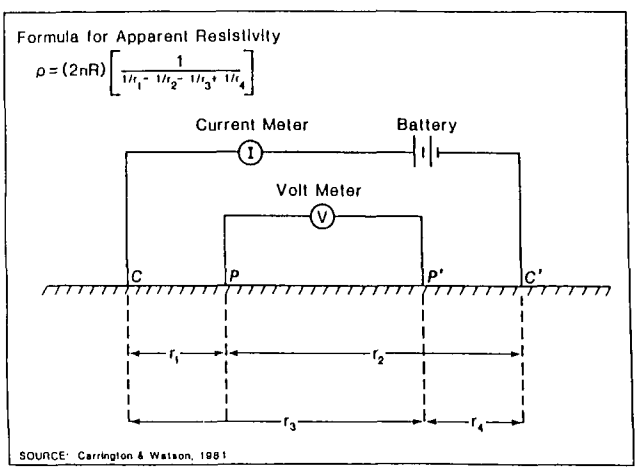

Figure 1
"Modified Wenner" Array
Diagram of Electrode Spacing

The electrode arrangement in the "Modified Wenner" method is shown in Figure 1. In this arrangement, the current or outer electrodes (C and C') are stationary while the potential or inner electrodes (P and P') are moved at equal distances from the center of the array. The arrangement of the electrode array can be varied depending on the objective and depth to subsurface targets.

Numerous investigators have discussed the advantages and disadvantages of empirical versus theoretical interpretations, and a discussion here will not be attempted. A partial list of references is included at the end of this paper.[2-4] The author has applied the "Modified Wenner" method and empirical interpretations in numerous subsurface investigations because of the method's ease of operation and the relative simplicity of the interpretations. The correlation between the sounding interpretations and actual subsurface drilling data has been reasonably accurate.

EXAMPLE SOUNDINGS

Five example soundings are presented to illustrate the application of the "Modified Wenner" method and empirical interpretations. The method has proven to be an asset in solving stratigraphic and structural control problems, the solutions of which have improved the effectiveness of subsequent resistivity profiling, monitoring well placements and groundwater contaminant plume tracking.

SHALLOW AND DEEP SOUNDING COMPARISONS

Resistivity soundings at a landfill in the mid-western states were conducted to aid in the understanding of the stratigraphy underlying the landfill as well as determining the thickness of the landfill cap. Figure 2 illustrates a shallow sounding to 5 ft below ground. An apparent resistivity change is evident at approximately a 2 ft depth which was interpreted as the thickness of the landfill cap. Similar soundings over the landfill were conducted, and the apparent resistivity responses varied only slightly (mainly due to the variation of cap saturation and lithology). A limited number of shallow borings on the landfill had confirmed the cap thickness to be approximately 2 ft deep. Resistivity profiling identified variations across the landfill which aided in the determination of possible recharge occurring through the cap.

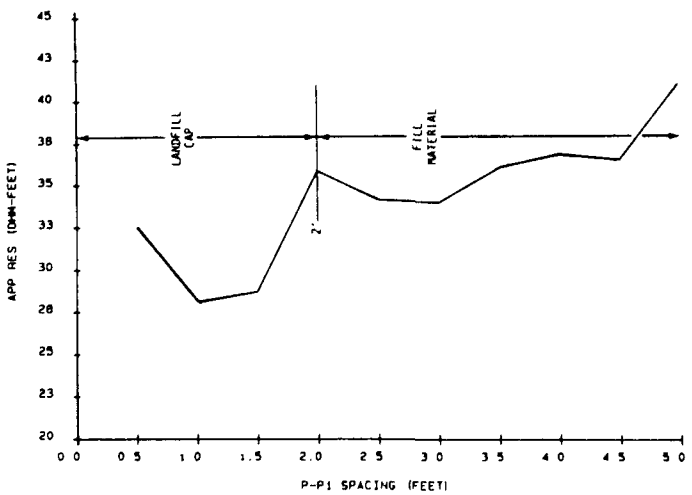

Figure 2
Results of Resistivity Soundings at a Landfill

A deep sounding to 100 ft over the landfill was conducted to aid in understanding the deep stratigraphy underlying the site. Figure 3 illustrates this sounding showing interpreted features such as the water table, sand/clay lenses, limestone rock and possible fractures in the rock. The actual drilling logs from both landfill borings and a nearby water supply well are presented to show the correlation with the interpretations. Note the depth correlation of the apparent resistivity graph to the boring logs, especially the deflection of the graph at 2 ft (cap-fill interface) and between 90 and 96 ft which correlates with the 90-ft water-bearing zone identified by the water well log. The deep sounding at this landfill site aided greatly in the understanding of the site-specific stratigraphic and structural control.

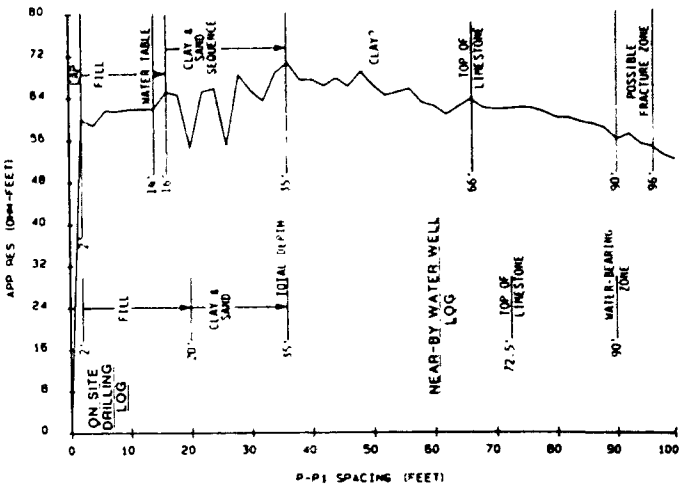

Figure 3
Deeper Sounding at Landfill

SOUNDINGS IN HIGHLY CONDUCTIVE GROUNDWATER

Soundings were conducted downgradient of a leaking lagoon at a site in the southeastern states. This site is underlain by crystalline rocks. The groundwater downgradient of the site contains highly conductive salts which created special problems during the soundings. Figure 4 illustrates a 60-ft sounding conducted with all four electrodes in the center of the highly conductive groundwater plume. The graph is essentially flat, and interpretations are impossible to make.

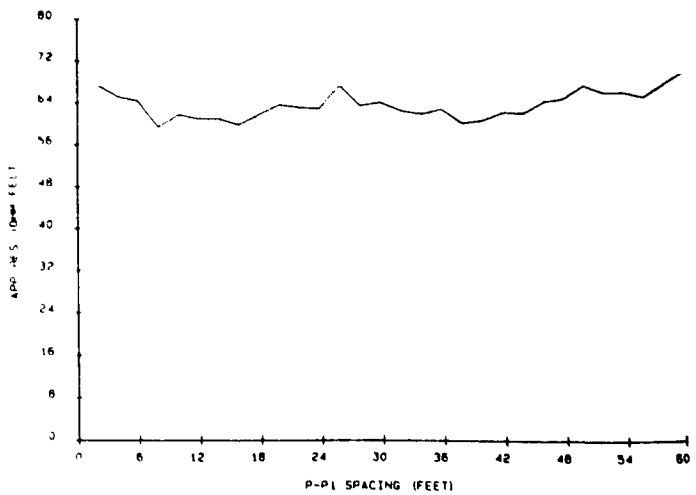

Figure 4
Results of Sounding Downgradient of a Leaking Lagoon

Figure 5 illustrates a 200-ft sounding conducted with the current electrodes placed outside the plume. This graph is more representative of the subsurface than is the graph in Figure 4. Note that the low apparent resistivity between 50 and 69 ft on Figure 5 is not seen on Figure 4. The low resistivity values at this zone were confirmed to represent contaminated groundwater within weathered and fractured crystalline rock. The sounding in Figure 5 aided in the understanding of the stratigraphy and structure below a highly conductive groundwater plume.

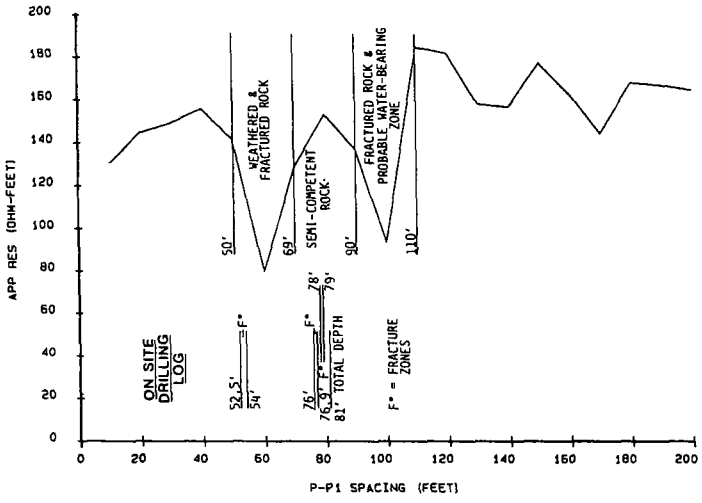

Figure 5
Results of Sounding Near and Leaking L.agoon with Electrodes Outside the Plume

CONCLUSIONS

Understanding the stratigraphic and structural control underlying and in the vicinity of a waste site is critical in the overall hydrogeological assessment of a site. Surface resistivity soundings aid this understanding by yielding data which can be correlated with existing and/or subsequent drilling results. Subsequent geophysical surveys, resistivity profiles for example, can be planned by the proper interpretation of the soundings in terms of site-specific stratigraphy and structural features.

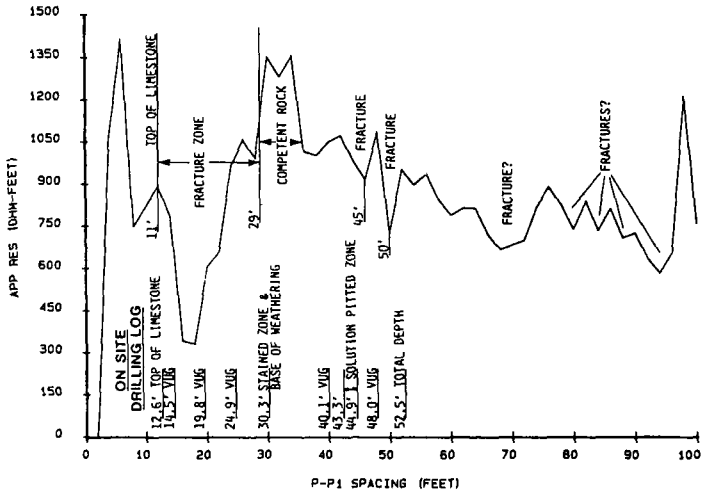

Figure 6
Results of Soundings in Sedentary Rocks to Identify Solution Cavities

SOUNDINGS IN SEDIMENTARY ROCK CONTAINING SOLUTION CAVITIES

Soundings were conducted to various depths at a waste site in the southeastern states to aid in identifying solution cavities within sedimentary rock. The rock at this site is limestone with solution cavities commonly occurring. The solution cavities are possible avenues of contaminant migration; therefore the understanding of the subsurface structure at the site is critical. Figure 6 illustrates one of the soundings conducted at the site. The sounding graph correlates well with the actual drilling log. Note the low resistivity between 11 and 29 ft and the zone of staining and vugs present at 14.5, 19.8 and 24.9 ft.

As the degree of weathering in the rock decreases with depth to 30.3 ft, the resistivity graph shows an increase (more resistive rock). Yet, between 40.1 and 48.0 ft where a solution pitted zone and small vugs are present, the resistivity graph shows a corresponding decrease (more solution and weathering). The monitoring well subsequently installed 27 ft deep at the sounding station yielded groundwater with higher conductivity levels than background wells. The resistivity sounding in Figure 6 aided in the understanding of the solution cavity distribution below the site.

Application of the "Modified Wenner" method and empirical interpretations has resulted in reasonably accurate correlations between the interpretations and actual drilling data as well as groundwater quality data. The ability to predict the presence of subsurface features with reasonable accuracy is a real advantage and time-saving element in the decision-making processes concerning a hazardous waste site.

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Detection and Measurement of Groundwater Contamination by Soil-Gas Analysis

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ABSTRACT

A soil-gas sampling probe which can penetrate calcareously cemented alluvium was developed and evaluated above a chloroform-contaminated groundwater plume. A linear correlation of greater than 95% significance between groundwater and soil-gas chloroform concentrations was observed. The precision of the method is controlled by sampling, with relative standard deviations between closely spaced samples ranging from 12 to 43%. A linear chloroform depth profile was observed; the profile, as delineated by the probe, agreed with calculations made assuming diffusion-controlled vertical flex of soil gases through the vadose zone.

INTRODUCTION

Contamination of groundwater is a problem of increasing concern. In efforts to detect and measure groundwater contamination, groundwater sampling and analysis is the traditional method of choice. Recently, preliminary surveys using remote-detection methods have been used as a tool for planning more cost-effective groundwater monitoring networks.[1] These surveys typically have been made using geophysical instruments such as electromagnetic techniques that can be effective for locating inorganic species but are not useful in detecting organic compounds. For the detection and measurement of subsurface contamination by volatile organic compounds (VOCs), a new technology, soil-gas measurement, has been developed.

Soil-gas surveying originally was developed for oil exploration.[2] Applications of the technique to delineate subsurface contamination by VOCs have been developed by several workers.[3,4]

Measurement of soil gases for detection of groundwater contamination takes advantage of Henry's Law, which states that the concentration of a volatile compound in vapors that are at equilibrium with a VOC solution is directly proportional to the VOC concentration in solution. The relationship between these two concentrations is quantitatively described by the Henry's Law constant for that compound. The magnitude of this constant is directly proportional to the vapor pressure of the compound and inversely proportional to the compound's solubility in water.

Because of their relatively low water solubilities and high vapor pressures, VOCs in contaminated groundwater tend to be present in soil gases above the source. Table 1 lists the 17 substances most frequently encountered at Superfund sites and their Henry's Law constants; of these chemicals, 10 are amenable to soil-gas surveying. In addition, major components of petroleum products which can leak from underground storage tanks can be detected using this technique.[5]

This paper describes a study undertaken to validate equipment and procedures for soil-gas surveying. The validation of the system involved assessing the bias of the technique for indicating chloroform contamination of groundwater, as well as assessing the precision and short-range variability of the method.

Table 1
Most Frequently Identified Substances at 546 Superfund Sites[a]

Rank	Substance	Henry's Law Constant (ppbv $L/_{\mu}g$)	Percent of sites
1	Trichloroethylene	72	33[b]
2	Lead and compounds	NA	30
3	Toluene	56	28[b]
4	Benzene	71	26[b]
5	Polychlorinated biphenyls (PCBs)	<<1	22
6	Chloroform	40	20[b]
7	Tetrachloroethylene	123	16[b]
8	Phenol	<<1	15
9	Arsenic and compounds	NA	15
10	Cadmium and compounds	NA	15
11	Chromium and compounds	NA	15
12	1,1,1-Trichloroethane	30	14[b]
13	Zinc and compounds	NA	14
14	Ethylbenzene	59	13[b]
15	Xylene	43	13[b]
16	Methylene chloride	23	12[b]
17	trans-1,2-dichloroethylene	580	11[b]

[a]Source: Kerfoot, H.B. and Barrows, L.J., "Soil Gas Measurement for the Detection of Subsurface Organic Contamination," U.S. EPA, Las Vegas, NV, 1986.
[b]Compound amenable to soil-gas surveying.

EXPERIMENTAL DESIGN

The objectives of the study were to assess the bias and the precision of this newly developed technique for detection and measurement of groundwater contamination by VOCs and to study the vertical distribution of VOCs in the vadose zone. The study location has a known chloroform-contaminated groundwater plume

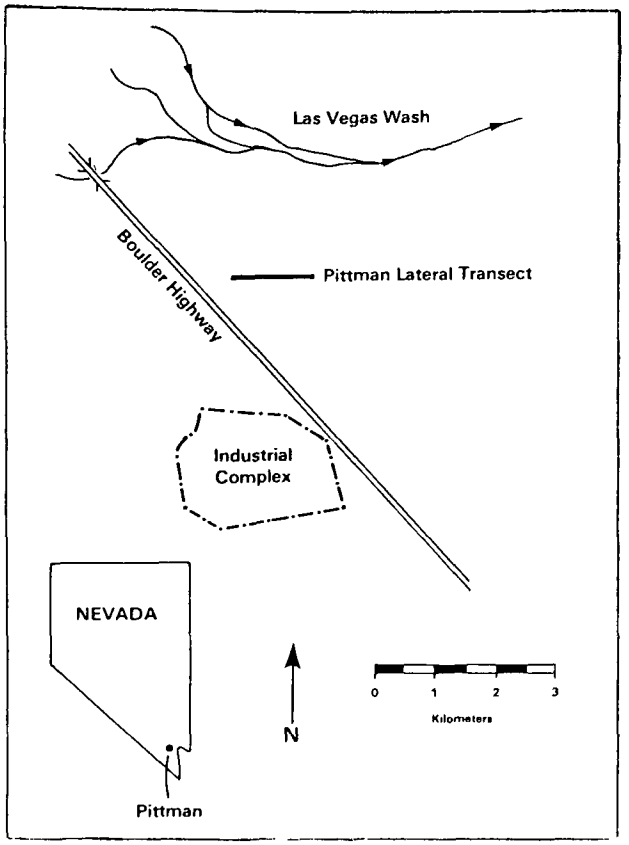

Figure 1
Survey Site Location, Henderson, Nevada

and an existing system of groundwater monitoring wells. These monitoring wells are separated by 200 ft and lie along a line perpendicular to the direction of groundwater flow.

For evaluation of the method bias, soil-gas samples were taken at a 4-ft depth at four locations 20 ft to the north, east, south and west of four monitoring wells within the boundaries of the groundwater plume. To delineate the edges of the plume, additional samples were taken at a 4-ft depth 20 ft to the east of a well at the western edge of the groundwater plume and 20 ft to the

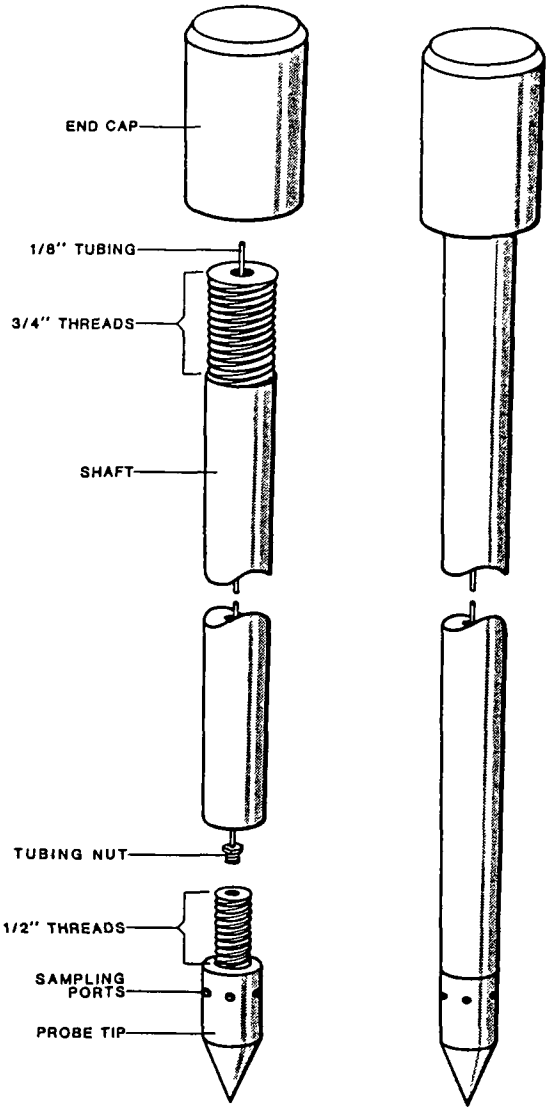

Figure 3
Sampling Probe Design

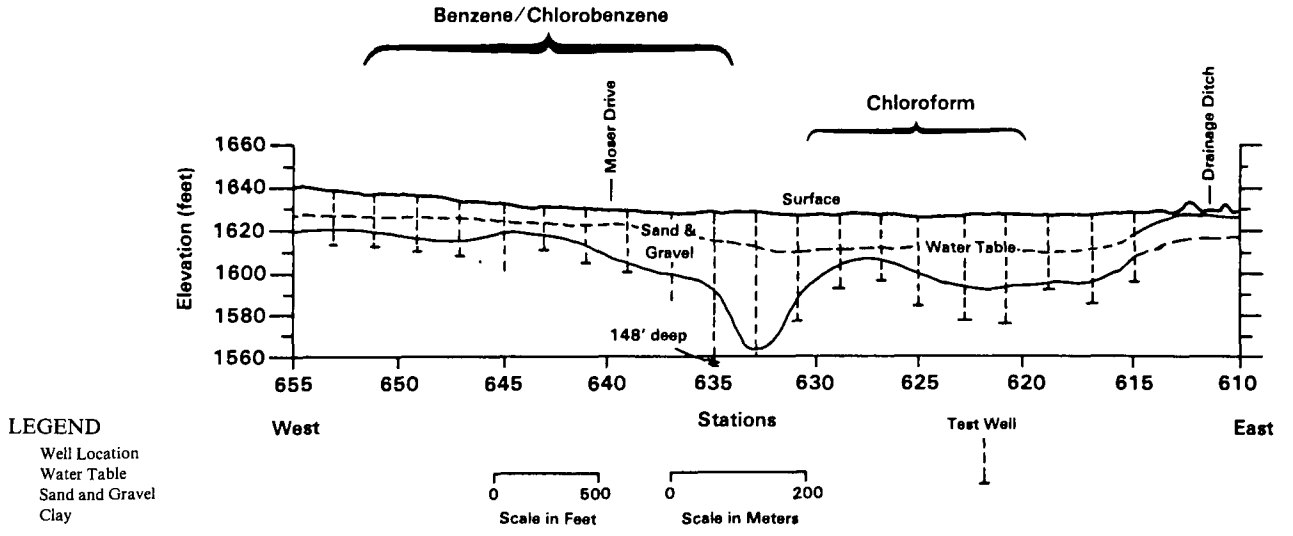

Figure 2
Subsurface Hydrogeology at the Pittman Lateral

west of a well on the eastern edge. Samples were taken in triplicate and were analyzed by gas chromatography on site. The triplicate analyses were used to assess the method precision.

At one sampling location, four points separated by 3 ft were sampled as a check on the short-range variability of the method. Halfway between two of the wells, three points separated by 3 ft were sampled in duplicate at depths of 1, 2, 3, 4 and 5 ft.

STUDY LOCATION

The geohydrology of the study area is relatively simple. Unconfined groundwater occurs at a depth of 7 to 15 ft in calcified, unconsolidated alluvium overlying a clay acquiclude. The ground surface, water table and acquiclude all slope downward about 1 degree to the north, and the groundwater moves northward about 1.5 ft/day. Figure 1 shows the site location, and Figure 2 shows the geohydrologic profile along the line of our survey.

EXPERIMENTAL

A shallow probe was used to obtain soil-gas samples from a depth of 4 ft. The probe consists of an outer pipe constructed of ¾-in. o.d. high-strength steel that ends in a tapered head with six horizontal sampling ports, each 1/8 in. in diameter. A 1/8-in. o.d. stainless-steel tube is connected to the sampling ports and runs through the pipe to the sampling manifold. The sampling manifold is assembled from commercially available stainless-steel fittings. Figures 3 and 4 show the probe design. Figure 5 shows the sampling manifold.

After insertion into the soil, the sampling manifold was purged with soil gas. Samples were then withdrawn from the manifold using gastight syringes and were transported to a mobile laboratory.

Soil-gas samples were analyzed on-site using an Analytical Instruments Development Model 511 gas chromatograph with a ^{3}H electron-capture detector. The gas chromatograph was operated at 43 °C, and the output was processed using a Shimadzu C-R3A integrator. Calibration standards were prepared by serial dilutions of chloroform headspace vapors.

Figure 6 shows the soil-gas sampling locations relative to the monitoring wells. Groundwater samples were taken and analyzed in April and August of 1985. The samples were analyzed by the purge-and-trap gas chromatography/mass spectrometry (GC/MS) method specified in the U.S. EPA Contractor Laboratory Program.[7]

RESULTS

The bias of the method was evaluated by comparing the mean soil-gas chloroform concentration measured to the results of the groundwater analyses. The soil-gas chloroform concentrations correlate strongly with the groundwater concentrations. Table 2 lists the soil-gas and groundwater chloroform concentrations at each well. Figure 7 is a plot of these data. A linear regression of the soil-gas concentrations on the groundwater concentrations indicates a correlation of better than 95% significance ($r = 0.85$, $n = 6$).[8] In addition, the spatial delineation of the chloroform groundwater plume, as shown in Figure 8, is very good.

The mean chloroform concentration from the four locations around each well was used in the above calculations; however, the relative standard deviation (RSD) of these mean values was often quite high (above 100%). We interpret this result to be an effect of spatial variability in the soil-gas chloroform concentrations over the 20- to 40-ft lateral distances separating these sampling points.

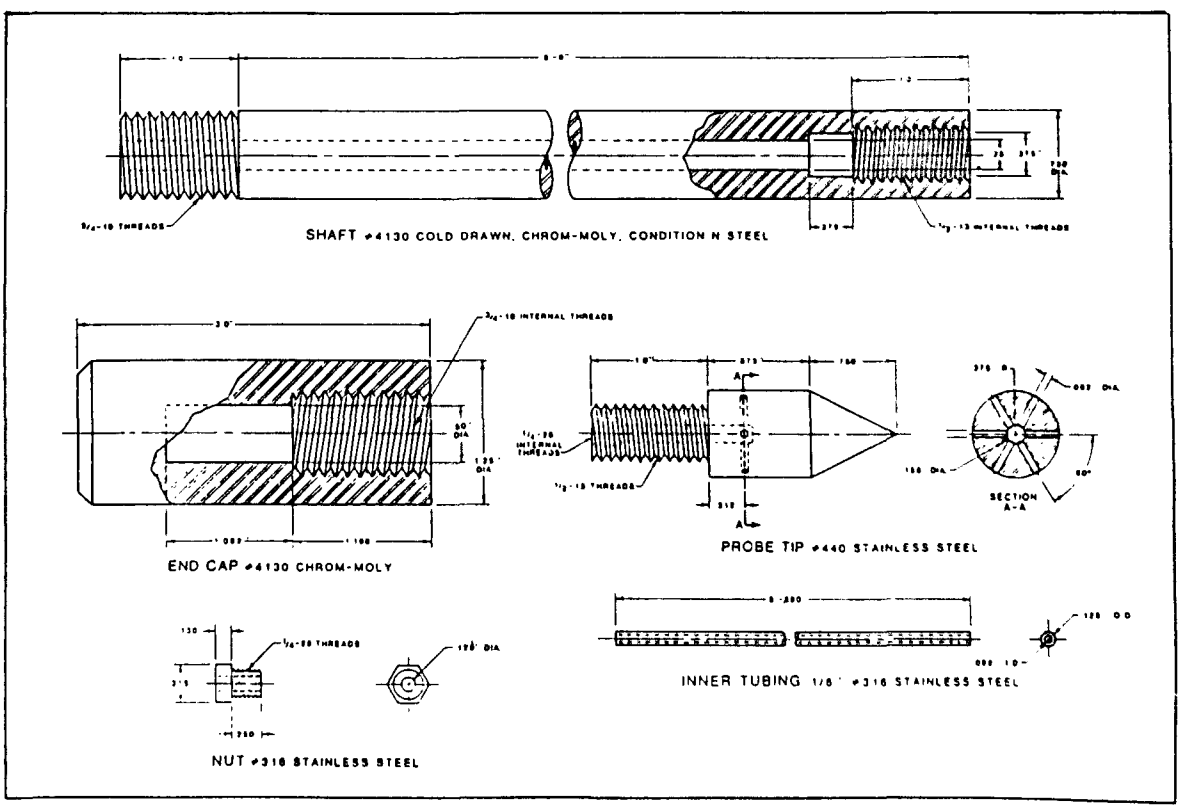

Figure 4
Probe Construction Specifications

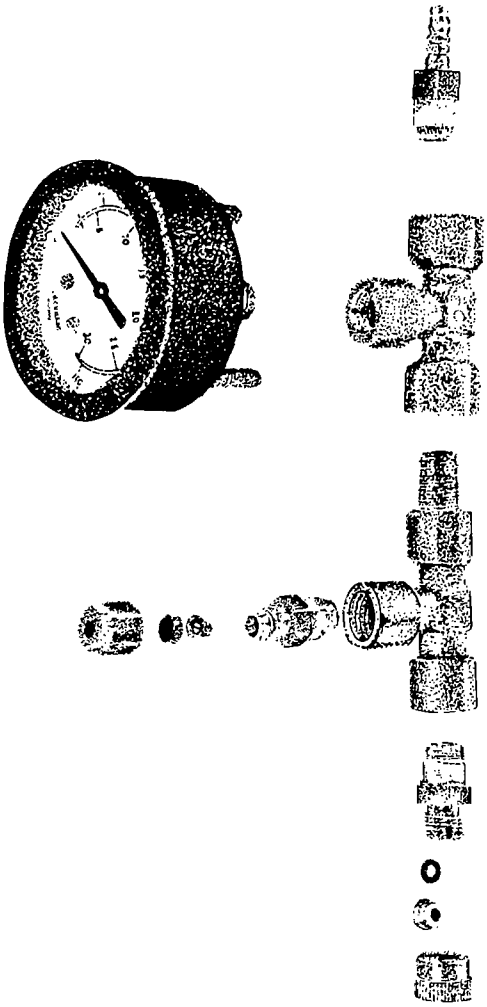

Figure 5
Sampling Manifold

The precision of the method was evaluated by analysis of multiple samples. The analytical precision, based on multiple daily analyses of calibration standards, showed an rsd value below 4%. The combined sampling/analysis precision, based on triplicate samples from each location sampled at a 4-ft depth, was characterized by a mean rsd of 12%.

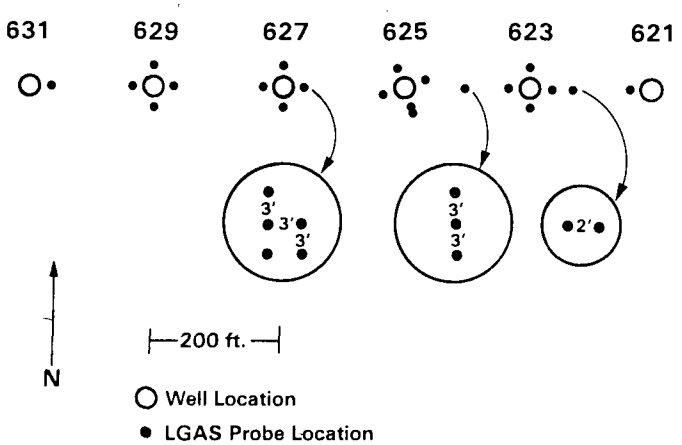

Figure 6
Soil-Gas Sampling Points (Sampling Depth = 4 feet)

Table 2
Groundwater and Soil-Gas Chloroform Concentrations

Well	Ground-water concentration (µg/L)	Soil-gas concentration (ppbv)[a] 20 ft. West	20 ft. North	20 ft. East	20 ft. South	Mean
631	ND[b]			5(0)		5
629	11	10(2)	25(2)	27(5)	31(1)	23
627	175	28(5) (WSW)	72.9(0.1) (WNW)	124(53)[c] (ENE)	45.6(0.2)[d] (25 ft. SSE)	67
625	866	266(6)	326(10)	376(6)	111(17)	370
100 ft. E of 625						150
623	555	115(6)	12(5)	6(3)	27(2)	40
621	28	10.5(0.3)				10.5

[a]Triplicate analyses; standard deviation in parentheses.
[b]Not detected; 5 µg/l used in regression.
[c]Mean of four closely spaced points (see text).
[d]Duplicate determinations.

The effect of short-range geologic variability on analytical results was assessed in two locations. At one location, four samples were taken at a depth of 4 ft, at separations of between 3 and 7 ft. Figure 6 shows the pattern of the sampling points. The rsd value of the chloroform concentrations among these points was 42%. At another location, three points 3 ft apart along a north-south line were sampled at five depths in 1-ft increments between 1 ft and 5 ft. The mean rsd value of the mean chloroform concentration for all five depths at the three locations was 12%. These results indicate the short-range geologic variability can be a major factor in soil-gas surveys and that the magnitude of this factor can vary.

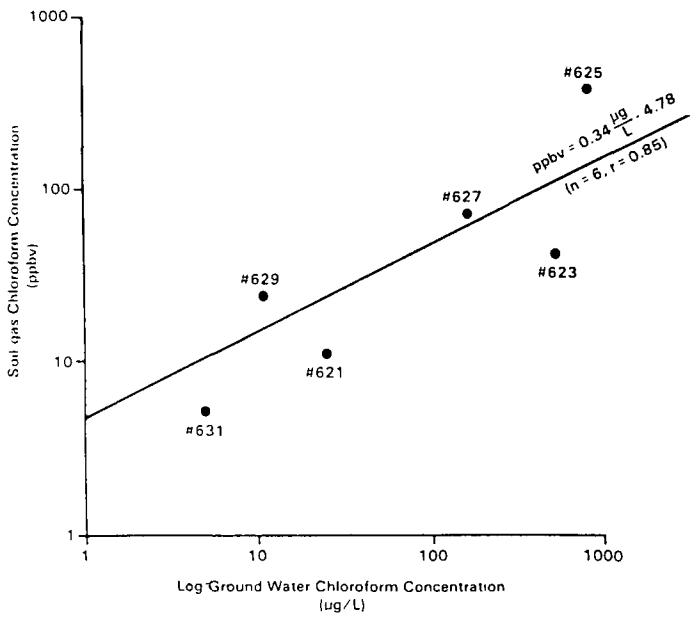

Figure 7
Plot of Chloroform Soil-Gas Concentration and Groundwater Concentration

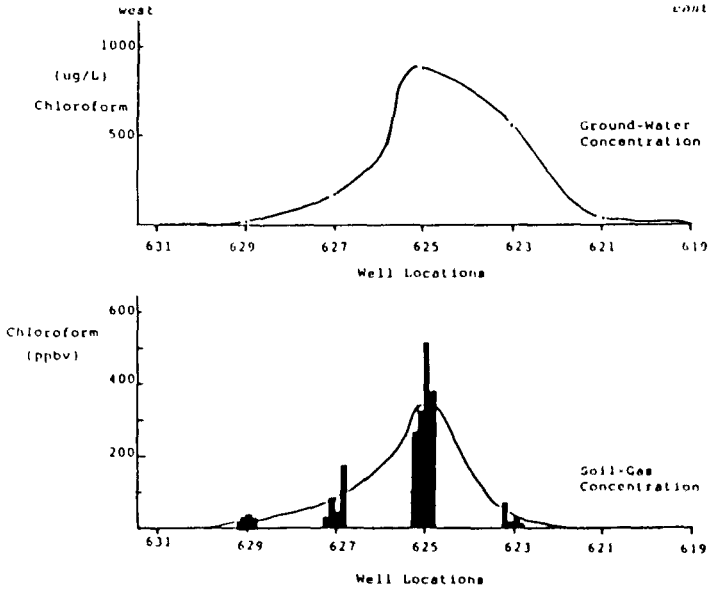

Figure 8
Spatial Distribution of Chloroform in Soil-Gas and Groundwater Samples

The results of an evaluation of the chloroform concentration vertical profile (Table 3) showed a linear dependence of concentration upon sampling depth. A correlation coefficient indicating greater than 99% significance was obtained ($r = 0.999$, $n = 5$). This result is in agreement with a model proposed by Swallow and Gschwend[8] that attributes vertical transport of VOCs through the vadose zone to gaseous diffusion. The water table below the sampling locations was at a depth of approximately 13 ft.

Table 3
Chloroform Concentration Vertical

Location	Depth	Mean chloroform concentration (ppbv) (SD[a])
base	1	23.0 (0.1)
3 ft. N	1	22.9 (0.8)
6 ft. N	1	19 (1)[b]
base	2	76 (1)
3 ft. N	2	70 (2)[b]
6 ft. N	2	58 (3)
base	3	109 (1)
3 ft. N	3	111 (1)
6 ft. N	3	99 (14)[b]
base	4	153 (9)
3 ft. N	4	149 (1)
6 ft. N	4	132 (14)
6 ft. N	5	205 (2)[b]
base	5	183 (8)
3 ft. N	5	167 (23)
base	6	236 (29)

[a]Duplicate measurements unless noted
[b]Triplicate measurements

CONCLUSIONS

Soil-gas surveying accurately indicated groundwater chloroform contamination at a site in Pittman, Nevada. The precision of the technique is controlled by sampling and short-range geologic variabilities. At the site studies, results of a depth study agreed along with a model for vertical transport of volatile organic compounds through the vadose zone by gaseous diffusion.

ACKNOWLEDGEMENTS

The authors would like to acknowledge contributions made by J.W. Curtis, K.L. Ekstrom, and L.J. Barrows to this study.

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Environmental Appraisals and Audits: A Case Study of Their Application

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ABSTRACT

The Bonneville Power Administration (BPA) has had an environmental audit and appraisal program for 2 years. BPA's unusual approach in implementing its appraisal program resulted in the program's quick acceptance and organizational effectiveness.

The first audits conducted under the appraisal program identified problems in the use of polychlorinated biphenyl (PCB) equipment at BPA substations. Subsequent U.S. EPA inspections confirmed these same findings. In response to this situation, the U.S. EPA and BPA entered into a Memorandum of Agreement (MOA) specifying corrective actions to be taken.

The U.S. EPA, recognizing the strength of BPA's appraisal program, agreed to forego their normal ad hoc inspections of BPA facilities. Instead, the U.S. EPA deferred to BPA's own audits with U.S. EPA inspections limited to followup or verification inspections.

In addition to ensuring compliance with environmental regulations, the Agreement's reliance upon BPA's appraisal program maximizes the effective use of limited staff resources in both agencies. The Agreement interjects a large measure of predictability and manageability into BPA efforts to achieve compliance.

INTRODUCTION

As a power marketing agency within the U.S. Department of Energy (DOE), the Bonneville Power Administration (BPA) sells and transmits the electrical output from 30 federal hydroelectric dams in the Columbia River Basin. The BPA service area includes 300,000 square miles primarily in the states of Oregon, Washington, Idaho and Montana, with small service areas in California, Nevada, Utah and Wyoming. The BPA transmission system serves as the backbone for the interconnected utilities in the Pacific Northwest and is connected with 18 other transmission systems at over 100 locations. The BPA transmission system consists of approximately 14,200 circuit miles of high voltage transmission lines and about 400 substations. Approximately 100 of the BPA substations contain polychlorinated biphenyl (PCB) equipment, primarily PCB capacitors. A total of about 140,000 PCB capacitors are in service at these substations.

In 1983 BPA instituted an environmental appraisal and audit program. Upon adoption of the program, BPA decided as a matter of policy to use its appraisal and audit program as a mechanism to ensure that BPA facilities comply with applicable environmental standards.

BPA APPRAISAL AND AUDIT PROGRAM

Equal to the importance of its adoption is the special approach BPA used in implementing its new program. BPA is convinced that, given its own organizational culture, any other implementation approach would not have been as readily accepted and therefore would have been much less successful in achieving the objectives of the program.

BPA appraisal program objectives include the following:

- Assure that DOE environmental policy and requirements are appropriately interpreted and implemented by BPA and BPA contractors.
- Help line managers achieve BPA's compliance commitments.
- Increase employees' awareness of environmental regulations and BPA's commitment to compliance.
- Provide management with objective, timely and reliable information on BPA and BPA-contractor environmental performance, including significant achievements and efficiencies.
- Evaluate the effectiveness and efficiency of BPA's implementation of measures to avoid, minimize, rectify or otherwise reduce adverse impacts to the environment and measures to compensate for impacts.
- Provide management with recommendations for improvement of BPA's environmental program performance.
- Develop and recommend long-term solutions to current environmental problems in anticipation of future standards or conditions.
- Evaluate the accuracy of environmental analysis or impact predictions and identify methods for improvement.

These objectives are relatively standard. What distinguishes the BPA program is the unusual approach taken in its implementation. Without compromising the objectives of the program, the approach taken was a positive one designed to find the facilities audited in compliance. As a practical matter, this simply meant that every effort was made to communicate, beforehand, what was required and what would be audited. This was accomplished by providing advance copies of checklists to be used during the audit and by meeting with the affected organizations prior to their actual audits. This approach was very well received by the affected field organizations. Given BPA's functional organization and culture, any other approach would have met with resistance. Other factors which ensured successful implementation were provisions to: (1) resolve problems at the lowest organizational level; (2) include representatives of affected offices on each appraisal team; and (3) resolve smaller problems in the field (i.e., labeling equipment), so that they need not be mentioned in the written audit reports. Taken together, these provisions were viewed as a sincere attempt by central headquarters staff to assist the field facilities to come into compliance without unnecessarily embarrassing them organizationally.

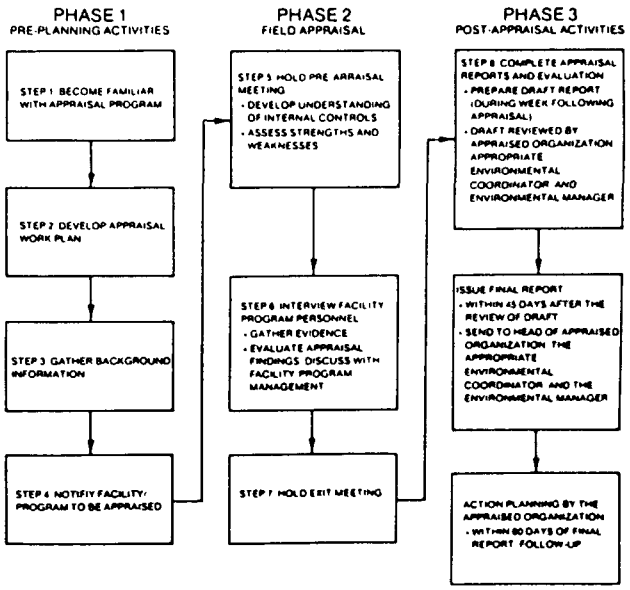

Figure 1
BPA Environmental Appraisal Process

DEVELOPMENT OF THE APPRAISAL PROGRAM

A useful strategy in the initial development of the Environmental Appraisal Program was to seek management consensus regarding both the scope of the program and the priorities of sites to be appraised.

To begin the program, meetings were held with all affected managers. The objectives and purposes of the appraisal program were discussed. As a result of these discussions, it was agreed that BPA's appraisals initially would focus on operations and maintenance activities.

It was also agreed that the first year's program should examine the requirements of those environmental laws and regulations dealing with oil spill prevention, hazardous and toxic waste management, noise pollution control, safe drinking water protection and commitments made to the public through documents prepared to comply with the National Environmental Policy Act.

After a schedule was developed for the first year and appraisal teams were identified, training was conducted for those who would participate in the program. BPA sought contractor assistance in conducting the initial training and obtained the services of a nationally recognized firm that had published information in the area of environmental auditing.

Through the training, the teams obtained skills regarding the use of checklists and how to document audit findings in a report. Also, environmental staff members contacted other electric utilities who had completed environmental audits or appraisals in-order to utilize their experience in performing environmental audits on facilities associated with the electric utility industry.

In the program's first 2 years, 23 field appraisals were conducted. Each of these appraisals required 1-2 days of field work at the site followed by the preparation of a written report; the equivalent of approximately four full-time positions have been required to implement the appraisal program.

Figure 1 illustrates the basic steps used in conducting the appraisal process.

STRUCTURE OF THE APPRAISAL PROGRAM

The BPA appraisal program contains three components. Each component has a different focus (site versus program) or em-

Figure 2
BPA Audit/Appraisal Program TSCA Checklist

Polychlorinated Biphenyls (PCBs) in Service

Definitions: PCBs in service at BPA facilities may fall into any of the following categories: (1) non-PCB equipment, where the level of PCBs is below 50 ppm; (2) PCB-contaminated equipment, levels of 50 to 499 ppm PCBs; and (3) PCB equipment with levels above 500 ppm. This checklist addresses all PCB articles in service, *whatever the distinction in PCB levels.* If appropriate, remarks regarding the levels of PCBs should be made in the Remarks Column or on the back of the page.

Note 1: Definition of Transformer: All transformers (e.g., power transformers, potential transformers, current transformers) are defined as any piece of equipment which contains the description "transformer" on the manufacturer's nameplate.

a) The transformers that have no PCB ppm tag, and which have the word "oil" marked on the manufacturer's nameplate, are assumed to be 50-499 ppm PCB until these are tagged with the actual PCB ppm level.
b) The transformers that have no PCB ppm tag, which have markings such as "liquid-filled" or "contains dielectric" (other than the word "oil") or do not give any indication of the content of the transformer, are assumed to contain more than 500 ppm PCB until these are tagged with the actual ppm level.

Yes No 0. Does the facility have any equipment which contains any levels of PCBs (either in service or in storage)?

1 PCB-Containing Equipment (Transformers, Circuit Breakers, Reactors, Reclosers, etc.)

Yes No 1.1 Has this facility ever conducted an inventory of its equipment which contains PCBs (or an inventory of all equipment including pieces containing PCBs)?

1.1.1 If yes, when was the inventory conducted? (date of printout) _____

Yes No 1.1.2 If yes, is the inventory complete? (Check each piece of equipment to see if it corresponds to the inventory.)

1.1.3 Describe each type of PCB-containing equipment, quantity, status, PCB concentrations and volumes (or include inventory list as working paper):

Type	Quantity	Status	PCB Conc.	PCB Volume

Yes No 1.2 Are all pieces of equipment marked with an appropriate PCB ppm level tag and or the appropriate PCB label (M_L)?

1.2.1 If no, list the ones that are not marked.

Yes No 1.3 Are any pieces of equipment leaking? (Identify)

1.3.1 What action is being taken to control these leaks? Describe: _____

Note 2: Action to contain and cleanup leaks in 500+ ppm PCB Transformers must be initiated within 48 hours of having knowledge of the leak. All leaks from any transformer or other piece of equipment should be contained and cleaned as soon as possible.

Yes No 1.4 Are all pieces of equipment inspected?

1.4.1 At what frequency? _____

Yes No 1.5 Are inspection records kept?

Where? _____

Yes No 1.5.1 Are operators' inspection records maintained for three (3) years after equipment disposal?

Where? _____

Yes No 1.6 Are pieces of equipment stored for use (spares) listed on the inventory?

Yes No 1.6.1 Are these spares inspected regularly as described above?

Yes No 1.7 Have any pieces of equipment been serviced or repaired (rebuilt) at the facility?

Yes No 1.7.1 Are maintenance records for these pieces of equipment kept? Where _____

Figure 2 (continued)

Yes No 1.8 Does the facility ever top-off or refill any existing pieces of equipment?

1.8.1 What materials are used? (include PCB ppm levels)

_____

_____

Note 3: No new oil will be procured with over 2 ppm PCB level.

Yes No 1.9 Have any pieces of equipment been removed from service at this facility?

Yes No 1.9.1 Are records kept on the disposition of these pieces of equipment? Where?_____

2. Capacitors

Yes No 2.1 Has this facility ever conducted an inventory of capacitors?

2.1.1 If yes, when was the inventory conducted? (date of printout) _____

Yes No 2.1.2 If yes, is the inventory complete?

2.1.3 Describe each type (or group) of capacitor, quantity, status, PCB concentrations and volumes (or include inventory list as working paper):

Group	Quantity	Status	PCB Conc.	PCB Volume

Yes No 2.2 Are all capacitors marked with an appropriate PCB label (M_L) or in an appropriately marked area?

2.2.1 If no, list the ones that are not marked.

_____

_____

_____

Yes No 2.3 Are any capacitors leaking?

2.3.1 How many? _____

2.3.2 What action is being taken to control these leaks? Describe _____

_____

_____

_____

Note 4: Action to contain and cleanup leaks in PCB capacitors must be initiated within 48 hours of having knowledge of the leak.

Yes No 2.4 Is there a designated area for capacitors stored for use?

Yes No 2.4.1 Is this area appropriately marked?

Yes No 2.5 Are all capacitors inspected?

Yes No 2.5.1 At what frequency?_____

2.6 Where are inspection records kept?_____

Yes No 2.6.1 Are operators' inspection records maintained for three (3) years after equipment disposal? Where?_____

Yes No 2.7 Are capacitors stored for use (spares) listed on the inventory?

Yes No 2.7.1 Are these spares inspected regularly as described above?

Yes No 2.8 Have any capacitors been removed from service at this facility?

Yes No 2.8.1 Are records kept on the disposition of these capacitors? Where?_____

3. General Procedures

Yes No 3.1 Has or is a PCB analysis done before any oil handling?

Yes No 3.2 How are solvents, filters or rags disposed of if used on equipment of unknown PCB level? _____

_____

_____

_____

Yes No 3.3 Does the facility have the SPIFs on handling, inspecting, storing PCBs and PCB equipment?

3.3.1 Where are they kept? _____

3.3.2 List the SPIFS found at the facility:

_____

_____

4. Other Equipment Containing PCBs (Light Ballasts, Relays, etc.)

Yes No 4.1 Does the facility have any other equipment containing PCBs? List:_____

_____

_____

_____

Yes No 4.2 Has any of this other equipment leaked?

Yes No 4.3 Was cleanup initiated?

4.4 Describe how the material was contained, cleaned up and disposed of: _____

_____

_____

_____

Yes No 4.5 Has any of this other equipment been removed from service, but retained for backup at this facility?

phasis and each is the responsibility of a different organization (field personnel versus central staff). These three components are listed below.

Functional Appraisal

The functional appraisal is an evaluation of the agency's overall performance based upon a compilation of findings obtained from the individual field appraisals. This appraisal is conducted annually by BPA's Environmental Manager's office. The functional appraisal focuses its attention on major or repetitive problems identified in the field appraisals. In addition to apprising top management of its findings, the functional appraisal is used as a means for securing management support for implementing those recommendations that require an organizational commitment of resources.

Field Appraisal

The field appraisal is a documented, on-site appraisal of program effectiveness for specific disciplines, namely hazardous and toxic waste management, oil spill containment, noise and safe drinking water regulations. Following the field appraisal, a written action plan is prepared. The action plan outlines an agreed upon course of action to implement recommendations designed to correct problems identified in the field appraisal. The action plan is prepared within 60 days after completion of the field appraisal.

Internal Audit

A self-audit is a less formal evaluation, conducted by the line organization on a particular part of its environmental program. These audits are scheduled on an as needed basis.

The three types of appraisals described above permit appraisals to be specific to a particular audience or level within the organization and to focus upon issues of greatest concern to that level.

MEMORANDUM OF AGREEMENT WITH THE U.S. EPA

In February 1985, the BPA and the U.S. EPA entered into a Memorandum of Agreement (MOA) to clarify each agency's responsibilities and commitments for conducting actions required and authorized by TSCA and CERCLA.

Among other things, this Agreement specifically provides that BPA will audit its field installations for compliance with TSCA PCB regulations. The Agreement requires that these audits be done on a scheduled basis and that they be administered by central headquarters staff. Any deviations from the PCB regulations that are found in the conduct of these audits are to be documented, and a compliance plan is to be included in the audit report. All reports are forwarded to the U.S. EPA. A copy of the PCB audit checklist, which reflects U.S. EPA Region 10's interpretation of the TSCA regulations, is included in Figure 2.

With the Agreement in place, the U.S. EPA agreed to forego ad hoc inspections of BPA facilities. Instead, U.S. EPA inspections are limited to verification inspections to be conducted only after the facilities have been audited by BPA.

CONCLUSIONS

The utility of BPA's environmental appraisal and audit program was evident even before the Agreement with the U.S. EPA, but its usefulness to the agency was certainly increased when the U.S. EPA agreed to use the appraisal program as a substitute for its ad hoc inspections of BPA facilities.

From the U.S. EPA standpoint, this ensured not only that potential violations would be corrected, but that the underlying causes would be corrected as well. From BPA's standpoint, rather than reacting to the U.S. EPA's inspections, this arrangement resulted in an opportunity to prioritize corrective actions at BPA facilities based on environmental and operational considerations. Consequently, a large measure of predictability and manageability was introduced into what could have been a counterproductive and possibly adversarial relationship with the U.S. EPA.

Chlorinated Organics and Hydrochloride Emissions Sampling from a Municipal Solid Waste Incinerator

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INTRODUCTION

As the use of solid waste incinerators in Texas increases, so do the questions regarding the environmental impact of their emissions. Are the incinerators creating or releasing potentially toxic materials from the waste?

Currently, there are eight municipal incinerators operating in Texas, and permit applications are pending for several more. The purpose of this paper is to report the levels of chlorinated organic, chlorine and chloride measured during the stack sampling conducted at the City of Waxahachie municipal waste incinerator. The sampling was performed in August 1985, by staff from the Texas Air Control Board (TACB) Sampling and Analysis Division. Three sets of 3-hour samples were collected.

The results of this sampling will be reviewed to determine whether or not additional preventive measures are needed to reduce the emission of toxic chlorinated organic compounds or hydrochloric acid. The hydrochloric acid emissions generally are thought to result from the burning of plastics in the refuse.[1] The chlorinated organic compounds (i.e., polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) may originate as contaminants in the refuse or as byproducts of the combustion of precursors in the incinerator.[2] In addition, these data will be used by the Permits Division of the TACB to develop emission factors to be used in permitting new incinerators.

The stack sampling procedure was a modified version of U.S. EPA Reference Method Five. The sample is collected by XAD-2, florisil, alkaline arsenite solution and glass fiber filter media.

RESULTS

At this time, analysis of all the samples collected is not complete. Results of the hydrochloric acid testing show the emissions to be on the order of 2 lb/hr. A preliminary list of compounds detected (but not quantified) is presented in this paper. The compounds that were detected are listed below with some information about their use, toxicity and exposure limits in air:

- *Dichlorobenzene*—used as a process solvent and as an intermediate in the synthesis of dyestuffs and herbicides;[3] causes hemolytic anemia and liver necrosis in humans; can also cause irritation of eyes and nose; the OSHA occupational exposure limit (OEL) has been set at 50 ppm upper limit.[4] The TACB Health Effects staff uses 1% of the OEL as a guideline for permit and health effects review.
- *Hepta and hexachlorodibenzofurans*—similar properties and health effects to dioxins of similar molecular weight. The Ontario Ministry of Health has set 1×10^{-3} $\mu g/m^3$ as a standard.
- *Hepta and hexachlorobiphenyls*—used in electricity transmission transformers; can cause cancer and adverse skin, liver and reproductive health effects. The NIOSH standard is 1 $\mu g/m^3$.
- *Hexachlorobenzene*—used as an herbicide, wood preservative and also is a byproduct from chlorinated hydrocarbon production;[5] can cause death in breast-fed infants, skin sores, skin discoloration and enzyme disruptions.[6] There are no standards set for this pollutant, however, the TACB Health Effects staff uses 1% of the estimated OEL of < 1 ppm as a guideline for permit and health effects review.
- *Pentachlorobenzene*—used as a precursor to fungicide production and as a flame retardant; also occurs as a product of the degradation of Lindane;[7] may cause mutagenic and carcinogenic effects in mice.[8] There are no air standards set for this compound, but 1% of the estimated OEL is used as a guideline by the TACB.
- *Tetrachlorodibenzo-p-dioxin*—occurs as a byproduct of herbicide production;[9] causes liver cirrhosis, spontaneous abortions, kidney disease and chloracne.[10] The New York Air Pollution Control has set a standard of 9.2×10^{-9} $\mu g/m^3$.
- *Trichloroethane*—used as a degreaser, "cold" cleaner and dry-cleaning agent;[11] acts as a narcotic to depress the central nervous system; can cause dizziness, uncoordination, drowsiness and death systematically. Locally, it is irritating to eyes and causes dermatitis.[12] Air limits include TLV of 10 ppm. The short-term exposure limit (STEL) value is 20 ppm (tentative).[13] The OSHA standard is 10 ppm.[14]

The compounds detected in the analyses of these samples are consistent with compounds measured in stack sampling conducted in other areas.[15,16] Stack sampling conducted by the state of California and Scott Environmental (contracted by EPA) indicates the small amounts of PCDDs and PCDFs were detected in municipal solid waste incinerator emissions.

INCINERATOR DESCRIPTION

The municipal solid waste incinerator stack sampling was conducted from Aug. 13 to 15, 1985. Three separate sets of samples were collected over a 3-hr period each time. A representative portion of the stack emissions was collected isokinetically using standard operating procedures described in the TACB Sampling Procedures Manual.

The incinerator sampled is located on Singleton Drive in North Waxahachie, Texas. It has two dual-chambered incinerators that operate at approximately 1600°F. The incinerators are permitted to destroy 2088 lb/hr of solid waste. The residence time is approximately 45 min to 1 hr in the primary burn chamber and 1.22 sec

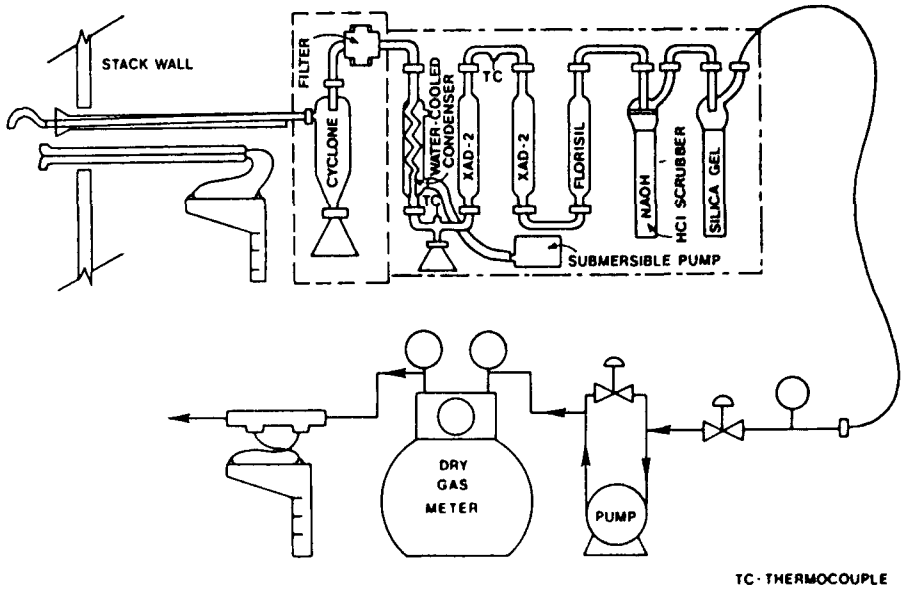

Figure 1
Chlorinated Organics Sampling Train

for the secondary burn chamber which is often used to burn effluent gases from the first chamber.

The California Air Resources Board recommends a flue gas temperature of 1800°F +/− 190° with a residence time of 1 sec under well-mixed conditions. These conditions should destroy 99.9% of the toxic organics compounds.[1]

The facility is operated 24 hr/day, 6 days/week. There is down time for maintenance and cleaning each day. The facility is permitted to emit 12 lb/hr or 53 tons/yr of particulate matter.

SAMPLING TRAIN

The sampling train used to collect chlorinated organic compounds is shown in Figure 1. The sampling apparatus is made entirely of glass except for the stainless steel nozzle and teflon tape seals used between the ground glass joints. Following the standard front-half, the back-half is modified to consist of a water jacketed condenser followed by two XAD-2 and one Florisil resin traps in series. The remainder of the train consists of two impingers. The first impinger contains 200 ml of sodium arsenite to collect chlorides/chlorine and to protect equipment downstream. The second impinger contains silica gel to insure the complete dryness of the sampled gas. The Organic Laboratory Section performed the analyses of the samples using the Finnigan triple quadrupole mass spectrometer (TSQ).

The hydrochloric acid emissions were captured using the collection system as described in Chapter 5 of the TACB Sampling Procedures Manual. The stack exhaust gas entered the system isokinetically through a stainless steel probe and traversed a non-heated probe across a glass fiber filter which was maintained at 250 to 275°F. The condenser train consisted of a series of impingers containing deionized water, alkaline arsenite and silica gel. The analyses followed the procedures described in the TACB Laboratory Procedures Manual.

Leak checks were performed several times during the process to insure sample integrity. If acceptable, the sampling process was continued. The sample air was circulated through a condenser filled with cold water. Due to the large volume (approximately 100 ft^3) and the high moisture content of the air drawn from the stack, a large volume of condensate was collected in the flask following the condenser. As necessary, the condensate was removed from the flask, the volume recorded, transferred to an amber glass container and returned to the TACB laboratory for analysis. A check for air leakage in the sampling system preceded and followed the condensate transfer to insure sample integrity.

Following the completion of sampling, the three adsorption tubes and impingers were weighed again and their final weights were recorded to determine stack air moisture content. The probe and glassware in front of the filter were rinsed with tetrahydrofuran (THF). All rinsate was collected in amber bottles. The amber bottles were used to prevent rinse solutions from reacting with ultraviolet light. The glass fiber filter was returned to its protective aluminum foil and stored in plastic envelopes until analysis. The connecting glassware and two impingers were rinsed with deionized water and the rinsate was collected for analysis at the TACB laboratory.

ANALYTICAL METHODS

The XAD-2 and Florisil adsorbers were extracted using hexane in a Soxhlet extractor for 8 hr. The distillate then was evaporated down to 2 or 3 ml using a rotary evaporator. The product was injected into a gas chromatogram/mass spectrometer (GC/MS). The pollutant results were interpreted by a TACB chemist who used graphic responses compared to a chemical library to identify the pollutants.

The front-half and back-half rinsates were concentrated by evaporation. Separately, the products of the evaporation were injected into the GC/MS. The results were interpreted as discussed in the previous paragraph.

The impinger containing deionized water was used to collect hydrochloric acid. The samples were analyzed turbidimetrically. Chlorine was collected in the arsenite solution. The solution also was analyzed turbidimetrically.

The glass fiber filter also was analyzed for chlorides and chlorinated organics. A 37 mm diameter circle was cut from each of the three filters. The exposed filters were analyzed versus the field blank for chlorine on an x-ray fluorescence spectrometer system. Duplicates also were run to test the method's precision. In addition, the filters were analyzed for chlorinated organics. They were extracted separately using hexane and a Soxhlet extractor. The resulting solution then was reduced to 2 or 3 ml with nitrogen. The product was injected into the TSQ and analyzed as described previously.

CONCLUSIONS

More stack sampling of municipal solid waste incinerators in Texas is needed. During this initial stack sampling exercise, there were some problems with the plant operation and with the stack monitoring process due to malfunctions in the incinerator. Preliminary determinations of the hydrochloric acid test have been made. The emissions of hydrochloric acid are approximately 1 lb/hr. This value is lower than expected.

Particulate matter collected during the test was analyzed and found to contain significant amounts of chloride salts. It is believed that the chlorides exiting this process were primarily chloride salts with relatively low hydrochloric acid emissions. Further testing is required to determine if this is the case.

Also, some of the pollutants detected in preliminary analysis are very toxic and warrant additional attention. PCDDs and PCDFs have been described by some sources as unsafe at any level. This project has not produced enough information to prescribe incinerating at higher temperatures, having longer residence times in the burn chamber, requiring additional pollution control devices or sorting out plastics before incineration.

Whether or not the Waxahachie municipal solid waste incinerator is representative of incinerators in Texas also is not known. Stack sampling at other sites may be needed to adequately characterize incinerator emissions. Other types of air quality monitoring also may be warranted. Perhaps monitors placed downwind may help correlate stack emissions levels to levels nearby residents may eventually breathe. Therefore, developing conclusive emission factors is premature.

ACKNOWLEDGEMENT

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CARE—Modeling Hazardous Airborne Releases

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ABSTRACT

Emergency preparedness for airborne hazards means being able to answer such questions as where the material will go, who it will effect, what areas are safe as evacuation centers, how long the chemical will take to disperse and which preplanned response option would be most effective in the event of an incident. To help answer such questions, Environmental Systems Corporation (ESC) has developed an assemblage of sophisticated mathematical models into a user-friendly and truly capable computer system called the CARE (Computerized Airborne Release Evaluation) System.

CARE provides the capability to perform a variety of functions, such as risk assessment, hazardous materials training, monitoring and emergency response. In short, CARE provides the tools needed to prevent an emergency from becoming a disaster.

INTRODUCTION

Are you ready for a hazardous materials accident? What would you do if a toxic cloud from a spill or a ruptured tank threatened your facility? What if burning chemicals were threatening your town today? Where would the cloud go? Who would be effected and who would be out of danger? What areas would need to be evacuated? Where could people go to be safe? What is the best way to respond to the emergency? How do you get answers to these questions in time to prevent the emergency from becoming a disaster?

To answer such questions, Environmental Systems Corporation (ESC) has developed a system called CARE, which stands for Computerized Airborne Release Evaluation System. CARE gives you the capability to perform a variety of emergency preparedness functions:

- Risk Assessment
- HazMat Training
- Real-Time Monitoring
- Emergency Response

CARE is a system that puts truly capable emergency preparedness on your desk. In the event of an accident that releases a hazardous material into the air, CARE will tell you where it will go, who it will effect, which areas are safe as evacuation centers, how long it will take to disperse and which preplanned response options would be most effective. CARE gives you the ability to neutralize the danger, to assess alternative defense strategies and to keep abreast of changing situations. In short, CARE gives you the tools you need to prevent an emergency from becoming a disaster.

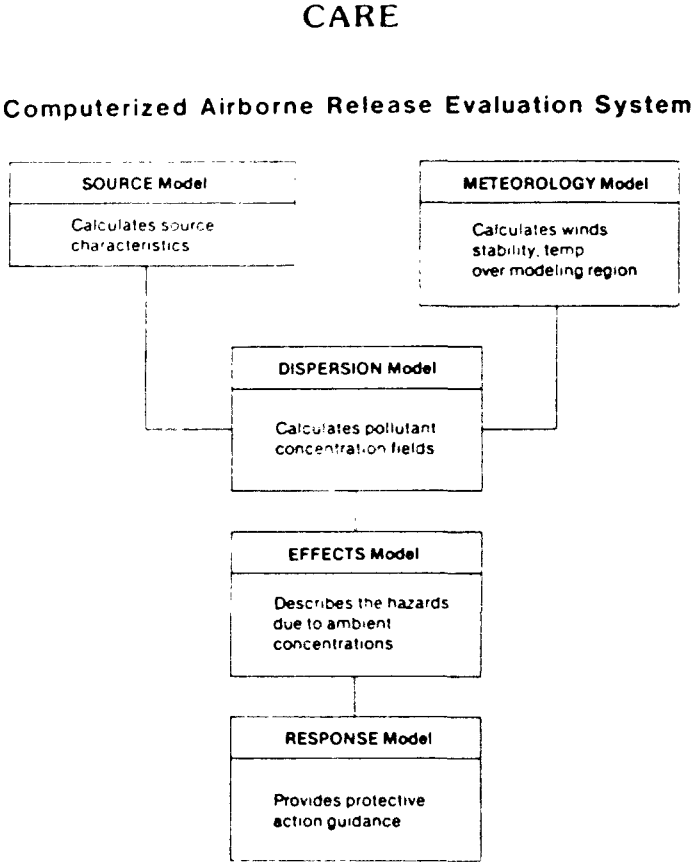

Figure 1
CARE System Diagram

SYSTEM DESIGN

CARE uses sophisticated mathematical models, assembled by ESC's meteorologists and engineers, to provide a realistic depiction of the hazard due to a cloud of airborne material. These models are grouped into five modules (Fig. 1):

- Source Module
- Meteorological Module
- Dispersion Module
- Effects Module
- Response Module

The Source Module provides one of the two basic mathematical models required to estimate atmospheric concentrations of airborne materials. For chemical spills, it calculates the evaporation rate of the chemical into the atmosphere. This rate of evaporation, determined through heat and/or mass transfer mechanisms, it used as the emission rate in the second mathematical model, the air dispersion model. The final product is then the calculation of the geographical distribution of pollutant concentration at selected times since the spill, via the atmospheric dispersion model. Specific source modules are available for various applications such as chemical spills, fires and transportation accidents. nuclear plant accidents, fossil plant emissions, airborne pesticide releases, military smoke generators, etc.

The Meteorological Module is a group of several models that, in combination, characterize the weather conditions that effect the dispersion of hazardous materials. This module uses observed meteorological data, such as wind speed, wind direction, turbulence and temperature and provides the necessary inputs to the dispersion module.

The Dispersion Module, using the source and weather inputs, provides a realistic depiction of the movement of the cloud of hazardous material and calculates its concentration with respect to time and distance from the release. The model, which is the key to systems realism, is a variable-trajectory, puff-advection model. This kind of model treats the airborne release as a series of puffs which are moved by the air flow that has been calculated by the meteorological module. The puffs are diffused along the way according to the character of the atmosphere. The resultant dispersion of the material is displayed on the computer as a meandering plume which flows over and around obstacles, much as one would expect a plume to move once released to the air.

The Effects Module assesses the critical concentration values and provides information on the hazard to health and welfare posed by the materials in the plume. This module examines the concentration fields for critical levels based on the application. For example, the effects module for chemical accidents determines exceedances of Threshold Limiting Values or Lower Explosive Levels; for nuclear releases, it calculates dose and dose rate; for smoke obscurant releases, it calculates transmission or visibility; for ambient air quality, it determines exceedances of the National Ambient Air Quality Standards; and so forth.

The Response Module provides the user with recommended response actions based on the effects assessment. The response module is tailored by ESC to meet user requirements, special conditions and capabilities.

The CARE system assembles the aforementioned capabilities into a user-friendly system that is fully documented and tested. The near real-time display of the location and concentration of hazardous airborne materials provides the information needed to make informed decisions that can save lives and property.

SOURCE MODULE

The Source Module for toxic releases is based on the SPILLS model developed by Shell Development Company.[1] SPILLS is an unsteady-state model which calculates the evaporation of a chemical spill to determine the source strength of the vapor cloud. Used in conjunction with the atmospheric dispersion model, it is used to estimate concentrations of the vapors as a function of time and distance downwind of the spill.

Three options depending on the nature of the spill have been incorporated in the model: (1) continuous spills, such as leaks from tank cars, tanks or pipelines; (2) instantaneously-formed pools of liquids or liquified gases; and (3) stacks, where the emission rate is assumed to be known. For options 1 and 2, thermophysical properties (available as a subroutine in the computer program) of 36 potentially hazardous chemicals are used to calculate, through heat and mass transfer mechanisms, the evaporation rate, which becomes the emission rate for the atmospheric dispersion calculations.

The computer program was adapted for use with complex atmospheric dispersion models to provide a realistic prediction of hazard caused by an airborne toxic cloud. The program now contains the necessary properties of 36 potentially hazardous materials commonly handled, used or transported by industry, but the data easily can be expanded to include the thermophysical properties of other substances. The air dispersion model takes into account the atmospheric conditions, type of source and emission rate to calculate downwind concentrations. The source strength can be specified by the user (stacks) or is determined by the evaporation rate models if the chemical is known. Atmospheric and soil conditions and chemical properties are utilized to predict the effects of heat and mass transfer on the vapor cloud formation.

Evaporation Rate Models

The objective of an evaporation rate model is to predict the amount of material emitted in the case of a continuous or an instantaneously formed spill from a transport line or a storage tank. Although the basic theory is the same for both cases, the calculations are different, and thus they are presented separately.

Three evaporation rate models are discussed in this section. First, the continuous leak case which corresponds to emissions generated from small ruptures in transport equipment (e.g., pipelines, storage tanks or tank cars). In this case, the chemical is assumed to flow at atmospheric conditions through the rupture to form a quiescent pool on the ground. Since the chemical will be at ambient temperature, no heat transfer will occur between the material spilled and the surroundings, and the amount of mass taken by the wind blowing over the pool will be limited by mass transfer.

Two key variables involved in the mass transfer model are simultaneously unknown: (1) the area of the spill and (2) the emission rate into the atmosphere. It was assumed that the area of the pool would be the more difficult variable to predict during the accidental spill. Therefore, the computer program requests the value of the emission rate through the rupture, which the model takes as the emission rate into the atmosphere. The model then determines the spill area by assuming that this emission occurs by convective mass transfer. The evaporation then is assumed to occur indefinitely at the same rate unless the user specified the elapsed time from the beginning to the end of the flow through the rupture. At this point, the program would set the emission rate to zero.

Evaporation from instantaneously formed pools, the second option in SPILLS, corresponds to the spill of a chemical from a storage tank or transport line. In this case, however, the spill and the resultant pool at the ground are assumed to occur instantaneously. The area of the pool is assumed to remain constant during the evaporation process so that its estimation at the scene of the accident would be easier than the continuous spill case. The computer program then requests the value of this spill area in addition to the total amount spilled.

Chemicals with a normal boiling point below ambient temperature will first flash off due to the pressure drop between the storage pressure (the storage temperature has to be specified by the user) and atmospheric pressure. The evaporation rate due to this adiabatic flash calculation is assumed to occur during the first minute after the spill. The chemical will then form a pool of liquified gas at its normal boiling point. The difference between this temperature and the ambient temperature will cause heat to be transferred from the ground (the soil is assumed to be at am-

bient temperature) to the pool by conduction and from the atmosphere to the pool by convection.

Mass transfer, due to the wind blowing over the pool, takes over when the heat transfer evaporation rate becomes equal to the mass transfer evaporation rate. Note that this occurs because the heat transfer rate decreases as time increases, whereas the mass transfer rate is independent of time.

Finally, the emission rate is equated to zero when all the chemical is evaporated. Chemicals with a normal boiling point higher than ambient temperature are assumed to form a liquid pool at ambient conditions. Here, the chemical is assumed to evaporate only by convective mass transfer.

Continuous Leaks

Continuous leaks are regarded in the present work as emissions from a small rupture of a transport line (such as a pipeline) or a storage tank (such as a tank car). It is assumed that the mass flow rate through the orifice is known and that the chemical flows at atmospheric conditions, i.e., as a gas or as a liquid depending on the normal boiling point being below or above ambient temperature, respectively.

The chemicals of interest in the present program are all more dense than air so that a gaseous plume or a liquid pool will be formed at ground level after the chemical exits the original carrier. Convective mass transfer is assumed to be the limiting process for the chemical to be transported by the wind. The spill area then is predicted by equating the mass transfer rate to the flow rate through the rupture.

The pool size is determined for both laminar and turbulent flow cases and is used to predict the corresponding Reynolds numbers. The value that gives the consistent flow regime is chosen as the final pool length.

The area of the spill is used as a ground level area source in the air dispersion model. In addition, the flow rate through the rupture is utilized as the emission rate in the air dispersion calculations. The user has the option of specifying the length of time from the beginning to the end of the flow. This time can be estimated by knowing the amount of material to be emitted. This case is approached by the air dispersion model as an unsteady-state case where the constant emission rate is dropped to zero at the corresponding time. The program assumes a steady-state operation if no time is specified by the user.

Instantaneously Formed Pools

The time-dependent evaporation rates of stationary, instantaneously formed pools are calculated by two different procedures depending upon the chemical spilled: (1) liquified gases or (2) liquids. However, both methods assume that the chemical pool does not spread on the land as a function of time, such that the spill area specified by the user remains constant.

Liquified Gases

An initial adiabatic flash calculation is performed based on the pressure drop of the liquified gas (i.e., from the pressure of the chemical while stored, to atmospheric pressure).

The original enthalpy of the chemical is evaluated as the enthalpy of the saturated liquid at the user's specified temperature. For conservative purposes, the amount of vapor which is flashed off initially is assumed to be emitted in a period of 1 min.

The rest of the liquified gas remains in the liquid pool specified by the user at its normal boiling point. From this point on, the chemical can undergo two different transport processes: heat transfer or mass transfer.

Due to heat transfer, which occurs mainly by conduction from the soil assumed at ambient temperature and by convection from the atmosphere, the chemical evaporates off the boiling liquid pool. It is assumed that solar radiation is negligible and that no thermal resistance exists between the soil and the boiling liquid. The mass range at which the chemical evaporates is then determined.

The air dispersion model uses the time-dependent mass rate calculation to estimate the source strength during a heat transfer evaporation mechanism based on the total amount of mass evaporated between a time t(0) and any later time t.

Since all the chemicals treated in the present work are more dense than air, the emission rate into the atmosphere is mass transfer limited. This means that only a portion of the evaporated mass will be transported by the wind. Mass transfer governs this take-up flux into the atmosphere. The rest of the evaporated chemical remains as a gas cloud above the liquid pool. For conservative purposes, and due to the fact that the person at the scene of the accident will report an estimate of the size of the pool, it is assumed in the present work that all the mass evaporated by heat transfer will be emitted into the atmosphere.

Mass transfer occurs predominantly by forced convection over the liquid pool due to the wind. The amount of chemical emitted, used in the air dispersion model, is obtained from integration with respect to time of the amount of material emitted by mass transfer during the specified interval of time.

Heat transfer dominates at the beginning of the process. As time increases, the heat transfer emission rate decreases and reaches a point in time where it becomes equal to the mass transfer rate.

Liquids

Liquids are defined as those chemicals with a normal boiling point, T(B), higher than the ambient temperature, T(0). These chemicals are transported at conditions very close to ambient so that emission into the atmosphere after a spill will occur only through mass transfer by convection. The risk to health and life from an atmospheric release of hazardous effluent is a function of the ambient downwind concentrations and the length of the exposure period.

THE DISPERSION MODEL

A vital element in such a consequence assessment is the ability to estimate the location and concentration of an airborne effluent plume. To provide this estimate, the dispersion models employed must include both the transport and diffusion properties of the atmosphere. Consequently, the models must account for the physical, temporal and spatial changes that the atmosphere undergoes during the course of the release and during transport.

To estimate the downwind location and concentration of airborne effluents, CARE uses a highly sophisticated atmospheric dispersion model. The model includes both transport and diffusion components which account for the temporal and spatial changes that the atmosphere undergoes during the course of the release and during transport.

Atmospheric dispersion calculations are performed using the ESC variable trajectory, puff-advection model—TRAJ. The model simulates a release as a series of superposed puffs which are transported by the local atmosphere. Each specification of new meteorology is considered a new transport interval. During such a transport interval, the puffs are diffused according to standard Gaussian theory. The dimensions of an individual puff are proportional to its travel distance (or travel time). The model accommodates multiple point sources and includes algorithms for plume rise and shoreline effects. The model provides a rigorous treatment of the spatial and temporal variations in the atmosphere and accounts for influences due to local meteorological effects.

The advection of the puffs is accomplished through inputs of local meteorological variables, wind speed and direction. The

model can accommodate several meteorological stations by applying a weighting to each station variable. For these applications in areas of complex flow fields (e.g., mountains, valleys, shorelines, etc.), a three-dimensional wind field model can be added to provide a rigorous, dynamic treatment of the spatial and temporal variations in the atmosphere.

The dispersion model calculates the concentration over a grid covering the modeling region and also at specified special receptor locations within the grid. Special receptor locations are stored as data to facilitate modification should additional stations be needed. Site-specific run parameters, which are input as data, define the various site-specific characteristics unique to this model application. The calculation is performed in a time-wise, step-by-step analysis of the plume path from the release point through the limits of the calculation grid.

THE METEOROLOGICAL MODULE

Dispersion modeling requires the input of critical meteorological data. Wind speed and direction are needed to define the transport of airborne material; stability data are used to determine the spread of the material as it travels downwind. The depth of the layer of the atmosphere where mixing occurs is called Mixing Depth; this parameter defines the maximum height of the plume. Temperature data are used to determine the bouyant rise of the plume and, where applicable, the existence of a sea breeze.

At each modeling time increment (generally 15 min), input meteorological data are used to determine:

- Transport wind (u,v,w) components
- Plume dispersion coefficients (sigma-y; sigma-z)
- Atmospheric temperature

The meteorological data can be acquired in real-time from an on-site meteorological tower or, if data are acquired manually from alternate sources such as National Weather Service stations or United States Air Force bases, they can be input from the console via menu responses. Wind data, input as speed and direction, are converted to transport wind (u, v and w) components at the grid points. Horizontal and vertical plume dispersion coefficients (sigma-y and sigma-z) can be derived from direct measurements of turbulence (sigma-theta and sigma phi) or from routine meteorological observations using well-known stability classification schemes, depending on the available input data.

Stability Classifications

The most commonly used method to determine dispersion coefficients is the indirect method, requiring the determination of a stability class which then determines the dispersion curve. The Pasquill-Turner stability classification scheme or the NWS-Turner method are typically used with the Pasquill-Gifford dispersion curves. Stability categories cannot be measured directly but must be determined from other meteorological parameters. Any of the following approaches can be used:

- Sigma phi (standard deviation of the vertical wind direction)
- Sigma theta (standard deviation of wind direction)
- Delta temperature (the difference in temperature with height)
- Cloud conditions (i.e., clear, scattered, broken or overcast, and ceiling height)
- Default conditions (e.g., F-nighttime; D-daytime)
- Manual override inputs (operator discretion)

When using sigma theta or sigma phi to determine stability classifications, and changes in dispersion are expected because of surface roughness, a factor of (Zo/15 cm) ^ 0.2, where Zo is the average surface roughness in centimeters, may be applied to the tabular values. Suggested Zo values that may be used as a guide to estimating surface roughness are given in Hogstrom and Hogstrom.[2]

The sigma stability classification schemes are adequate for daytime use, but during nighttime (1 hour to sunset to 1 hour after sunrise), adjustments adapted from Mitchell and Timbre[3] are used.

If cloud cover inputs from NWS or USAF sources are used, the values are compared to criteria published in the U.S. EPA CRSTR model. Default dispersion classes (e.g., D-daytime; F-nighttime) can be provided for the operator in the event no other data are available.

Dispersion Coefficients

The purpose of establishing a stability class is to be able to calculate the horizontal and vertical dispersion parameters, sigma-y (Sy) and sigma-Z (Sz), which are used in the calculation of downwind concentration. Sy and Sz are approximated by a curve fitting process which describes the PGT curves with power laws as a function of the total distance traveled, x:

$$Sy(x) = a*v\text{^}b \quad (1)$$

$$Sz(x) = c*v\text{^}d + e \quad (2)$$

where the coefficients (a,b,c,d,e) are a function of stability class. The coefficients are taken from the POLYN routine found in NUREG/CR-2919, the manual for the XOQDOQ model, written by Sagendorf, *et al.*[4] but have been modified slightly to improve the continuity of sigma-z from the region of x <1000m to x< = 1000m.

Mixing Height

The boundary layer height (H) is used to limit the vertical dispersion parameter (Sz) to values < 0.8*H. The mixing depth will be determined by applying the climatological mixing heights according to the method described in the U.S. EPA CRSTER manual,[5] which is the standard Holzworth method.

Sea Breeze

In regions near large bodies of water where a sea breeze phenomenon may be a significant meteorological feature, the Thermal Internal Boundary Layer (TIBL) will be used as the maximum mixing height. The software will determine if a sea breeze condition is likely to exist, using the following rules:

- The sun is above the horizon (based on the data and time)
- The lower-level air temperature is greater than the sea water temperature, or monthly climatological temperature if temperature data are not available
- The lower wind direction measurement indicates on-shore winds within a 180 degree sector

If a sea breeze is determined to exist, the mixing height is set equal to the height of the Thermal Internal Boundary Layer (TIBL):

$$H = C * \text{sqrt}(d) \quad (3)$$

where H is the TIBL height (in meters) at distance d (in meters) inland[6,7] and C is a constant determined for the local area.

Wind Field Model

For applications in areas of complex flow (e.g., valleys, mountains, seashores, etc.) a three-dimensional, mass-consistent flow field model is used to provide a rigorous, dynamic treatment of the spatial and temporal variations in the movement of the cloud.

The ESC windfield model (ESCWIND) was adapted from code available in the public domain from several sources. It was developed to provide the user with an economical windfield

predictor. The model produces three-dimensional, terrain-dependent, divergence-free windfields given observed surface and/or upper-air data as input. Given the wind components for each meteorological station and at each level, a 1/r weighted interpolation is used to "fill out" the rest of the windfield along each horizontal plane.

The terrain surface boundary is approximated using obstacle cells to represent the terrain in a stairstep fashion. For computational purposes, the irregular surface boundary is removed by a coordinate transformation in which the terrain surface also becomes a coordinate surface. This "sigma-space" computational domain has two main advantages. First, the bottom boundary condition is defined more accurately; second, the option of variable vertical zoning improves the model's accuracy and economy.

ESCWIND follows a procedure of extrapolating and interpolating the input data to determine an estimated three-dimensional windfield on a specified finite difference grid. This prospective windfield then is adjusted to account for terrain effects and atmospheric stability considerations constrained by the condition that the resulting windfield be nondivergent.

The basic set of model equations was derived from the approach that minimizes the squared variation of the windfield subject to the constraint that the adjusted field be nondivergent.[8-10]

APPLICATIONS

The CARE Dispersion Modeling System has many applications such as toxic spills, nuclear dose assessment, pesticide drift, ambient air quality assessments in complex terrain, chemical fires and visibility obscurations. The dispersion model is designed to provide physically realistic calculations of the position and concentration of downwind airborne effluents. These calculations then are available for application in any scenario that relies upon atmospheric dispersion calculations. The type of application for which the system is to be used will dictate the type of source term calculations and the effects and response modules that would be useful in the CARE system.

Nuclear Accidents

The system is applicable for risk assessment and operational dose assessments from radioactive releases. It has been implemented for real-time, operational dose assessments using actual meteorological data signals, for manual and back-up dose calculations and for training purposes. The model can be used for dose projection estimates based on forecase or historical meteorological data. For training exercises, the operator would run the model using the interactive menus where input data and run parameters have been selected to simulate the desired exercise conditions.

Toxic Spills

For toxic spills emergency response, a chemical source term model has been added which calculates the appropriate release rate based on chemical properties, release mode and weather conditions. The effects model provides recommended response actions based on the concentration Threshold Limiting Value or the Lower Explosive Level.

Visibility Obscurations

By using a visibility model to calculate the effects of an aerosol released to the air, the system has been used to calculate the obscuration effects of various smoke releases for military applications. This capability also is useful in determining visual impacts on U.S. EPA Class I areas.

Ambient Air Quality

The system is extremely useful for calculating ambient air quality in complex terrain where traditional straight-line Gaussian models typically perform unrealistically. The use of the variable-trajectory calculation capability of the system helps to account for terrain-induced dispersion. This capability is useful in transport studies such as odor and toxics impacts.

CONCLUSIONS

CARE gives one the capability to perform a variety of emergency preparedness functions:

- Risk Assessment
- Hazmat Training
- Real-Time Monitoring
- Emergency Response

CARE is a system that puts truly capable emergency preparedness on one's desk. In the event of an accident that releases a hazardous material into the air, CARE will tell one where it will go, who it will effect, which areas are safe as evacuation centers, how long it will take to disperse and which preplanned response options would be most effective. CARE gives one the ability to neutralize the danger, to assess alternative defense strategies and to keep abreast of changing situations. In short, CARE gives one the tools needed to prevent an emergency from becoming a disaster.

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The Use of PC Spreadsheet-Based Graphics to Interpret Contamination at CERCLA/RCRA Sites

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ABSTRACT

During site investigations, large amounts of environmental data are generated in the form of lists of chemical analyses from different sampling locations over various periods of time. These tables of data are difficult to analyze and are seldom fully interpreted because of the magnitude of the task and the difficulty of visualizing trends from long lists of numbers. Electronic spreadsheet software for personal computers, originally developed for use by the business community for financial analysis, may be employed to store site data and to graphically display contamination patterns at CERCLA/RCRA sites. This software allows the input of numbers, formulas and words into a matrix of rows and columns and provides an ideal format for listing contaminant concentrations in the air, soil, surface water and groundwater.

When the above data are entered into a spreadsheet and integrated with graphics software, it is a simple task to rapidly visualize contamination distribution at a site over space and time. The following spreadsheet-based graph types are illustrated: the line, bar, stacked bar, x-y and pie chart. Each type is well suited to a particular application. For example, the pie chart is useful for showing a connection between a source area (such as a lagoon) and a receptor (such as a downgradient well). The expanded bar chart can be used to indicate if new sources of contamination are affecting the downgradient groundwater. Specific applications of the spreadsheet-based graphics are illustrated using data from Region 1 CERCLA/RCRA sites.

INTRODUCTION

The advent of the personal computer and its increasing availability, as well as the increase in user sophistication, has led to new applications of this powerful instrument. The spreadsheet has become the basis for many financial as well as scientific applications. One recent example of the use of the spreadsheet is that of Olsthoorm.[1] In this case, the spreadsheet was used to model groundwater flow in two and three dimensions.

The spreadsheet is used because it is a general purpose, inexpensive software product and one need not be a computer specialist to use it. In the above application, the spreadsheet replaced three or more specific programs. This paper applies the spreadsheet analysis to aid in understanding the flow of contamination from an uncontrolled hazardous waste site and from an active manufacturing site.

Often there is a great deal of information known about a specific site. This information is available as tables of chemical data collected while sampling the groundwater, surface water, soils, sediments and air at the site. Without being able to organize and visualize this data, one often does not utilize the data to the full potential. The computer-based electronic spreadsheet, combined with graphics, provides the means to more fully interpret data.

The spreadsheet, more than any other software program, has revolutionized the use of the personal computer. The spreadsheet consists of a matrix of rows and columns in which numbers, formulas and words are input. It is also a very user-friendly software tool that is limited only by the imagination of the user. Examples of popular spreadsheet-based software are: Visicalc, Multiplan, Lotus 1,2,3 and Symphony.

The spreadsheet used in this paper is Symphony, which along with Lotus 1,2,3 represents a new generation of integrated software; word processing and graphics are directly available while working with the spreadsheet. The Symphony spreadsheet contains 256 columns and 8,192 rows. This capacity allows all known chemical information from a specific site to be stored on one spreadsheet. The size of the spreadsheet is demonstrated by the fact that the above matrix may hold 63,000 individual analyses consisting of 30 chemical elements or compounds. In total, the spreadsheet contains over 2 million available data points, limited only by the computer's Random-Access Memory. The advantage of storing all the data from one site on one large spreadsheet is the ability to rapidly compare different sections of data and to conduct direct statistical analysis on specific ranges of data. The application described in this paper is the ability to focus on sections of data in the spreadsheet and to make a picture or graph of the numbers. An important assumption made is that the data are accurate and have passed a quality screening test.

APPLICATION OF SPREADSHEET-BASED GRAPHICS AT A SUPERFUND SITE

Table 1 is a portion of one spreadsheet of data from a Superfund site in southern New Hampshire. It is displayed in the standard spreadsheet format: i.e., the information is listed in rows and columns. Note that both numbers and words are used. At this site, there are a sufficient number of monitoring well sampling locations to define the cross-section of a contaminant plume adjacent to a water supply. The horizontal axis of the table represents the distance in feet from the assumed center of the contaminant plume to the center of the sampled monitoring well screen. All samples were taken in the same period of time.

An examination of the data shows that total contamination decreases with distance from the center of the plume. Also, the concentration of 2 -butanone decreases rapidly, but it is not as apparent that t-1,2-dichloroethene is decreasing much less rapidly across the plume cross-section.

Table 1
Distribution of Contamination, Plume Center to Water Supply

Distance from Plume Center	0	70	130	175	250		310
Sample number	NUS 2-3	NUS 2-2	NUS 2-1	NUS -2	GZ 11	NUS 2BR	WP-4
Compounds							
Benzene	10	7	7				
1,2-Dichlordethane	51	41	32		19		
1,1,1-Trichloroethene	24	38	24	34	35		0.5
1,1-Dichloroethane	48	43	37	25	12	32	
Chloroform		7	5				
1,1-Dichloroethene		5	5				
t-1,2-Dichloroethene	760	810	590	520	300	18	5
1.2-D ichloroethene		5	5				
Ethylbenzene	17	15	9				
Tetrachloroethene	14	12	10	15	5	5	
Toluene	410	350	240	11			
Trichloroethene	27	23	20	36	22	11	0.5
Vinyl Chloride	13	10	10				
2-Butanone	1100	520	310			27	
4-Methyl-2-Pentanone	69	58	37				
Total Xylene	48	43	24				
Chlorobenzene					11		
Total: (PPB)	2591	1987	1365	641	404	93	6

Note: All concentrations in ppb (or µg/l)

Figure 1 is an x-y plot of the distribution of specific organic contaminants versus distance from the center of the plume. Using this plot, one can see the partition of different organic chemicals in the plume diffusion gradient perpendicular to a groundwater flow direction. This distribution may be due to differences in sorption as discussed by Mackay, *et al.*[2] This hypothesis can be modeled by taking additional data from the spreadsheet (such as analyses from downgradient wells) and comparing these analyses to the above theory. Because the data are readily available on the spreadsheet, examination of contaminant distribution in the water supply well and the bedrock well is facilitated. These two analyses are listed in the columns headed by WP-4 and NUS 2BR on Table 1. The pie chart (Figs. 2 and 3) is used because it graphically depicts the relative percentages of organics impacting these different receptors and specifically shows the persistence of t-1,2-dichloroethene.

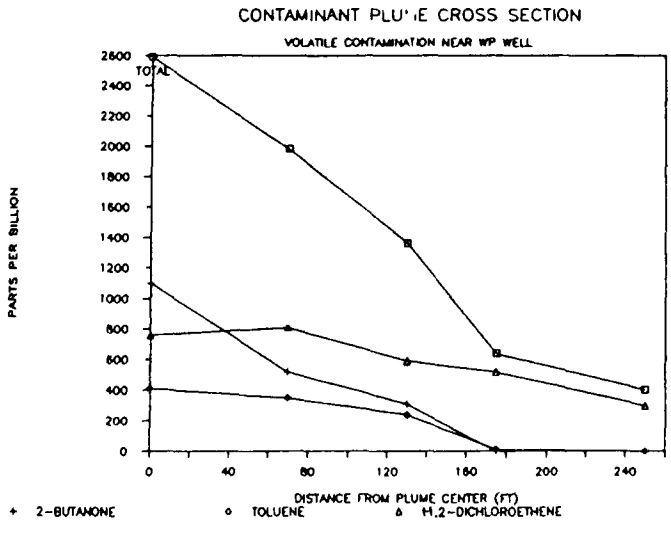

Figure 1
X-Y Diagram of Volatile Contamination in a Groundwater Plume

APPLICATION OF SPREADSHEET-BASED GRAPHICS TO AN RCRA SITE

Groundwater monitoring at manufacturing facilities is a critical aspect of the U.S. EPA RCRA permitting process. Implementation of the 40 CFR Part 265 and 270 groundwater monitoring sequence generates much data related to the permitting process, either closure or post-closure. If the detection monitoring wells at a land disposal site detect contamination, the site immediately goes into assessment monitoring.

The goal of this monitoring is to clearly identify the rate and extent of hazardous waste constituent migration and to establish the concentration of individual constituents in the plume. For all of the above assessment data, the spreadsheet provides an ideal storage file for later retrieval and interpretation.

The following discussion is an example of the ways in which one can use the above data once they have been entered into the electronic spreadsheet. The site utilized for illustration is a northern New England metal machining and plating company that has been active since the early 1950s. From 1970 to 1985, an unlined waste lagoon was used to manage hazardous waste at the site. Detection monitoring wells were installed in 1981 to assess the site groundwater flow and potential contaminant migration from the waste lagoon. During the early 1980s, about 100,000 gal/day of waste from the manufacturing process entered the lagoon. The waste stream was composed principally of solvent wastes from metal degreasing, waste oils from metal machining and sludge from electroplating operations. In order to assess the changes in contaminant migration at the site, all data collected from 1981 to 1985 were entered onto the spreadsheet. Table 2 contains the data collected during the fall of 1982. The following figures are based upon this table.

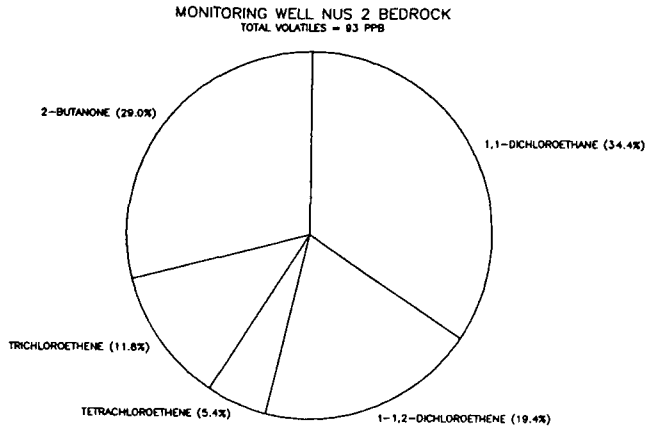

Figure 2
Pie Diagram of Volatile Distribution in Monitoring Well NUS-2BR

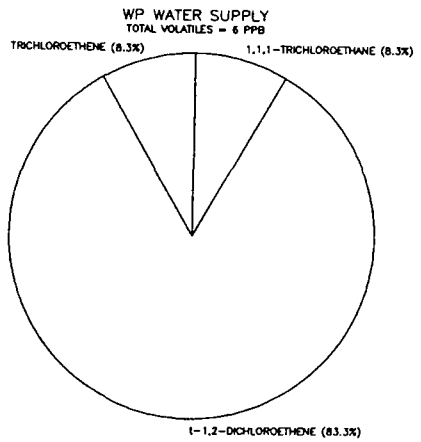

Figure 3
Volatile Organic Contamination in WP Water Supply

Figure 4 is a stacked bar chart that illustrates the composition of the oily waste lagoon. This graph is used because it gives a visual summary of the contaminant profile at different depths in the waste lagoon in 1982. Figure 5 shows the distribution of contaminants at mid-level in the lagoon. Figures 6, 7 and 8 illustrate the volatile distribution in wells 3, 4 and 7, located 50 ft adjacent to and 50 and 1,450 ft downgradient from the lagoon. The main difference in contaminant profiles is the absence of methylene chloride in the farthest downgradient well MW-7. The other organic chemicals are present at lower concentrations than in the lagoon.

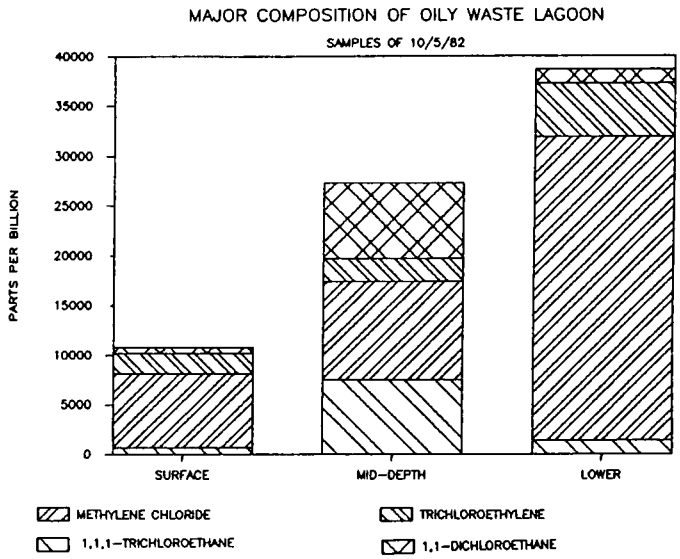

Figure 4
Volatile Organic Concentrations in Waste Lagoon

The pie diagram is an ideal graph to show the hydrologic connection between source area, lagoon and receptor which in this case is the downgradient well. At sites where there are multiple source areas, such as separate lagoons used for waste oil and plating and degreasing wastes, the pie chart represents a signature that is useful for indicating which downgradient wells are connected hydrologically with a specific lagoon.

Table 2
Lagoon Composition at Surface, Mid-Depth, Lower and Sludge (10/82)
Monitoring Well Groundwater Composition (10/81)

DATE	10/5/82	10/5/82	10/5/82	10/5/82	10/16/81	10/16/81	10/16/81	10/16/81	10/81
SAMPLE NUMBER	Surface	Mid-Depth	lower	sludge	MW-1UPG	MW-2ADJ	MW-3	MW-4	MW-7
DISTANCE FROM LAGOON	0	0	0	0	150	150	50	50	1450
1,1-Dichloroethane	630	7550	1390	13700	0		830	1500	570
1,1-Dichloroethylene							170		110
Ethylbenzene						11			
Methylene Chloride	7500	9900	30500	96900			820	470	
Tetrachloroethylene				1240			340	14	70
Toluene	174	0	121	1180	0	12	21		
t-1,2-Dichloroethylene						22	140	1300	1100
1,1,1-Trichloroethane	2586	3000	6350	23100	34		1000	33	430
Trichlorethylene	2070	2325	5370	28200			270	1300	950
Total: (PPB)	12960	22775	43731	164320	34	45	3591	4617	3230

Note: All concentrations in ppb (μg/l)

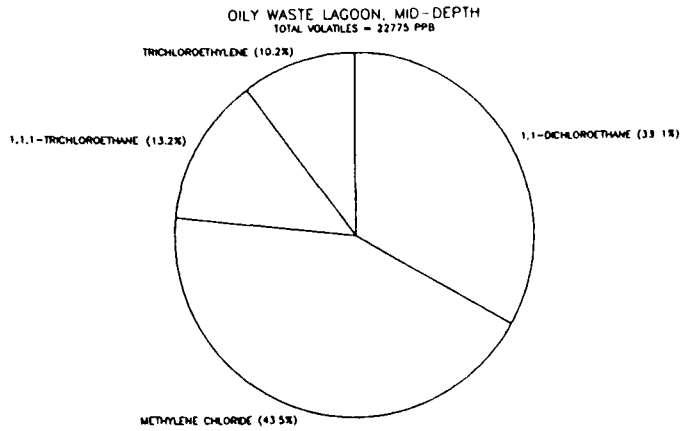

Figure 5
Volatile Organic Concentrations at Mid-Depth in Waste Lagoon

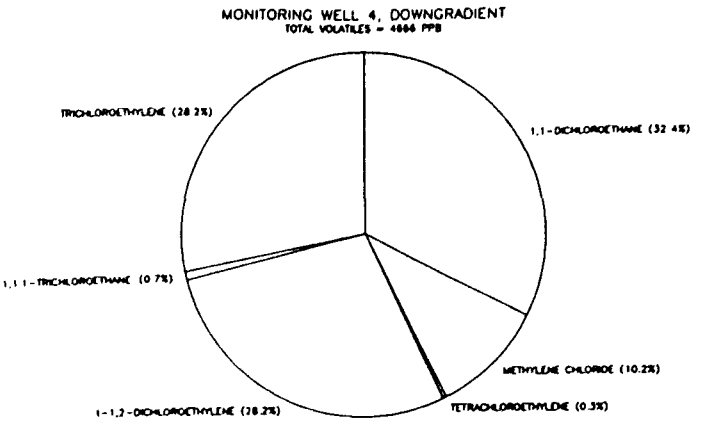

Figure 7
Volatile Organic Contamination of Groundwater at MW-4

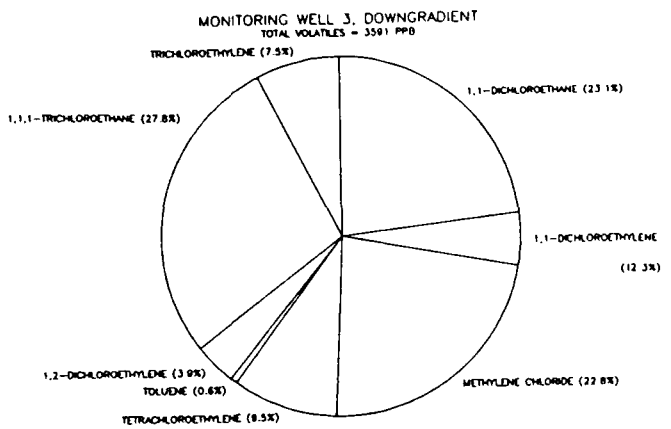

Figure 6
Volatile Organic Contamination of Groundwater at MW-3

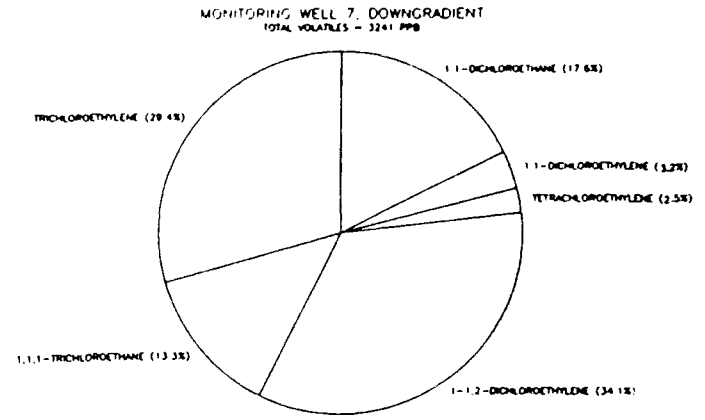

Figure 8
Volatile Organic Contamination of Groundwater at MW-7

Table 3
Manufacturing Site Well #3 Analytical Results (10/81-10/85)

Date:	10/30/81	2/19/82	10/5/82	8/11/83	5/25/84	10/7/85
Sampler						
Compounds						
Chloroethane				30		
1,1-Dichloroethane	830	320	718	1010	1600	1200
1,1-Dichloroethylene	170	160		90	135	90
1,2-Dichloroethane					60	45
Methylene Chloride	820	1900	9780	2680	3600	11800
Tetrachloroethylene	340	260		500	160	370
Toluene	21			2		
t-1,2-Dichloroethylene	140	86		200	600	225
1,1,1-Trichloroethane	1000	2100	3150		1600	1300
Trichloroethylene	270	110	2560	120	270	200
Total: (PPB)	3591	5436	16248	4632	8025	15130

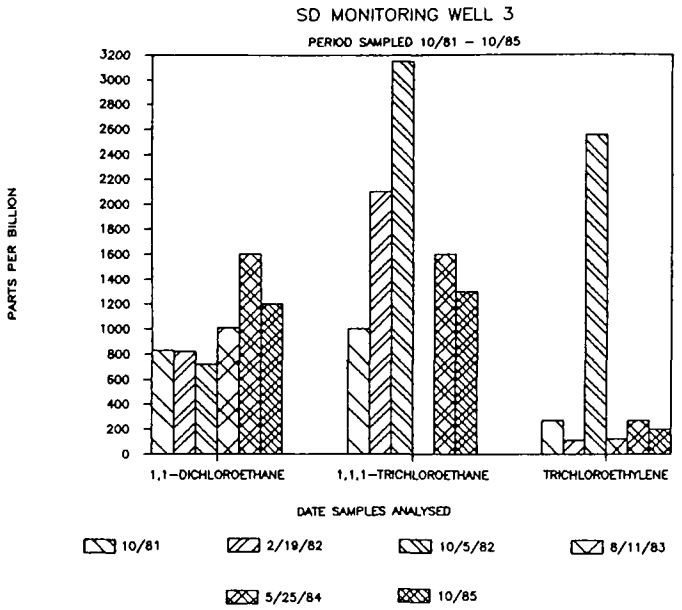

Figure 9
Volatile Organics Present in MW-3 (10/81 - 10/85)

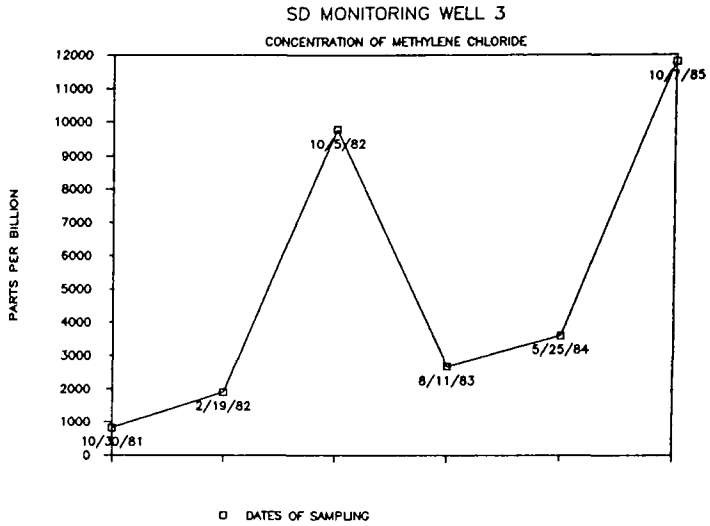

Figure 10
Concentration of Methylene Chloride at MW-3 (10/81 10/85)

The spreadsheet also provides the basis for comparing changes in organic contaminants at a specific well over a number of years. This comparison is facilitated since data can be moved rapidly from one section of the spreadsheet to another. Table 3 contains data from monitoring well 3 which were collected from October 1981 to October 1985. Figure 9 is a bar graph of the major organic contaminants, which, with the exception of methylene chloride, are contained in the groundwater. The graph illustrates that the highest organic contamination at well 3 occurred in late 1982. Since then, there has been a decrease in the concentration of the three compounds, as shown in this figure. Figure 10 shows the concentration of methylene chloride over the same time period. The highest concentrations of this species were observed in October 1982 and October 1985. The later date coincides with the final closure of the lagoon and may be related to it. This line chart is particularly useful for showing changes in contamination over a period of time.

In summary, spreadsheet-based graphics allow one to visualize the changes in concentration of organics in the source area, lagoon and downgradient monitoring wells and changes over a 4-year period in well number 3.

CONCLUSIONS

The spreadsheet is the fundamental way to store data in the computer. Once data from a hazardous waste site or manufacturing site are entered into the spreadsheet, one can readily combine data, move data and, when the spreadsheet is combined with graphics software, one can generate graphs from any portion of the spreadsheet. In this paper, the spreadsheet has formed the basis for quickly assessing the contamination at two sites. The software also has been used by the author to prepare graphs for overhead projection at a meeting, to prepare tables and graphs for reports and to forecast when increasing contamination in a well will cause the water to exceed Safe No Action Response Levels (SNARLS). With the increasingly available portable computers, the above site-specific information can be taken to the manufacturing company and used as a resource during discussions regarding contaminant distribution at an RCRA site. As stated earlier, the application of this new generation of software is limited only by the imagination of the user.

REFERENCES

1. Olsthoorm, T.N., "The Power of the Electronic Worksheet: Modeling Without Special Programming," *Groundwater, 23,* 1985, 381-390.
2. Mackay, D.M., Roberts, P.V. and Cherry, J.A., "Transport of Organic Contaminants in Groundwater," *Environ. Sci. Technol., 19,* 1985, 384-391.

Emergency Response to Toxic Fumes and Contaminated Groundwater in Karst Topography: A Case Study

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ABSTRACT

This paper presents a preliminary report on the on-going control of contaminated aquifers in karst topography. Over the past several years, there has been a growing concern over the presence of volatile hazardous chemicals in the karst formation cave systems in the Bowling Green, Kentucky area. By April 1985, contamination and related chemical fumes warranted an "emergency response action" by the U.S. EPA, Region 4. The management of migration procedures under these conditions are discussed and summarized. Dye tracing, geophysical studies, speleological cartography, exploratory drilling, down hole cameras and sampling techniques have been utilized to locate the primary flow characteristics of the "Lost River" and its tributaries and to identify the source(s) of contamination and mitigate its effects.

Karst formations present peculiar and distinct management difficulties. The impact of leaking underground storage tanks and illegal dumping may be magnified by the motility of spilled substances. Pollution source determination is especially problematic.

Many methods used in this emergency response action were relatively experimental with few strong precedents. These methods are comparatively analyzed for the benefit of future cleanup activities.

INTRODUCTION

Karst topography, evident to some degree almost anywhere carbonates are found at or near the surface of the earth and subjected to humidity and water movement, presents unique and perplexing difficulties to the professional involved in hazardous waste management. By definition, karstic terrains are characterized by closed depressions, i.e., sinkholes or dolines and uvalas, caves and the prevalence of underground drainage. Although these conditions can be beneficial, as in the case of high capacity groundwater accessibility (it is the closest thing in nature to a fresh water pipe), extreme liabilities also may be present. For example, the impact of leaking underground storage tanks and illegal dumping may be greatly magnified by the motility of lost substances. While permeability in non-karst areas may be measured in ft/day, permeability in karst can be measured in miles/hr. Discrete sources of groundwater recharge are numerous and varied and the velocity of recharge so high that pollution source determination can be especially complex.

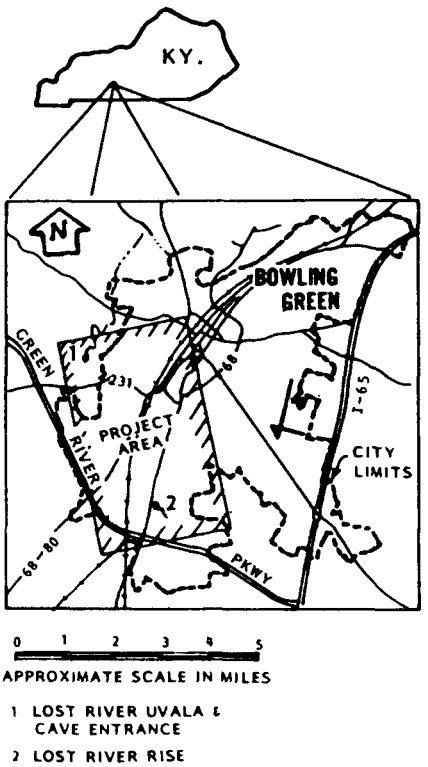

Figure 1
Bowling Green Location

Located on the textbook karstic terrain of south central Kentucky, Bowling Green is the only city of such size (pop. 41,000) in the United States to rest almost entirely over a cave system. The Lost River, which is exposed in a uvala in southwest Bowling Green, flows into the Lost River Cave entrance and has been mapped for 4 miles. At this point, the river sumps and takes an undetermined flow path through the St. Genevieve and St. Louis limestones underlying Bowling Green until it exits north of the city at the Lost River Rise.

Fixed facility and transportation related spills, deliberate dumpings and undetected leaks, all associated with oil and hazardous materials, have become daily occurrences in every major city across the nation. Bowling Green is no exception. Its location in a sinkhole plain and over an extensive cave system, makes the city highly susceptible to groundwater pollution and to the related problems associated with karst areas.

Many contaminants can immediately affect the watershed either through unobstructed flow into the cave system or through rapid percolation through thin cover soils. In Nicholas Crawford's earlier research, he showed that heavy metals and road salts from urban detritus quickly entered the groundwater system,[1] but volatile materials pose special problems. As the substances flow through the subterranean labyrinth, they can volatilize in the cave air space and ultimately find their way to the surface. The control of gases and vapors in the atmosphere usually is not attempted because natural dispersion dilutes vapors and gases rapidly. However, fumes rising from cave systems may concentrate in areas of concern. If these fumes collect in a basement, crawl space or simply in or near public areas, a potentially explosive situation exists.

Bowling Green's Problem

The toxic and explosive fume problem in Bowling Green dates back to 1969, when explosive fumes were detected and believed to have caused a residential explosion. In 1981, the residents of five homes in the Riverwood area were evacuated when fumes, rising into their basements and crawl spaces, reached explosive levels.

In 1982, benzene and methylene chloride were detected in the Lost River Cave. Subsequently, the U.S. EPA, Region 4, initiated an emergency response action in March of 1983. Preliminary investigations showed alarmingly high levels of volatile chlorinated hydrocarbons[2] flowing into the spring-fed Keith Farm pond, which discharges into the Lost River drainage system. Dye traces pinpointed the source of the contamination to be a series of leaking industrial underground storage tanks. The U.S. EPA treated 1.9 million gal of contaminated pond water, and the responsible party removed the leaking tanks and excavated the contaminated soils.[3]

Throughout 1984, toxic and explosive fumes plagued the homes in the Forest Park and Parker-Bennett School areas. In January 1985, toxic and explosive fumes were detected in the Dishman-McGinnis Elementary School. To date, fumes of this type have been investigated in over 100 homes and commercial buildings, two schools, one church, 18 drainage wells and 24 sinkholes.

After an extensive public health evaluation of the fumes by the Center for Disease Control, a health advisory was issued on the grounds that explosive levels existed and that the detectable fume levels of benzene, toluene and xylene exceeded standards for "non-occupational settings," At that time, the U.S. EPA Region 4 Emergency Response Branch initiated a "Superfund" emergency response to address the problems designated in the public health advisory. Mitigation efforts were initiated to reduce the threat, identify the source or sources of contamination and define the underground drainage system controlling the transport of chemicals in the Bowling Green area.

FUME OCCURRENCE HYPOTHESES

Although not fully documented, there is an apparent direct relationship between increased reports of fumes and wet weather;[4] similarly, there have been fewer fume incidents during dry weather. Thus, the fumes appear increasingly manifest in periods of heavy precipitation. The hypotheses which follow are based upon the assumption that continuous releases or intermittent dumpings into the Lost River drainage system, i.e., sinkholes, solution joints and fractures, have resulted in a chronic flow of chemicals within the caves.

The first hypothesis is that, once in the cave, the chemicals volatilize; a volatilization that is accelerated by natural structures. Waterfalls and riffle areas provide an indigenous turbulence which increases the rate of volatilization, increasing, in turn, the fume concentration within the cave atmosphere. During high water flow, the air space within the cave is decreased, forcing the gases to the surface. This process not only occurs during high water flow, but also during normal cave breathing due to changes in barometric pressure.

The second hypothesis is that water-filled passages, forming a natural underflow dam, trap floating chemicals and restrict them from flowing downstream. This flow restriction, in turn, causes low density and volatilize chemicals to become concentrated in these areas. This frequently occurs during increased river discharge when heavy rainfall causes the river within the cave to rise. Consequently, the floating chemicals and the fumes are pushed upstream.

As the water recedes, the floating chemicals adhere to the ceiling and walls forming a "bath tub ring" within the system. This bath tub ring phenomenon coats the surface of upstream perched pools with floating chemicals. The rise and fall of the river level results in a repetitive deposition of chemicals within the cave, leaving a stratified layer of aliphatic hydrocarbons and mud.

Finally, it is proposed that contaminants have been dumped or spilled in soils and areas underlain by perched water tables or water pockets and are flushed into the Lost River Cave system when meteoric water percolates through the soil or overflows a perched water table. Perched water tables and water pockets are associated with the pinnacle nature of the limestone at the limestone/soil interface (Fig. 2).

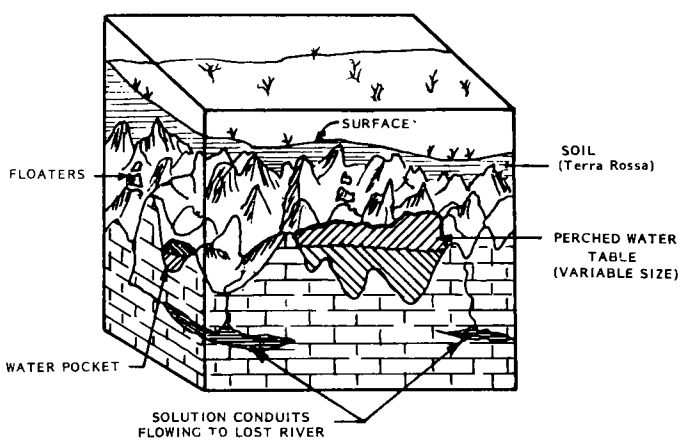

Figure 2
Generalized Illustration of Pinnacle Nature of Limestone Showing Possible Perched Water Table and Water Pockets

These hypotheses are not mutually exclusive. Investigative techniques in verifying them and solving the resulting problems associated with them have been varied. In this verification, geological techniques were used in conjunction with sound environmental studies and common hazardous waste site cleanup practices.

SEARCH FOR THE LOST RIVER

The logical place to start this investigation was to locate the contaminated medium, i.e., the Lost River. In this search, an integrated team approach based on multidisciplinary scientific support was utilized to address the diverse problems associated with the fumes rising from the cave system.

Excavation of sinkholes and crevasses initiated the physical exploration of the project. In the search for possible entrances into cave passages, sinkhole breakdown was removed with a trackhoe or a backhoe and by hand. Excavations were made adjacent to homes and buildings at identified channels from which fumes were reaching the surface. Excavations also were made within sinkholes along the hypothesized Lost River flow path and where historical accounts indicated the closing of cave entrances.

Concurrent with these excavations, exploratory drilling was initiated. However, with few means of locating drilling sites for cave passages other than topographic features, the production of exploratory wells at 10-ft intervals appeared to be a costly and time-consuming method of cave discovery. Clearly, a method was needed to locate drilling sites more precisely and economically. This need led to the implementation of gravity survey techniques.

Gravity Survey

Gravity surveys are utilized by, and in fact originated in, the oil industry, where there is great interest in detecting large underground structures. In microgravity surveys, which include corrections for tidal effects, more sensitive instrumentation and more precise techniques, it is possible to detect very small and finely localized variations in geologic structure. In Bowling Green, it was anticipated that microgravity surveys would detect the presence of void space (or absence of solid rock) along a given transect.

Using a Lacoste and Romberg Model D Microgal Gravity Meter, 10-ft stations were measured over thousands of feet of transects in the study area. The readings were plotted and large anomalies were investigated by exploratory drilling. It often was found that anomalous readings represented unusually deep troughs of soil between pinnacles of limestone or break down zones of possible cave collapse (Fig. 3). Nevertheless, microgravity surveys proved to be the most reliable means of locating void space or cave passages when no historic or surface indications were available.

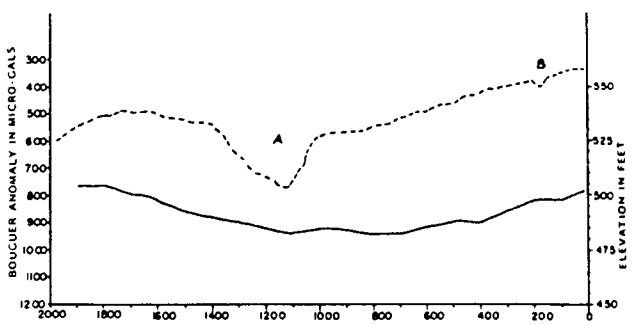

Figure 3
Representative Comparison Between Topographic (Solid Line) and Microgravity (Dotted Line) Surveys Showing Probable Breakdown Zone (A) and Small Solution Void (B)

Drilling

Exploratory and core drilling, utilizing rotary water and forced air hammer drill rigs, continued throughout the investigation to verify the microgravity data and to correlate localized stratigraphic columns. Many of the exploratory and core wells later became monitoring wells used to record a wide variety of relevant variables. In certain instances, monitoring wells were placed by survey and drilled into the stream thalweg of cave passages, eliminating the need for lengthy and labor intensive cave sampling and/or monitoring trips.

Standard hydrologic methods, including dye tracing and piezometric surface contouring, were used to locate primary flow characteristics, while air monitoring was used to locate and characterize areas of fume contamination. A 1.5-in. downhole camera with both downhole viewing (Lighted Actual Viewing Attachment, LAVA) and sideviewing (Right Angle Viewing Attachment, RAVA) capabilities also were used to investigate the subterranean environment.

The investigation team occasionally experienced difficulty in distinguishing between solution voids and breakdown zones and between true void space and mud-filled cavities. The downhole camera allowed visual inspection of these features, ensuring cost-effective and time-saving verification of the presence of cave passages. Also, the downhole camera confirmed the indications of microgravity data and historic accounts that a large cave existed in the vicinity of Creason Street and Robinson Avenue area.

This discovery prompted drilling of a new caliber. A 30-in. core barrel drill rig was employed to drill entrance wells into Robinson's Cave and Creason Cave. These caves were actually one prior to a 1960s road construction blasting accident which collapsed 100 ft of road, effectively severing the original cave passage.

Utilizing a team of experienced spelunkers, detailed speleological investigations and complete surveys of the caves were initiated. From these explorations it was determined that the Robinson's and Creason Cave system represented a paleo-channel of the Lost River, allowing the realization that the river was not confined by the resistant Lost River chart,[3] but that it had broken through into what Crawford calls a "Karst Sandwich" (Fig. 4).

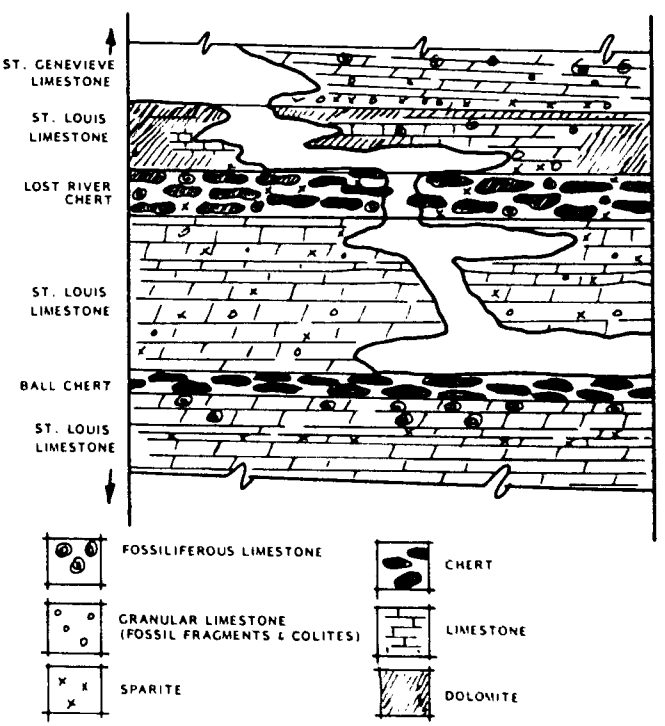

Figure 4
Partial Section Showing Generalized Flow of Lost River into "Karst Sandwich" of Chert and Limestone

Unfortunately, the Lost River proper has yet to be found by way of Robinson's Cave. The cave does, however, represent a tributary conduit into the Lost River system contributing contaminants from perched water tables and/or soil percolation.

Another cave investigation was prompted by fumes rising to the surface. In one residential crawl space and in an adjacent storm sewer and drainage well, fumes reached explosive levels frequently. The investigation team began hand excavation accompanied by continuous air monitoring in the drainage well. During this apparently minor excavation, fumes peaked at levels above 300 ppm and 100% LEL, prompting a more comprehensive excavation. Using spark-proof tools, an entrance to a new, hitherto unknown, cave was discovered. This cave, Napier's Cave, became the focal point of further study and investigation. Physical exploration of this cave required positive pressure flushing of contaminant fumes, utilizing two high volume smoke exhaust fans blowing into the cave. Exploration revealed floating contaminants, wall staining and contaminated perched pools, all indicating contamination transport at high and low water flows.

SAMPLING

The ultimate success of determining locations where investigations could be efficiently performed, of determining mitigation procedures and of initiating possible enforcement actions depended on accurate and valid analysis of the chemicals involved and of the vulnerability of the environment to their effects. This information was obtained by extensive sampling and monitoring of soil, air and water matrices characterizing the contaminants and affected medias. Potential and real effects on the environment, immediate and long-term risk to public health and to the investigating team were established and monitored. Several methods were employed.

Air monitoring was performed with the use of real-time, direct-reading, portable instrumentation, photoionization detectors, combustible gas indicators and oxygen meters. This highly mobile instrumentation proved very convenient in screening cave atmospheres and monitoring stations over the large study area. However, instrumentation limitations were revealed. The HNU photoionizer, Model PI 101, gave unreliable readings within the cave environment and in the monitoring wells. This problem was due to the cave humidity and subsequent condensation on the ultra violet light source.

The GasTech, Hydrocarbon Super Surveyor, Model 1314, was the most practical portable instrumentation for use in cave environments. It enabled monitoring for the parameters of total organics, combustible gas and oxygen with one instrument. Its light weight and size, ease in calibration and relative insensitivity to moisture made it the preferred instrument for speleological monitoring.

Once initial contaminant parameters were identified, species-specific instrumentation provided accurate quantification. Specifically, monitoring was aided by the use of a Photovac, a programmed photoionization gas chromatograph. The Photovac was placed within a crawl space in the Parker-Bennett Elementary School. Scheduled samples were automatically collected and immediately analyzed before and during building occupation. Generated chromatographs provided the specific qualitative and quantitative data utilized for public health considerations.

The U.S. EPA Environmental Response Team's mobile environmental unit (SCIEX) also was utilized in the study. The computer-coupled tandem mass spectrometer, mounted in a specially adapted bus, provided real-time measurements of contaminants in ambient air from the atmosphere, monitoring wells and within buildings and homes. This versatile field laboratory was not limited geographically and provided quality assured quantitative and qualitative analysis in minutes. It proved to be the most efficient and accurate means of screening air samples and identifying compounds.

Tedlar air sample bags were used for capillary soil gas sampling and occasionally for atmospheric sampling when subsequent qualitative laboratory analysis was indicated. The soil gas technique was employed at industrial sites to establish a correlation between volatile chemicals associated with those sites and those identified rising from the Lost River Cave system, and where fumes were detected in the absence of any surface evidence of escape paths. In addition to real time air monitoring and sampling, Tenax collector tubes were employed, while subsequent desorption and analysis provided time weighted average concentrations for public health considerations.

Soil, sediments and water samplings completed the characterization of chemicals involved and the assessment of this complex problem. Surface and cave sediment samples were collected from drainage ditches, cave walls and cave stream beds to identify contaminants and to establish correlations between industrial releases of chemicals and cave contamination. Soil samples also were collected, specifically as a means of documentation during underground storage tank excavation.

Due to the scarcity of surface streams in the Bowling Green area, surface water samples were limited to the Lost River Cave Entrance and Rise. However, groundwater samples were collected directly from the caves, monitoring wells and potable wells. Cave stream and monitoring well samples helped to verify contaminant flow paths, while potable well samples were useful in public health determination and helped to locate contaminated perched water tables.

MITIGATION

A priority throughout the investigation was mitigation of immediate and potential threats to health and safety. Prompted by the 1983 U.S. EPA identification of leaking underground storage tanks as a source of Lost River contamination, an extensive search was performed to locate all storage tanks in study areas. Data were compiled to indicate the integrity of the tanks. Several underground storage tanks were tested and removed or repaired if leaks were detected.

Similarly, the discovery of one residence that relied entirely on wellwater and the subsequent determination that this water was contaminated, led to an extensive data search and public survey in an effort to identify all water wells in the study area. Residents on contaminated potable water supplies were connected into the city water system.

The desired culmination of mitigation with regard to hazardous fumes is the ultimate elimination and removal of those fumes and their sources. However, prior to the identification of the chemical nature of the fumes and their precise sources, the most immediate and obvious mitigation procedure was the venting of homes and public buildings. Using exhaust fans in crawl spaces, basements and cave entrances, fumes were dispersed into the atmosphere instead of being allowed to concentrate in closed and inhabited areas.

CONCLUSIONS

As a part of an on-going study, the following conclusions on particular aspects of the investigation and mitigation of contaminated aquifers in karstic terrains are tentative. Based on information derived from this study, the body of this paper might provide guidelines for future investigations of hazardous waste generation and handling in karst areas.

Ventilation of fumes

Venting provides a convenient short-term means of lowering or eliminating fume concentrations in living areas and public buildings. Venting is, of course, a short-term solution to a long-term problem.

Monitoring

Clear-cut advantages were noted between instruments applied to various monitoring tasks. The GasTech proved superior in speleological monitoring due to its relative insensitivity to moisture and multiple function capacity. Single function instruments used in conjunction with multi-function instruments provided data checks. The HNU with its increased sensitivity was ideal for surficial monitoring of organic vapors. Similarily, the explosimeter's specialized function provided a comparison and verification of data accuracy.

Microgravity Survey

Not overlooking topographic features and historic information of an area, microgravity surveys were the most effective technique utilized in this study for the remote sensing of karstic features.

Smoke Testing

Although smoke testing met with little success in this investigation, we believe that a very dense particulate and aromatic smoke with an efficient injection system could be an effective tool in locating small or hidden cave openings.

Drilling

Although rotary water drilling initially was used as a safety precaution to prevent spark ignition of cave fumes, it is now thought that forced air rotary and hammer drilling are acceptable methods in all but the most dangerous areas; the forced air would flush fumes away from any spark generation.

Tank Testing

As national attention to the Leaking Underground Storage Tank Program and hazardous material handling grows, special attention should be paid to karst areas. Precision testing of underground storage tanks identified leaking tanks. Their removal or repair possibly may have eliminated the source of contamination and the subsequent fume problem in a Lost River tributary.

Chemical Assessment

The only substance releases whose consequences might be minimized in karstic terrains could be those of acids which rapidly neutralize in contact with limestone. In all other instances, oil and hazardous substances releases in karst areas can rapidly migrate and generally pose more complicated and variable problems than in non-karst regions.

These studies further concluded that all of the water wells in the study area, with one exception on its boundry, were contaminated with a variety of hazardous substances. Some of these contaminants were not present in the Lost River; hence it was inferred that these contaminants were trapped in perched water tables, migrating down well into the phreatic zone.

As general methods and specific techniques of hazardous waste management continue to develop and improve across the country, special attention should be paid to environmental influences on hazardous waste dispersion. Karst areas, in particular, require specific guidelines and possibly regulative measures governing hazardous material generators, transporters and emergency responses.

FOOTNOTES

1. Crawford, N.C., "Sinkhole Flooding Associates with Urban Development upon Karst Terrain: Bowling Green, Kentucky," in B.F. Beck, ed., *Sinkholes: Their Geology, Engineering, and Environmental Impact*, A.A. Backema, Rotterdam, 1984, 283-292.
2. U.S. EPA, "Superfund Cleanup, Keith Farm Pond, Bowling Green, Kentucky," Vols. I & II, 1983.
3. *Ibid.*
4. This section owes much to the formal work of, and informal discussions with, Nicholas C. Crawford; see footnote 1, above.
5. The relative position of the Lost River chart in the stratigraphic column is subject to some disagreement. The Geological Survey places the Lost River chart at the base of the St. Genevieve formation; however, authorities in the field place the Lost River chart in the Horse cave member of the St. Louis formation. Cf. Palmer, N., *A Geological Guide to Mammoth Cave National Park*, Zephyrus Press, Teaneck, NJ, 1981, 196; Pohl, E.R., "Upper Mississippian Deposits in South Central Kentucky," *Kentucky Acad. of Sciences, Trans., 31*, 1970, 1-15. This placement has been further confirmed through personal communication with Nicholas Crawford.

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1. Beck, B.F., ed., *Sinkholes: Their Geology, Engineering and Environmental Impact*, A.A. Backema, Rotterdam, 1984.
2. "Bowling Green Toxics," U.S. EPA Report, Vol. I., 1985.
3. Crawford, N.C., "Toxic and Explosive Fumes Resulting from Contaminated Groundwater Flow through Caves Under Bowling Green, Kentucky," unpublished research proposal submitted tothe City of Bowling Green, KY, April 1985.
4. Palmer, A.N., *A Geological Guide to Mammoth Cave National Park*, Zephyrus Press, Teaneck, NJ, 1981.
5. Pohl, E.R., "Upper Mississippian Deposits in South Central Kentucky," *Kentucky Acad. of Sciences, Trans., 31*, 1970, 1-15.
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Use of Low Flow Interdiction Wells to Control Hydrocarbon Plumes in Groundwater

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ABSTRACT

This paper presents a case history and discussion of a situation where the initial hydrocarbon contamination occurred in 1969, remained undiscovered until 1980 and since has resisted massive efforts to even adequately define the situation. The paper details the installation of low-flow wells across the plume to block flow of contaminants. This interdiction resulted in a serendipitous activation of the naturally occurring soil microbes in the sediments down-gradient from the well field. The net result of the interdiction and microbiological activation was to effect a rapid and dramatic reduction in the hydrocarbon contaminants in the plume down-gradient from the interdiction well field.

INTRODUCTION

Hydrocarbon contamination of groundwater is rapidly becoming one of the most troublesome and costly problems to be confronted by both the regulators and the regulated community. Virtually every day, an article is written announcing another underground water supply that has become contaminated and that it appears virtually impossible and prohibitively expensive to contain and completely decontaminate the aquifer.

SITE HISTORY

In July 1942, the United States Navy established an Air Station at Traverse City, Michigan, a small and isolated community located in the northwestern section of the Lower Peninsula (Fig. 1). The purpose of the Air Station was to conduct highly classified research and development of pilotless drone aircraft that could be remotely guided by television to the target from chase aircraft. This research effort was continued until 1944 when it was suspended. When the war ended, the Air Station was turned over to the United States Coast Guard (USCG) to serve as a major Search and Rescue base for Lakes Superior, Huron and the upper portion of Lake Michigan.

Coast Guard Operation

Coast Guard operations at the site commenced in 1944 and have continued until the present with a mix of rotary-wing and fixed-wing aircraft. A review of operations revealed nothing extraordinary or unusual had been reported although historical records of the station are sketchy.

History of Problem

In 1979, during the removal of two fuel farms preparatory to the installation of a new system, there was some indication that leaks had occurred. The only soil contamination was in the Jet Fuel (JP-4) storage area. These soils were removed and disposed of under the direction of the State of Michigan Department of

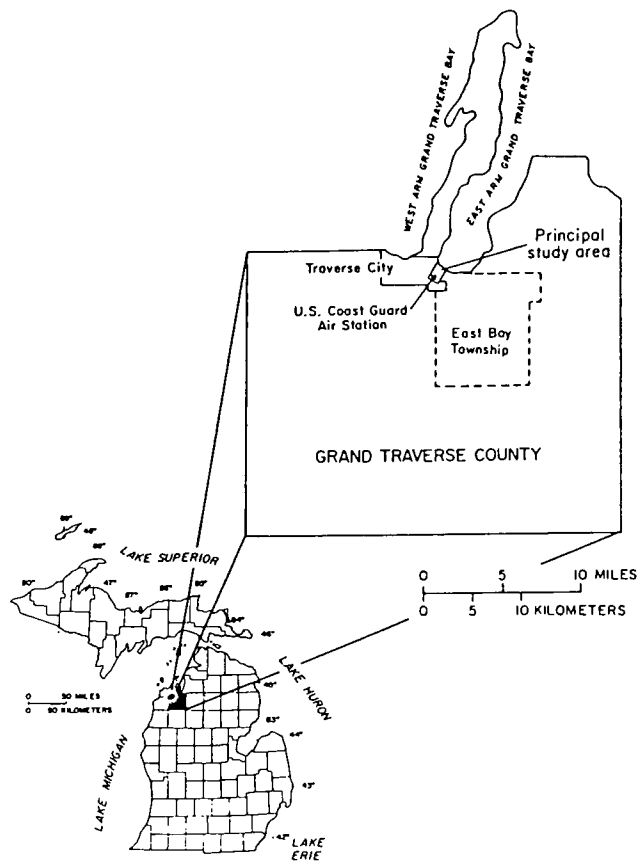

Figure 1
Location of East Bay Township and U.S. Coast Air Station in Michigan

Natural Resources (MDNR). This area was located some 1,500 ft upgradient and to the north of the area that was ultimately implicated as the "geographical origin" of the plume. The Aviation Fuel (115/145) fuel farm, located immediately adjacent to the "geographical origin" of the plume, was excavated at the same time with little indication that any unusual occurrences had taken place. There was some odor noted in the soil, but laboratory analyses did not confirm gross contamination, so no soil was removed.

In 1979 and 1980, residents in the Avenue E area of the Pine Grove Subdivision of East Bay Township complained to the local health department that their wells were producing discolored water, were foaming and had bad tastes and foul odors. The first

residence reporting the problem is located 1,200 ft to the northeast of the Coast Guard Air Station (CGAS). At that time there was no explanation for the contaminated wells and, unfortunately, the health department did not test for any of the possible organic contaminants. Later in 1980, the MDNR did a limited hydrogeologic study in the area and concluded that the source of the contamination was from some unspecified site on the CGAS.[1] In May 1982, the government was notified of the findings and began an attempt to elucidate the problem.

COAST GUARD ACTIONS

The U.S. Geological Survey (USGS) was retained in June of 1982 to do a thorough hydrogeological study of the area to define the plume of contaminants and to find the source. By April 1983, the USGS had determined the direction and velocity of groundwater flow through the area and had tentatively identified the boundaries of the plume (Figs. 2 to 5). The USGS was not able to determine the source of the contaminants. They did, however, conclude that the majority of the contaminants identified were related to components in fuels with some chlorinated compounds also present.[2]

Detailed Studies

In November 1983, the Coast Guard contracted with the University of Michigan (UM) for a scientific study and feasibility study of the site. Objectives for these studies included a temporal analysis of the plume and a positive identification and location of the contaminant origin(s). The final report[3] included a description of the time variation of contaminants and adsorptive characteristics of soils, including side-by-side comparisons of

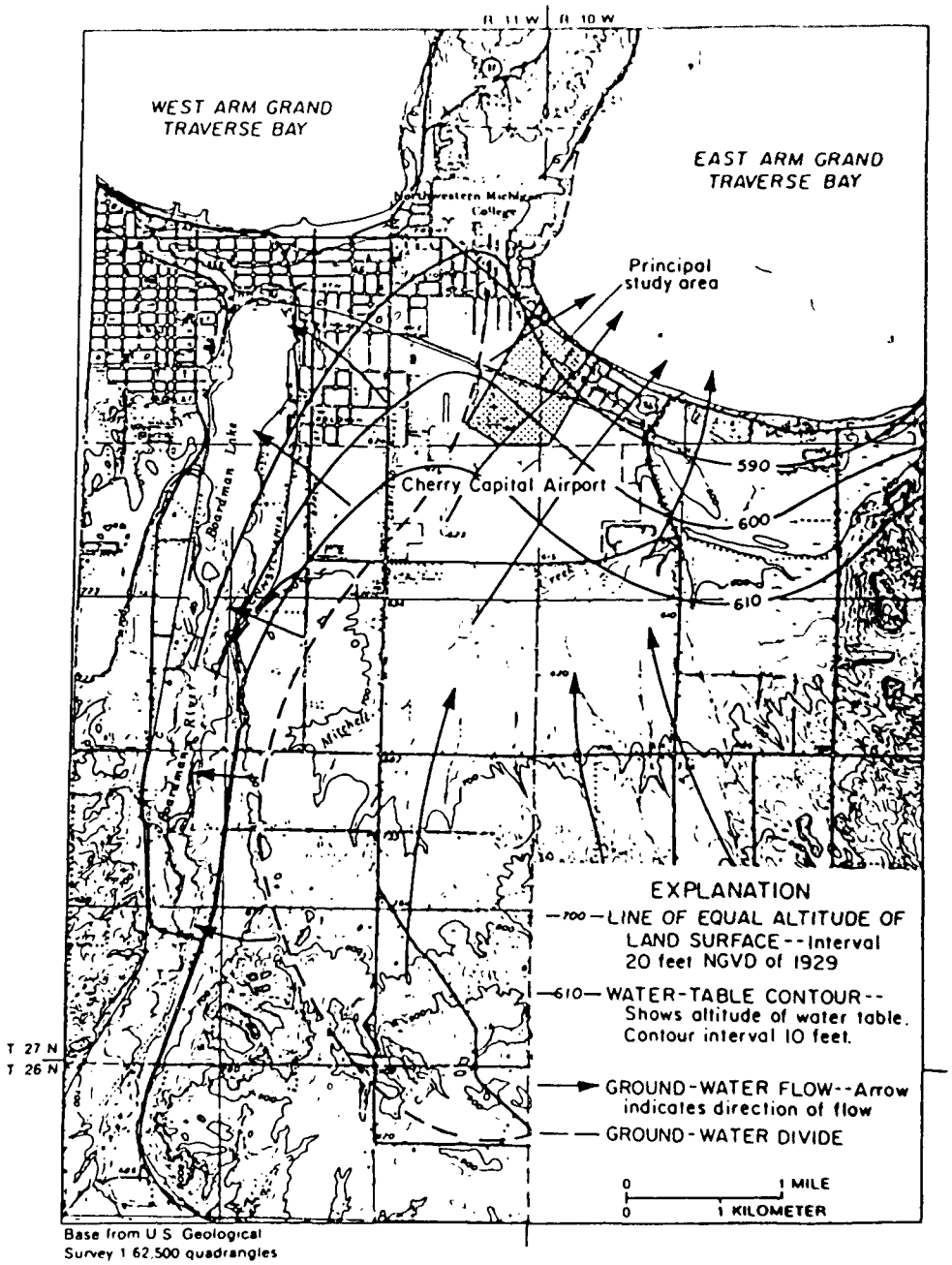

Figure 2
General Direction of Groundwater Flow

water and soil concentrations found by MDNR, USGS and UM; a description of the quality assurance program for collection and analysis of groundwater samples; a preliminary risk assessment for chemicals found in the groundwater and a description of the effort to numerically model the behavior of the groundwater plume, a description of the groundwater sampling program and a preliminary remediation analysis that identified several cleanup alternatives.

During this time, the USCG was pursuing an internal investigation which resulted in the discovery of an Aviation fuel spill incident. In November or December of 1969, a flange in an underground pipe line under a 115/145 high octane Aviation Gasoline fueling station failed, resulting in the loss of approximately 2,000 gal of product over a 12-hr period.

The Traverse Group Inc. (TGI), an Ann Arbor-based multidisciplinary consulting firm, was contracted by the USCG to do a detailed feasibility study that included the design, construction and operation of groundwater treatment plants (involving carbon adsorption and air stripping techniques) and to continue a sampling program for selected wells to monitor the plume. This part of the investigation was completed in February 1985.[4] TGI was then asked to continue the project to include the following tasks:

- Selection of a specific cleanup technology
- Design, construction and operation of an interdiction well system
- Design and installation of monitoring wells
- Design, construction, operation and evaluation of a full-scale carbon adsorption system
- Assembly, installation and evaluation of an advanced rotary air stripping and vapor incineration system

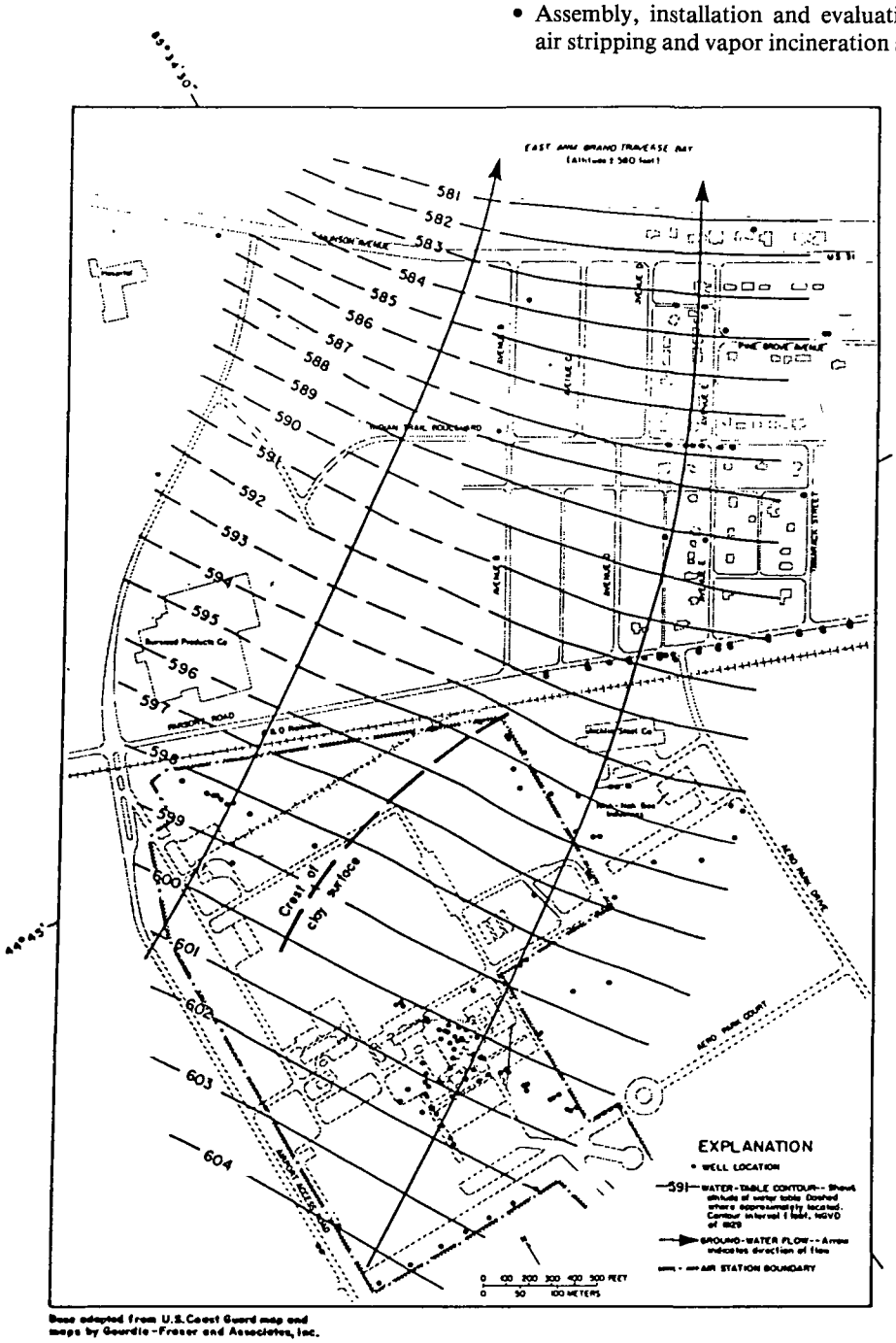

Figure 3
Water Table and Direction of Groundwater Flow on Apr. 5-7, 1983

In February 1985, new hydrocarbon contamination was discovered at the JP-4 fuel farm south of the Hangar/Administration building (HAB). The four fiberglass underground storage tanks at the station were tested; three were found to be leaking and were removed. In March 1985, routine sampling indicated the presence of high levels of benzene, toluene and lighter hydrocarbons in monitoring wells along the south boundary fence of the USCG property upgradient from the JP-4 Fuel Farm. The origin of this contamination was not then, nor is it now, understood since these wells are now clean. One possible explanation for the contamination in these wells was a spill of approximately 2,000 gal of Jet-A at the Republic Air Lines fuel farm some 1,800 ft directly upgradient from the south boundary of the USCG property. What cannot be explained is the high contaminant levels when the wells were sampled in March 1985, and the current absence of contaminants in the wells.

Plume Characterization

Much of the investigative effort focused on the location and characterization of the groundwater plume. All agencies involved installed and monitored observation wells for this purpose. Due to temporal variations of the contaminants and differences in analytical techniques, not all results were in complete agreement; however, there is sufficient similarity to delineate locations and concentrations of the plume's major constituents.

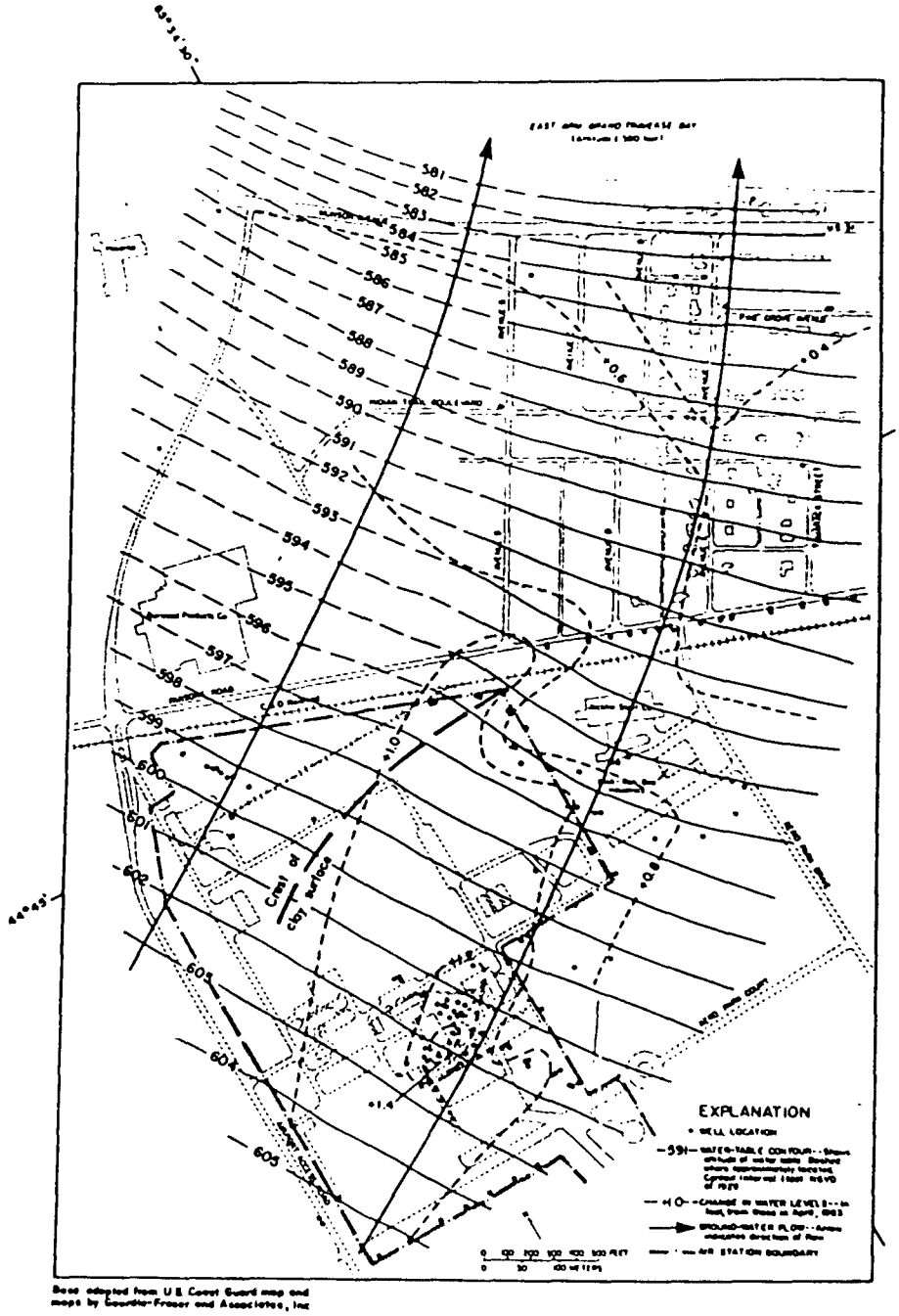

Figure 4
Water Table and Direction of Groundwater Flow on July 19-20, 1983

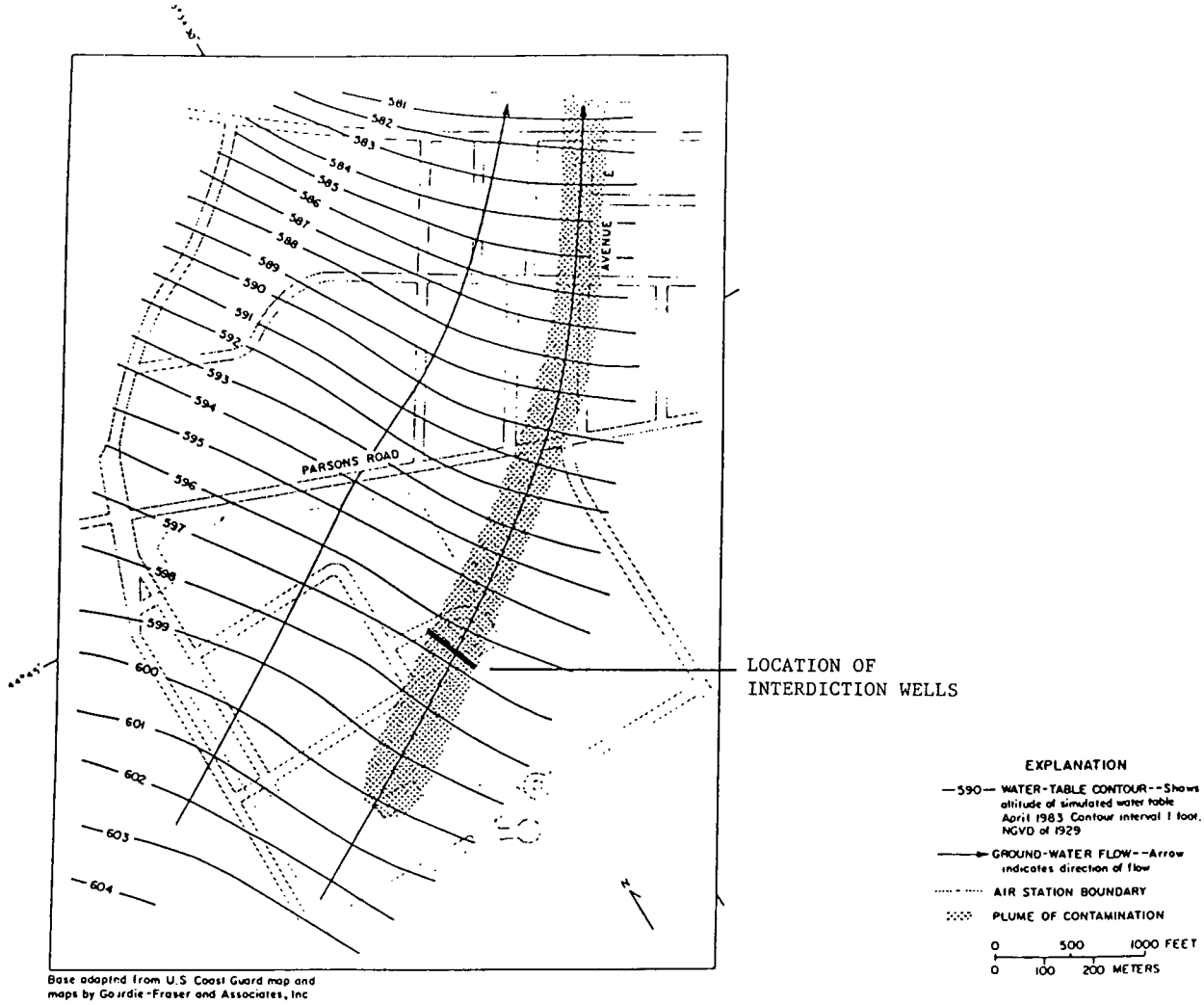

Figure 5
Water Table for Apr. 1983, Simulated by Groundwater Flow Model

The UM study[3] identified benzene and toluene as the components in the plume presenting the greatest health risk. The largest concentrations occurred in the vicinity of the Hangar/Administration Building (HAB) at the geographical head of the plume (Figs. 6 and 7) although significant amounts of some compounds such as benzene were found at some distance downgradient. Other chemicals also were found in the plume but at smaller concentrations and reduced distributions.[3]

The USGS provided a detailed map of the plume's size and location (Fig. 1). From the HAB, the plume follows groundwater flow to the northeast and off the base, passes under an industrial park and turns slightly north, narrowing as it passes underneath Parsons Road and widening out again under Avenue E (Fig. 5). The plume is approximately 4,300 ft long and varies from 180 to 400 ft in width. Its vertical dimension ranges from 25 to 80 ft.

Small concentrations of benzene and toluene have been detected in the water of East Bay. The USGS[2] reported maximum values of 20 μg/l benzene and 3.1 μg/l toluene aproximately 330 ft from shore. The vast majority of subsequent measurements by the TGI have been less than those found by the USGS with the majority being below the detectable limit.

Soil Contamination

Both the UM study and the USGS study reported numerous measurements of organics in the soils at the Air Station, again with discrepancies due to analytical, temporal and areal variations. The UM study found maximum concentrations of 25.4 μg/l benzene, 27.6 μg/l toluene and 229 μg/l xylene. Analyses were done for seven other hydrocarbons with negative results. Analysis of soil borings indicates that much of the organic material is retained in the soil in a 6 to 12 in. thick layer in the capillary zone immediately above the water table. It has been suggested that this zone is slowly leaking organics into the groundwater over time and is thus serving as a contaminant source for the plume.[3]

Proposed Cleanup

After consideration of the various long-term treatment or cleanup options available, it became clear that the most logical first step in any remediation action program would be to decrease or stop the further movement of contaminants off U.S. Coast Guard property.

This option was judged to have several advantages:

- Reduce any possible increase in risk to human populations that may have been related to fuel based contaminants present in the groundwater.
- Promote reductions in contaminant concentrations in the groundwater either by dilution or possible biodegradation of fuels by indigenous microbial consortia present in the subsurface soil-water system.
- Provide a better opportunity (e.g., more time) to efficiently select and design appropriate method(s) for dealing with the contaminants present in the geographical origin of the plume.

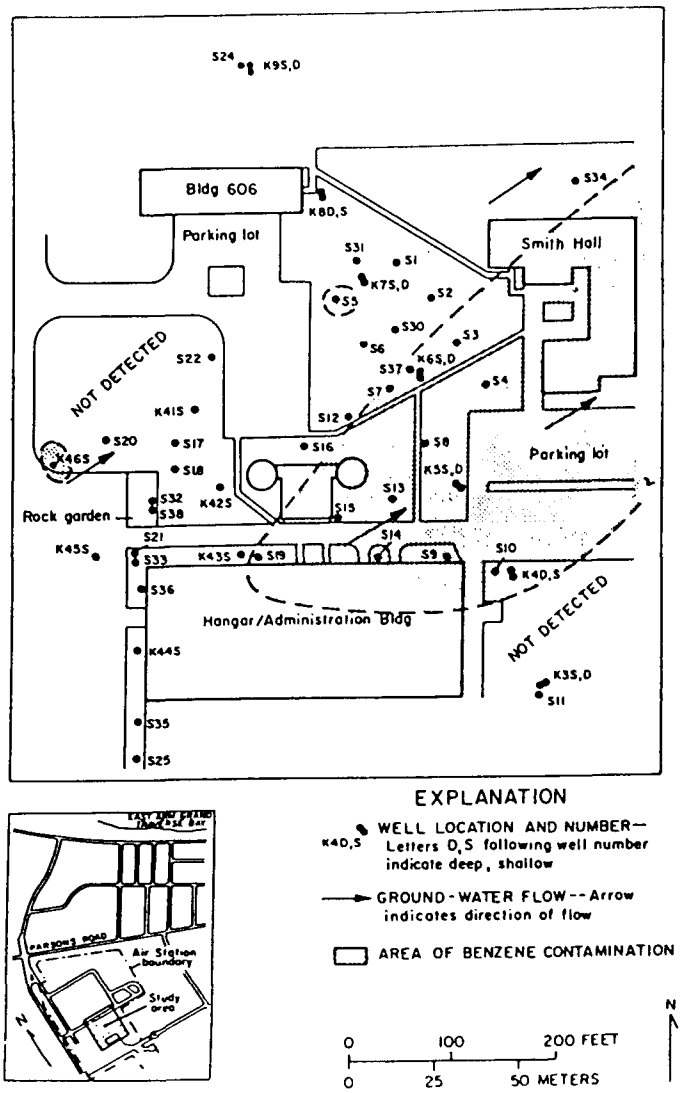

Figure 6
Benzene Concentrations in Groundwater near Hangar/Administration Building

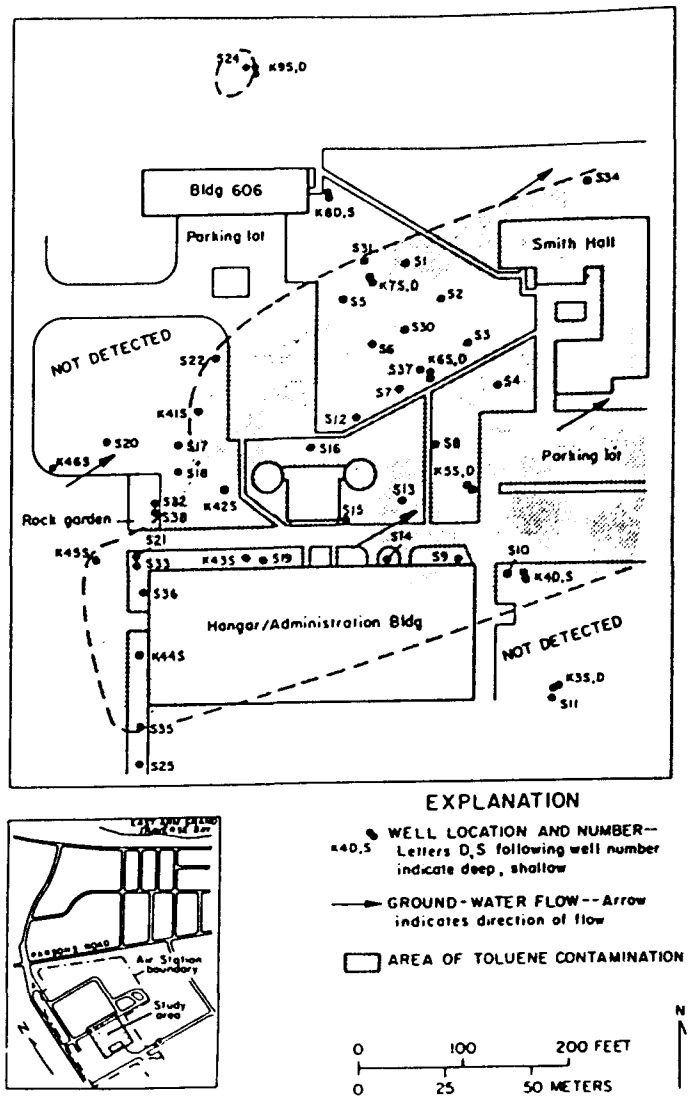

Figure 7
Toluene Concentration in Groundwater near Hangar Administration Building

A team was assembled by the USCG to design and implement a method to contain the contaminant plume on government property. The situation at the USCG Air Station differed from the usual cases of contaminant releases into the subsurface, because the contaminants in this case had been in the groundwater for at least 14 years. Thus, the task was the blocking of a plume that had migrated well beyond the boundaries of the government property. In effect, a "valve" was being designed to close the flow of a contaminant stream well-established over time. The major complication was to prove that the blocking was at least partially and hopefully fully effective.

Two major questions arose in considering the design of a containment or "interdiction" system:

- What would be the hydraulic effect of a blocking system on plume definition and direction as well as downgradient water levels?
- What could be done with the contaminated groundwater produced by such a system?

Several options were considered:

- Reinjection at alternative locations in the aquifer
- Reinjection directly upgradient to create a loop
- Spray irrigation on a seasonal basis
- Discharge to various surface waters or discharge to the Traverse City Publicly Owned Treatment Works (POTW)

The technical team, composed of representatives from the USCG, TGI and the USGS, examined the various options in detail. One issue that soon became the controlling factor was the question of process water disposal. Since the USCG did not have a National Pollution Discharge Elimination System (NPDES) Permit for point discharge, any disposal action would require a permit which could possibly take up to several years to obtain. The only reasonable solution reached was to route the produced water to the sanitary sewer since the Traverse City POTW already had an NPDES Permit.

After meeting with city officials, the USCG was given permission for an industrial sewer hookup. Estimated costs for processing the discharge were estimated at between $4,000 and $10,000 per month depending upon flow. The task was then to design a

system to withdraw the minimum amount of water yet still capture the contaminants passing through the aquifer so that no contaminants, or at least a significantly reduced amount, were leaving government property.

After reviewing several of the USGS groundwater model runs, the team selected a well field configuration shown in Figure 8. Seven wells were located laterally across the plume in the east-northeast area of the Air Station. These wells were 6 in. auger-drilled wells with full 10-slot stainless steel screens running from the top of the aquifer to the clay confining layer at the bottom (Figs. 5 and 8).

The system initially was constructed with all elements above ground. In 1985, the interdiction system was modified by installing pitless adapters and providing a heated building to protect the manifold and control systems from the extreme cold experienced at this site. The water produced from the interdiction wells is piped to a carbon treatment system consisting of four 20,000-lb carbon reactors. The carbon reactors were specified to reduce the levels of benzene and toluene in the water to less than 1 $\mu g/l$ as measured using headspace technique on a HP5710A Gas Chromatograph.

The USGS model gave clear indications that these flow rates would produce closure of the equipotential lines at the interdiction well line. One difficulty was that the two-dimensional nature of the model did not yield any prediction on the vertical movement of water at or near the individual well locations. However, because of the uniform nature of the saturated zone and the rapid mean field velocity of the aquifer, which was measured at 5 ft/day, it was believed that vertical movement in a fully screened well at 15 gal/min would be sufficient to capture contaminants flowing in the lower areas of the aquifer.

Table 1
Specifications for Groundwater Interdiction Systems

North Interdiction Field

Date Wells Installed:
Wells ID1-ID6 Feb. 26-Feb. 28, 1985
Well ID-7 Mar. 22, 1985

Date of Water collection system construction: Mar. 19-Apr. 18, 1985

Date Pumping commenced: Apr. 19, 1985

Well and Screen Data:

North Interdiction (6 in. diameter)

Well #	ID-1	ID-2	ID-3	ID-4	ID-5	ID-6	ID-7
Flow gpm	15	15	15	15	15	15	25
Top of screen (below ground)	13	13	13	13	13	13	13
Bottom of screen	53	53	43	43	43	43	58
Well pump location (bottom of pump below ground level)	43	43	33	33	33	33	48

Table 2
Monitoring Wells for North Interdiction

Five full screen wells installed—Mar. 20-27, 1985

Downgradient of North Interdiction Field on Mar. 20-Mar. 27, 1985

Four-inch diameter wells extending to clay liner beneath the aquifer

Well #	TGI-1	TGI-2	TGI-3	TGI-4	TGI-5
Depth below ground top of well screen to bottom of well screen (top of water at 13' below ground level)	13'-53'	13'-69'	12'-68'	13'-65'	13'-54'
Vertical location of sample pumps in wells, feet below ground					
Sample pump #1	15'8"	14'10.5"	14'6"	15'5.5"	14'10"
#2	25'8"	24'	24'	28'	17'
#3	35'8"	40'	41'	41'	33'
#4	45'8"	54'	57'	54'	43'
#5	54'5"	66'9"	68'	66'	53'5.7"

TGI-2 sample well located 50' downgradient from ID-3 on a line parallel to the flow lines of the plume drawn NE from ID-3. TGI-3 located 50' downgradient from TGI-2 on a line parallel to the flow lines through ID-3 and TGI-2. TGI-4 located 90' northwest of TGI-3 on a line through TGI-3 perpendicular to the flow lines. TGI-1 located 180' northwest of TGI-3 on a line through TGI-3 and TGI-4. TGI-5 located at the end of a line drawn perpendicular to a line through TGI-3 and TGI-4 starting at a point 90' SE of TGI-3 running 50' NE.

In most situations, contaminants such as benzene and toluene are found more predominantly in the upper areas of the aquifer. However, in this situation the original spill had been in the ground so long that visible product was no longer present and the product not contained in the interstitial area of the capillary zone had solubilized and had mixed downgradient so that it was present throughout the vertical cross-section of the aquifer. Thus, placement of the pump in the well had to be in conjunction with a full screen configuration to capture contaminants from all vertical locations.

A second consideration in the design was the monitoring of the interdiction system to obtain data on the effectiveness of the blocking of contaminant flow. Since the area of the aquifer downgradient from the interdiction system had been contaminated for several years, the monitoring wells must yield data in sufficient detail to prove any decrease in contaminant levels after the "valve" had been closed.

A sampling network of five wells was located downgradient from the interdiction well system (Fig. 9). The wells were located outside the zone of influence of the interdiction wells. Sampling was done using a dedicated "Well Wizard" sample pump system. Groundwater samples were collected following standard field procedures for the collection of volatiles and analysis was done within a few hours of collection, always on the same day that the sample was collected. Five sample pumps were located in each monitoring well at the top and bottom of the saturated zone and at three equidistant points (Table 1).

RESULTS

The results downgradient from the interdiction system have been satisfying to date. Toluene and benzene levels in the downgradient monitoring wells were monitored in one of the five wells (M2/TGI2) on a daily basis for the first 8 weeks and on a bi-weekly basis thereafter. The other four wells are monitored once a week.

Since benzene is the more mobile of the two constituents of interest and has the higher solubility, it should be slower than toluene to respond to the interdiction. In addition, there was speculation that some biodegradation by selective demethyoxylation might be seen and be reflected in the benzene and toluene concentrations found in the downgradient wells. A considerable amount of data have been collected which allow trend observations to be made regarding the fate of benzene and toluene in the downgradient area (Figs. 8 to 10).

Figure 8 shows the variations and trend of benzene concentrations as a water column average by month since the interdiction field was activated on Apr. 15, 1985. Figure 9 provides the same information for toluene. These data are from Well M-2 (TGI-2) located immediately downgradient and outside the zone of influence of the interdiction well field. This well logically would be the first monitoring well to provide data on the effectiveness of interdiction. Although microbiological activity would not be separated from hydraulic blocking, toluene levels decreased from a baseline level of 10329 μg/l to less than 10 μg/l in approximately 100 days.

Figure 10 shows benzene and toluene levels plotted against time from April to December 1985. Since this figure shows the variation of the two compounds, it could substantiate the microbiological activity. The decrease in toluene levels, together with the concomittant rise in benzene between May and July, could be attributed to the demethoxylation of toluene to benzene. Both compounds then began a steep downward trend with the toluene being the first to approach non-detectable levels in August. As can be seen, the benzene reached its lowest level during October.

The increase in benzene levels since October is attributed to the appearance of a red slime that plugged pump screens and coated the inside of the piping systems, resulting in a reduction of the hydraulic capacity of the system. The groundwater in this aquifer is high in iron content, and the substance has been tentatively identified as oxidized iron compounds and complexes, mineral deposits and biomass. Microbial action is believed to play a significant role in the dissolution of these solids in the aquifer and subsequent precipitation within the system. The slime is completely soluble in an acidic solution, and gamma logging of the wells does not indicate the presence of any clay layers that could be contributory. Obviously this situation must be better understood and controlled or the field will lose its effectiveness as may be indicated by the gradually increasing benzene levels.

The USCG has an active project with the U.S. EPA Robert S. Kerr Environmental Research Laboratory (RSKERL) in Ada, Oklahoma to evaluate the soil and water chemistry as well as the microbial consortia present at the site. The results of these studies should provide a mechanism to control the slime and elucidate the biodegradation phenomenon.

While monitoring of the interdiction system continues, there already is substantial evidence that the desired effect was achieved in terms of contaminant containment. Toluene has decreased to virtually non-detectable levels and, while it continues to be variable, benzene concentrations clearly demonstrate a downward trend. The benzene variability may be due in part to some, all or a portion of the slime problem discussed earlier. Biodegradation variability, the effect of recharge and the higher mobility of benzene in the groundwater system also may contribute to the variability of the benzene.

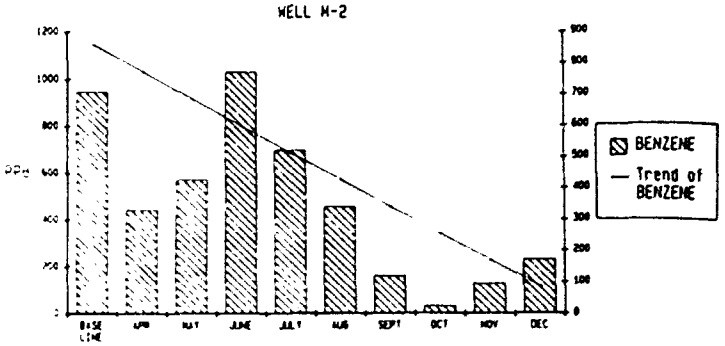

Figure 8
Benzene Concentration as a Function of Time

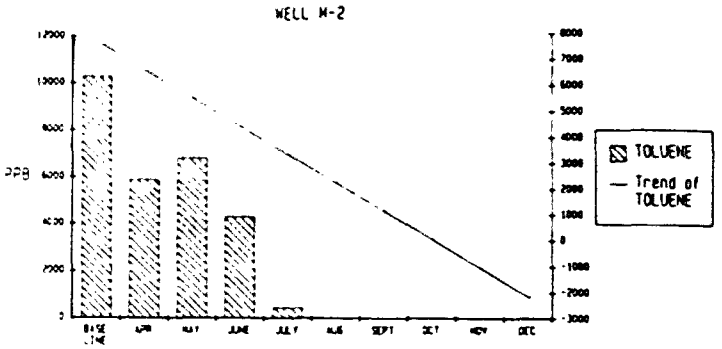

Figure 9
Toluene Concentration as a Function of Time

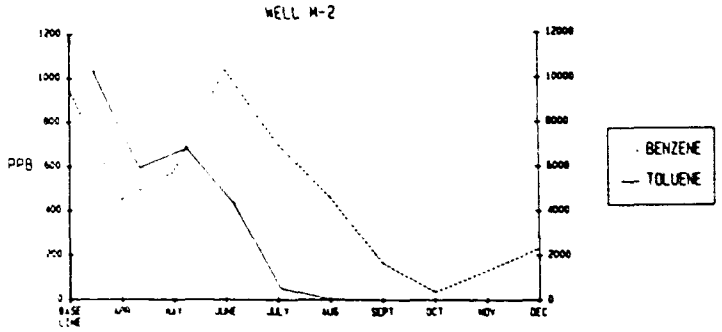

Figure 10
Benzene and Toluene Concentrations as a Function of Time

CONCLUSIONS

Based on the data collected over the past 9 months, it appears that, for well defined plumes, low flow interdiction is a viable alternative to intercept and block contaminant flow.

Careful attention must be paid to the mechanical as well as contaminant systems. The appearance of the biomass is a good example of this since no homeowners in the area using wells have reported a problem with slime.

The possibility of triggering increased microbial activity is a potential factor to consider.

Particular attention must be given to the vertical distribution of contaminants since withdrawal volumes may be significantly different for new plumes as compared to old plumes.

Minimum volume requirements as dictated by available process water disposal options are a major determinant in interdiction system design.

DISCLAIMER

The opinions or assertions contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Commandant or the Coast Guard at large.

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Computer Groundwater Restoration Simulation at a Contaminated Well Field

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ABSTRACT

The most obvious and direct means of contaminated aquifer rehabilitation is to remove the contaminated water by pumping from recovery wells. Factors affecting the technical and economic feasibility of this procedure include the number of recovery wells, the rate and duration of pumping and the method used to dispose of the contaminated water. Since the aquifer rehabilitation is assumed to be the reverse of the contaminant spreading process, the theory and models that have been developed for predicting the spread of a contaminant should provide a basis for predicting contaminant withdrawal.

The drinking water of western Vestal, New York, is supplied by Water District 1, which consists of wells 1-1, 1-2 and 1-3. Well 1-1, located on the bank of the Susquehanna River about 400 ft from the Endicott-Vestal Bridge, is contaminated with volatile organic compounds. Currently, a remedial investigation/feasibility study is being conducted at the site. The purpose of the remedial investigation/feasibility study is to locate the contaminant source, to define the extent of the contaminant plume and to evaluate the remedial alternatives. As a practical tool to assist in the feasibility study, a two-dimensional finite element model is being applied to this site. First, the model is calibrated against field data. Then the model is utilized to simulate the movement of the contaminant plume under the operation of a recovery well. The model results will be used to evaluate and refine the remedial alternatives.

INTRODUCTION

A groundwater contamination problem due to toxic organic chemicals exists in Water District 1 of Vestal, New York. In early 1980, organic chemicals were detected in a municipal well in Vestal. As a result of this finding, all wells in Vestal were tested for synthetic organic compounds. Well 1-1 of Water District 1 was found to contain large quantities of organic compounds. This triggered an assessment study of the potential of the pollutant to contaminate other water supply wells in the district. Currently, a remedial investigation/feasibility study is being conducted at this contaminated well field site. As a result of the remedial investigation, the contaminant source areas were identified and the extent of the contaminant plume was defined.[1,2]

A feasible alternative to cleanup of the contaminated well field is to remove the contaminated groundwater by pumping from recovery wells. Since the aquifer rehabilitation is assumed to be the reverse of the contaminant spreading process, the theory and models that have been developed for predicting the spread of a contaminant provide a basis for predicting contaminant withdrawal.

A two-dimensional finite element model is applied to this contaminated well field site to simulate the transport of the pollutant under a recovery well is being operated. The model utilized a quadrilateral element and the Crank-Nicholson method for calculation of the time marching scheme. The model result can be used to evaluate the effect of the recovery well and to refine the remedial alternatives.

DESCRIPTION OF THE SITE

The drinking water for most of western Vestal is supplied by Water District 1, which consists of well 1-1 and water supply wells 1-2 and 1-3. Well 1-1, located on the south bank of the Susquehanna River about 400 ft from the Endicott-Vestal Bridge, is contaminated with volatile organic compounds. Contamination was detected first in early 1980; since spring 1980, the well has been pumped directly into the Susquehanna River. At present, well 1-2 is supplying the Vestal drinking water; well 1-3 is serving as a backup supply. Because the water in well 1-3 is highly corrosive and well 1-2 has a limited capacity, it is important that well 1-1 be restored, especially to meet anticipated future peak demands for Water District 1 and other interconnected districts. Figure 1 shows the site of the contaminated well field and the groundwater table contours under wells 1-1 and 1-2 while in operation. The groundwater table contours were developed from field measurements.[1]

The area immediately surrounding well 1-1 is within the Susquehanna River floodplain and consists of marshland, wooded areas and commercial and residential land use areas. The river occupies a bedrock valley filled with glacial deposits ranging in size from clay to gravel. The bedrock surface, situated between 130 and 160 ft below ground level, is overlain by a productive aquifer consisting of about 40 ft of permeable sand and gravel. The aquifer is overlain by 120 ft of poorly permeable clays and silts. Within these deposits are locally permeable pockets of material which apparently have acted as contaminant pathways between the ground surface and the producing aquifer.

The high rate of pumping from this aquifer (approximately 1.5 million gallons daily, including the pumping of well 1-1 to waste) has induced organic solvent movement toward well 1-1 from the source area. The source area is an industrial park containing a variety of industries. Volatile organic levels exceed 10 mg/l in one monitoring well located within the area, but no information is available regarding spills or disposal or organic solvents.

DESCRIPTION OF THE MODEL

The governing equation of pollutant transport in porous media is the following:

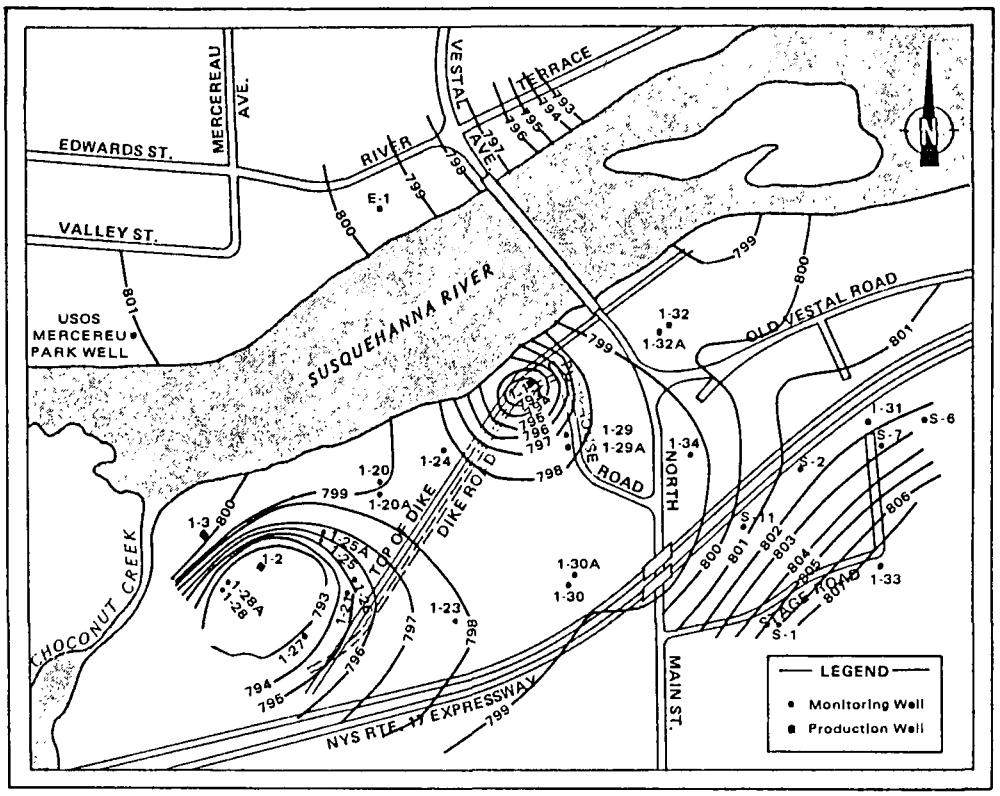

Figure 1
Map of Vestal Well Field and Groundwater Table Contours with Wells 1-1 and 1-2 in Operation

$$nR\frac{\partial c}{\partial t} = n\left[\frac{\partial}{\partial x}\left(D_{xx}\frac{\partial c}{\partial x} + D_{xy}\frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial y}\left(D_{yx}\frac{\partial c}{\partial x} + D_{yy}\frac{\partial c}{\partial y}\right)\right] - \left[\frac{\partial}{\partial x}(V_x c) + \frac{\partial}{\partial y}(V_y c)\right] - n\lambda R c + Q c^{*}. \quad (1)$$

in which:

c = concentration of the pollutant
$R = 1 + \varrho_s k/n$ = retardation factor
ϱ_s = bulk density of the porous medium
k = distribution coefficient of the pollutant
n = porosity of the porous medium
$D_{xx}, D_{xy}, D_{yx}, D_{yy}$ = component of dispersion tensor
V_x, V_y = Darcian velocity component
λ = 1st order decay constant
c^* = concentration of the source fluid
Q = flow rate of the source fluid

Let L denote the operator on c in equation (1), thus:

$$Lc = 0. \quad (2)$$

For the finite element method:

$$c \sim \hat{c} = \Sigma c_i(t) N_i = \{N\}^T \{c\} \quad (3)$$

where $\{N\}$ is the shape function. The residue becomes $L\hat{c}$. The principle of Galerkin method requires that:

$$< L\hat{c}, W_i >_B = 0 . \quad (4)$$

Equation (4) states that the inner product of $L\hat{c}$ and the weighting function W_i over the solution domain B vanishes. The integrations of Equation (4) are now carried out, and the results are expressed in matrix and vector notation as follows:[4]

$$\{c\}^T [M\{\dot{c}\} + (K - A + E)\{c\} - \{p\}] = 0 \quad (5)$$

in which:

$$\{\dot{c}\} = \left\{\frac{dc}{dt}\right\} \quad (6)$$

$$K = -\iint_B \left[nD_{xx}\left\{\frac{\partial W}{\partial x}\right\}\left\{\frac{\partial N}{\partial x}\right\}^T + nD_{xy}\left\{\frac{\partial W}{\partial x}\right\}\left\{\frac{\partial N}{\partial y}\right\}^T + nD_{yx}\left\{\frac{\partial W}{\partial y}\right\}\left\{\frac{\partial N}{\partial x}\right\}^T + nD_{yy}\left\{\frac{\partial W}{\partial y}\right\}\left\{\frac{\partial N}{\partial y}\right\}^T\right] dxdy \quad (7)$$

$$A = \iint_B V_x\left\{\frac{\partial W}{\partial x}\right\}\{N\}^T + V_y\left\{\frac{\partial W}{\partial y}\right\}\{N\}^T dxdy \quad (8)$$

$$E = \iint_B n\lambda R\{W\}\{N\}^T dxdy \quad (9)$$

$$M = -\iint_B nR\{W\}\{N\}^T dxdy \quad (10)$$

$$\{p\} = \iint_B Qc^*\{N\}dxdy + \oint_S \left[\left(nD_{xx}\frac{\partial c}{\partial x} + nD_{xy}\frac{\partial c}{\partial y} - V_x c\right)n_x + \left(nD_{yx}\frac{\partial c}{\partial x} + nD_{yy}\frac{\partial c}{\partial y} - V_y c\right)n_y\right]\{W\}ds . \quad (11)$$

The advantage of the finite element method over the finite difference method is its ability to handle complex boundaries and normal derivatives. In the time dimension, these advantages are not present, so the finite difference method will be used for the time derivative term of the solute transport Equation.[5]

With finite difference in time, Equation (5) becomes

$$\left[\frac{M}{\Delta t}+\mu\,(K-A+E)\right]\{c\}_{t+\Delta t}=\left[\frac{M}{\Delta t}-(1-\mu)(K-A+E)\right]\{c\}_{t} + [\mu\{p\}_{t+\Delta t}+(1-\mu)\{p\}_{t}] \quad (12)$$

in which $\mu = 1$ for backward-differences and $\mu = 0.5$ for the Crank-Nicholson differencing scheme. Along the boundary of the study area, Dirchlet boundary conditions were specified.

SIMULATION OF CONTAMINANT PLUME

For the preparation of input files for the computer simulation study, it was necessary to set up a grid system for the discretized site and determine several model parameters. According to the site history, production wells 1-1 and 1-2 are constantly in operation. Therefore, a non-uniform but steady-flow field was assumed from the measured groundwater table under wells 1-1 and 1-2 while in operation[3] as presented in Figure 1. As shown in Figure 2, the Vestal well site is discretized into 103 quadrilateral elements with 125 nodals.

Among the dissolved organics in groundwater, 1,1-dichloroethane was chosen to model the groundwater solute transport in the study area. The measurements from the samples at the monitoring wells are summarized in Table 1. The locations of the monitoring wells are shown in Figure 1. The 1- series wells were installed during the assessment study. The s- series wells were installed during the remedial investigation by E & E.

Since no field measurements are available for the dispersion coefficient, this value was selected based on the literature. The molecular diffusion is assumed to be small compared to the hydrodynamic dispersion. Values of 205 ft for longitudinal dispersivity and 12.9 ft for transverse dispersivity were used. 1,1-dichloroethane could be adsorbed on the solid phase of the aquifer. However, the retardation effect is believed to be small and will not seriously affect the qualitative prediction of solute transport. Therefore, a retardation factor of 1 was used for this study. The values of model parameters are listed in Table 2.

Table 1
1,1-Dichloroethane Concentration Measurements at Vestal Well Site

Well		1,1-dichloroethane	
No.	Node No.	Date	Conc.
S-1	65	4/26/85	0
S-2	77	4/26/85	945
S-6	103-112	4/26/85	58
S-7	94	4/26/85	1,280
S-11	68	4/26/85	158
I-33	84	4/26/85	860
I-34	78	4/26/85	1,300

Table 2
Model Parameters Used in Computer Program

Number of elements	103	Longitudinal dispersivity	205 ft
Number of nodes	125	Transversal dispersivity	12.9 ft
Number of wells	7	Retardation factor	1
Hydraulic conductivity	47 ft/day	First order decay constant	0

In order to verify the dispersion coefficient chosen for this study, a simulation of the dispersion of 1,1-dichloroethane was conducted. Two constant-strength sources located at nodals 84 and 94 were assumed in this computer run. The contaminant sources were found during the remedial investigation. The simulation time was 6 years. The assumptions were based on our best knowledge of the history of the site. The computed contaminant plume and comparison with field measurement are presented in Figure 3. The results show that the simulated concentration is very close to the field measurements. Other values of longitudinal and lateral dispersivity also were selected in simulating the dispersion of 1,1-dichloroethane. No satisfactory results were obtained from these tests. Therefore, the longitudinal and lateral dispersivities selected for the current study represent a rational choice for this site.

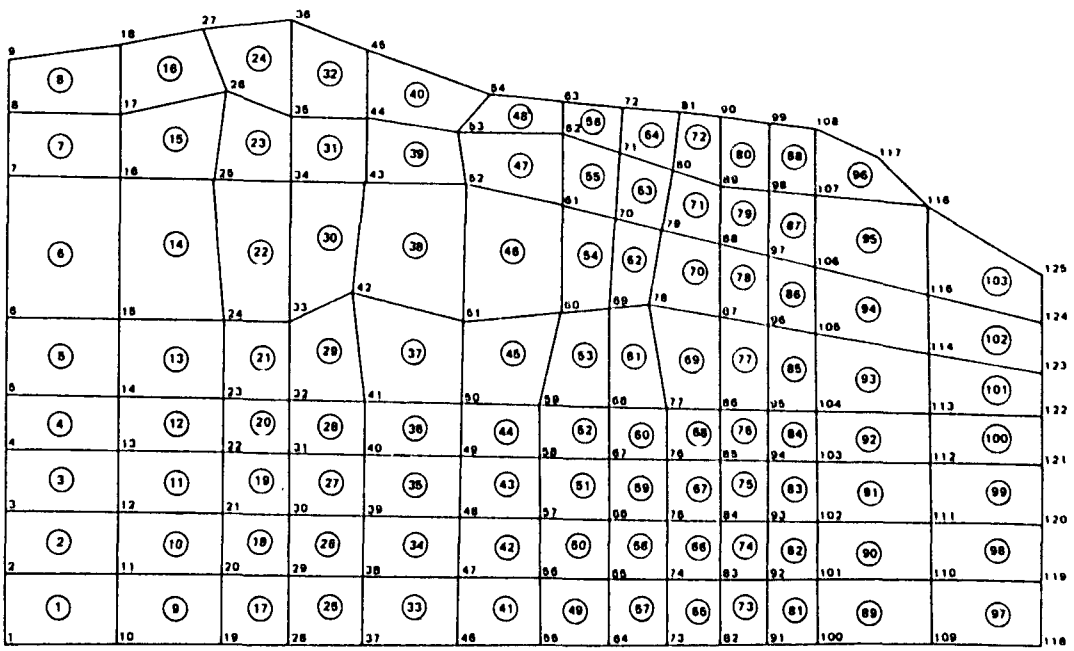

Figure 2
Finite-Element Grid System for the Vestal Well Field

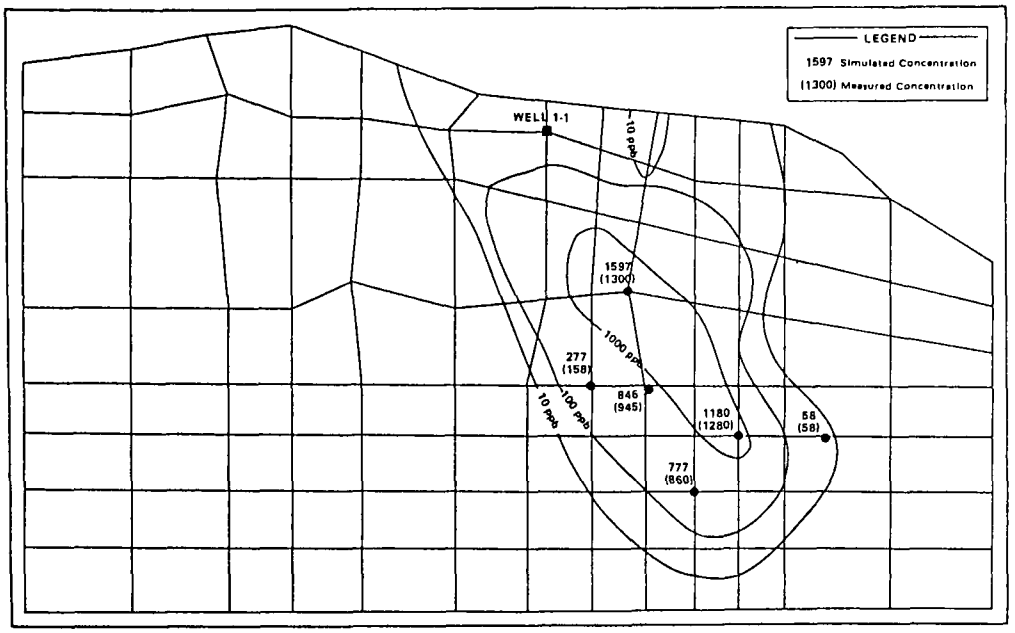

Figure 3
Computed Contaminant Plume and Comparison
with Field Measurement

Since spring 1980, well 1-1 has been pumped and discharged directly into the Susquehanna River. A possible remedial action would be the removal of the contaminant source and would continue use of well 1-1 as a recovery well to withdraw the pollutant from the aquifer. Computer simulation runs were conducted to simulate the movement of the contaminant plume after the removal of the contaminant source and while well 1-1 was in operation. Figure 4 presents the simulated concentration at the end of 5 years. A comparison of Figure 4 with Figure 3 shows that the 1000-μg/l iso-concentration contour is moving toward well 1-1, and the iso-concentration area is shrinking. Figures 5, 6 and 7 present the simulated concentration at the end of 10, 15 and 20 years, respectively. It can be seen clearly in these figures that the contaminant plume is moving toward recovery well 1-1 and that the high concentration region is shrinking.

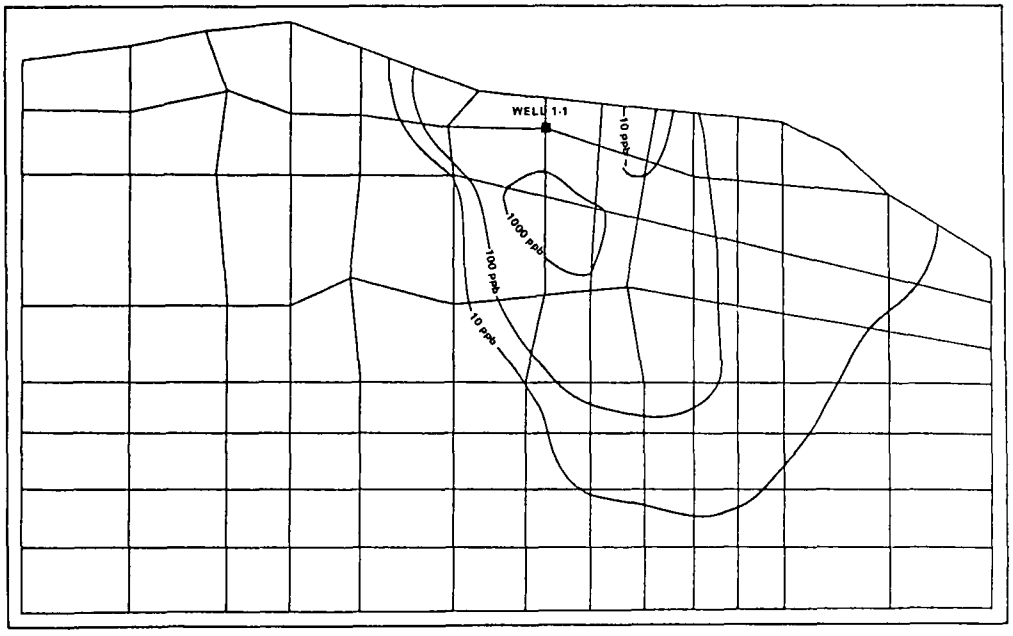

Figure 4
Computed Contaminant Plume, 5 Years After
Removal of Contaminant Source

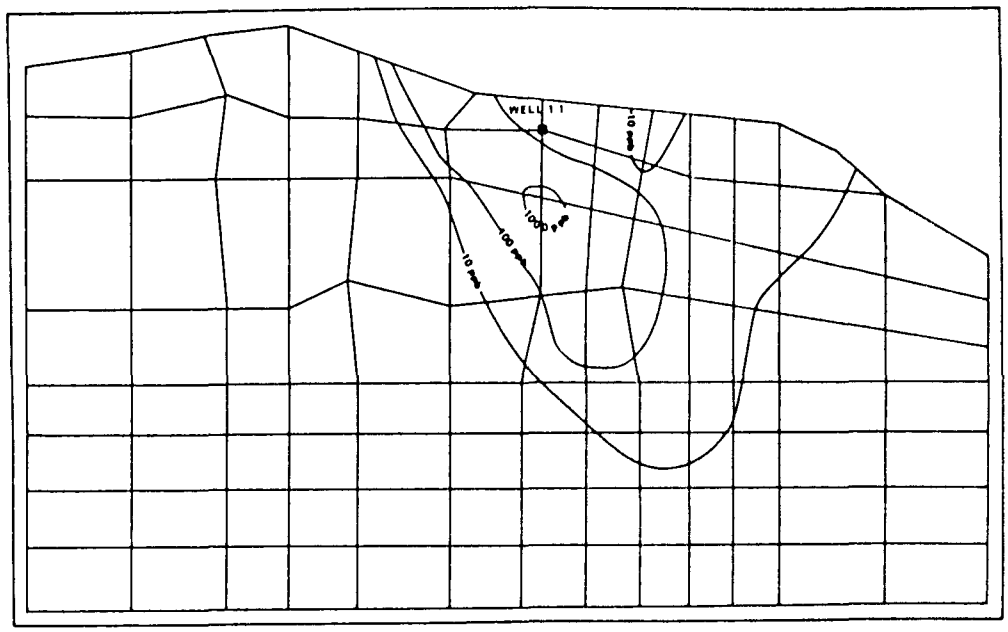

Figure 5
Computed Contaminant Plume, 10 Years After
Removal of Contaminant Source

CONCLUSIONS

The model predicted the movement of the contaminant plume under the operation of well 1-1 and the removal of the contaminant sources. The prediction was made for the time periods of 5, 15 and 20 years. The study provided a basis to evaluate the effectiveness and the cost of using well 1-1 as a recovery well. This summary paper demonstrates the usefulness of the computer model in assisting the feasibility study at uncontrolled hazardous waste sites. Further applications of computer groundwater restoration simulation can be conducted by varying the pumping rates, locations and numbers of recovery wells.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to U.S. EPA and the New York State Department of Environmental Conservation for their support in this study.

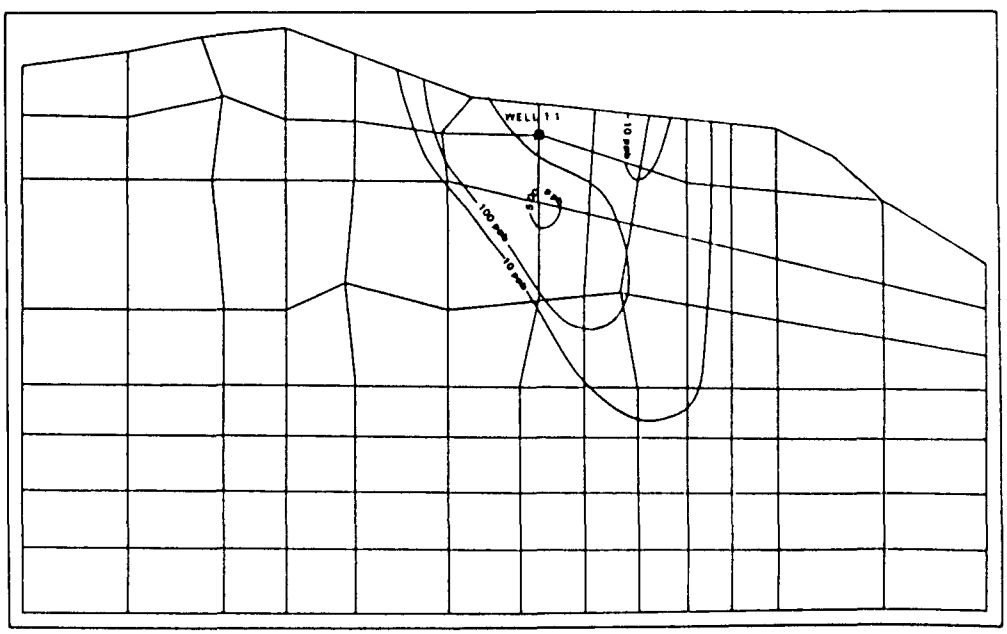

Figure 6
Computed Contaminant Plume, 15 Years After
Removal of Contaminant Source

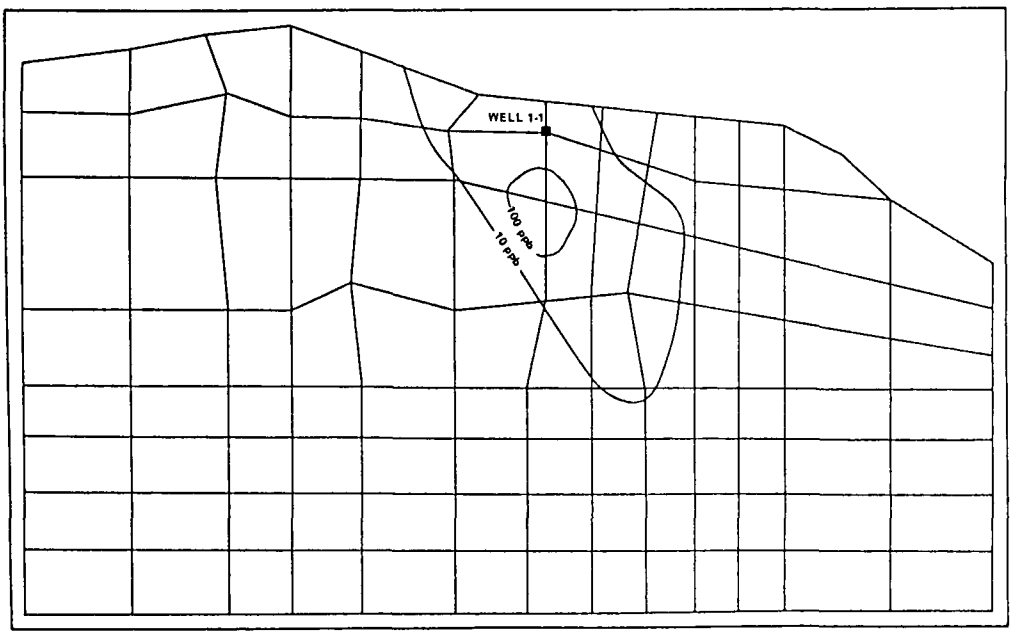

Figure 7
Computed Contaminant Plume, 20 Years After
Removal of Contaminant Source

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Enhancement of Site Assessments by Groundwater Modelling

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ABSTRACT

It is a commonly held misconception that extensive groundwater monitoring and other geologic and groundwater related data must be available before a groundwater model can be selected, calibrated and implemented. The primary use of models in this mode of operation has been to predict long-term groundwater flow and groundwater quality due to implementation of engineered groundwater supply systems and/or remedial cleanup programs.

Advances in computer technology have dramatically revised the utilization of groundwater models and expanded their utility with respect to groundwater investigation programs. Groundwater flow models are now readily adaptable to personal computers. To use these models in a site investigation, only a very limited amount of information is needed initially, and assumed data can be used to supplement this initial information.

Given the limited data, the model is responding primarily to the general equations of groundwater flow and not to unique site conditions. This uncalibrated flow model, however, provides the technical skeleton to which additional groundwater monitoring information can be input and assessed. As additional site data are added to the model, it is refined and calibrated. During the data gathering process, the model is used not only to identify data gaps, but also to determine when sufficient data have been gathered to quantify site conditions.

The groundwater model is not limited to utilization as a predictive model based upon exhaustive site information. Rather, the groundwater model is now most properly and cost effectively used in the groundwater monitoring program to assess data gaps, quantify site conditions and evaluate engineered remedial programs.

INTRODUCTION

The purpose of this paper is to discuss and present a method of site investigation using groundwater computer models to guide the investigation as well as to indicate when sufficient data have been collected. The methods used to implement this approach are neither unique nor technically complex, but they do require utilization of an integrated geoscience and engineering staff. This technical integration, plus the general availability of groundwater models on microcomputers, makes this approach to site investigation technically feasible and advantageous.

The need for quantitative groundwater resource assessment tools is growing at an accelerating rate. Water resources investigations for domestic, agricultural and industrial uses are increasing, and the investigation work associated with definition of contaminated groundwater due to hazardous materials is expanding daily. These latter investigations are particularly difficult because they require quantitative analysis methods to define the contaminant migration conditions as well as the remedial solutions. The use of groundwater flow models to quantify the site investigation work and standardize the basis upon which remedial systems are comparatively evaluated makes use of the inherent attributes of these methods. A brief discussion of the current practices in groundwater modelling is presented below followed by a detailed discussion of how models can be used in site assessments.

EXISTING METHODS OF SITE INVESTIGATION

The predominant practice for projects involving groundwater quality and water resource investigations is illustrated in Figure 1. The objective of the field investigation work is to obtain sufficient information to describe site conditions, specifically the geologic conditions. After these data are gathered, they are assembled and assessed to determine their adequacy.

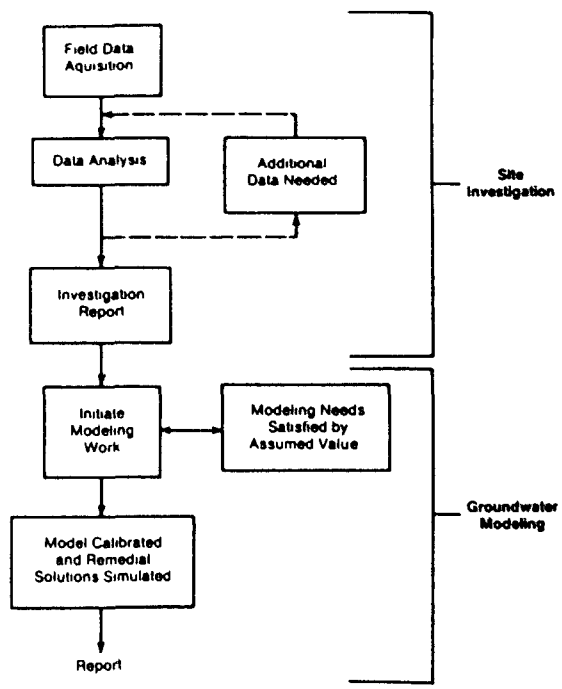

Figure 1
Site Investigation Followed by Groundwater Modeling

This data evaluation exercise might reveal the need for additional information to describe an anomalous or vague site condition, and a second phase of field investigation would commence. This interactive process would continue until the objective of understanding the geology, groundwater hydrology and water quality conditions is accomplished. A report describing the investigative procedures and the defined site conditions is finally prepared.

After the field investigation is complete, the engineer or engineering group receiving the final report develops a set of remedial action alternatives designed to mitigate any adverse chemical quality conditions identified during the field investigation. To conduct a comparative analysis of the identified remedial alternatives, a groundwater flow model is usually employed. The flow model is calibrated based upon the findings of the field report and run (exercised) to satisfy the identified needs of the engineer. If, during the conduct of the engineering analyses, the need for additional data is identified, it usually is assumed as part of the model input. The mathematical operations inherent to the flow model check these assumed inputs against measured site conditions. Thus, assumptions made at this stage of a site investigation are not totally unchecked, but they usually do not have the advantage of being field verified.

After the site model has been developed and calibrated, it is exercised to simulate the various remedial solutions being considered for the site. For example, a groundwater barrier wall, such as a soil bentonite slurry cut-off wall, could be simulated by the insertion of no-flow boundaries around the perimeter of the site. Guswa[1] noted that implementation of a remedial action plan can be very expensive, and it is desirable to have the preimplementation assurances that the proposed plan can be effective. While no type of modelling provides guarantees that any particular plan will be effective, they do provide a comparative basis against which all remedial alternatives can be evaluated.

THE MODEL AS INTEGRATOR

The use of the groundwater model is a good tool to evaluate various remedial solutions. This use of the model is obviously advantageous, but additional information can be obtained. That is, the groundwater model can be used not only to evaluate the facts gathered after conclusion of the field investigation, but also can be used to better define what information needs to be gathered and where it can be found.

Figure 2 illustrates how the groundwater flow model can be used during the site investigation phase of work and in the subsequent analysis of remedial alternatives. Comparison of this figure to Figure 1 shows that the steps leading to the final report have been reduced. This reduction primarily centers around integration of the groundwater modelling work into the analysis of data obtained during the field investigation exercise.

To initiate use of groundwater modelling during the field investigation phase of any project, a basic amount of site information must be known. General site geology, basic groundwater flow conditions and surface water conditions should be known to establish the initial flow parameters and boundary conditions for the model. Published literature is replete with geologic definition and groundwater and surface water factors for a large portion of the United States. If an assessment of existing information on a site area is conducted in a fairly exhaustive manner, the general information needed initially to establish the groundwater model usually can be accumulated.

One of the primary questions raised during conduct of a field investigation is how does one know when sufficient data are available to satisfy the objectives of the project? The groundwater flow model can provide significant assistance in answering this question. As indicated in Figure 3, in order to assemble or

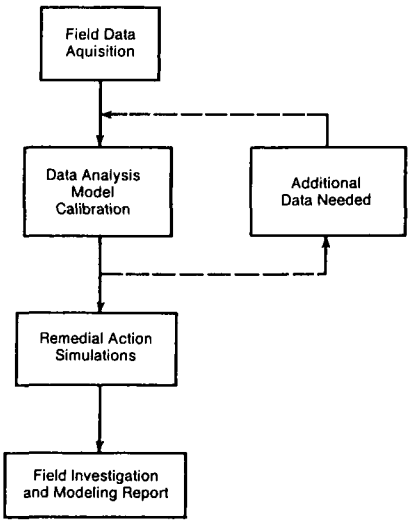

Figure 2
Integrated Site Investigation

establish the groundwater model, existing data as well as input from numerous technical disciplines must be obtained. Questions as to the area to be covered by the model, the geologic conditions to be considered and the overall engineering requirements associated with the model must all be discussed and incorporated. Thus, at this early stage of the project, the flow model has in effect served as a catalyst for integration of the technical disciplines that eventually will be needed to resolve the identified problem. This integration, properly carried to fruition, will result in the establishment of a set of objective criteria for the site investigation and the overall remedial action study. Specific data needed to satisfy these criteria would be identified for acquisition during the field investigation.

As field investigation work is conducted, new site information is developed and can be used with the established groundwater model. As these data are added, the aquifer characteristics are adjusted so that the model representations are consistent with identified field conditions. As more information is gathered in the site area, the adjustments that need to be made to the model will

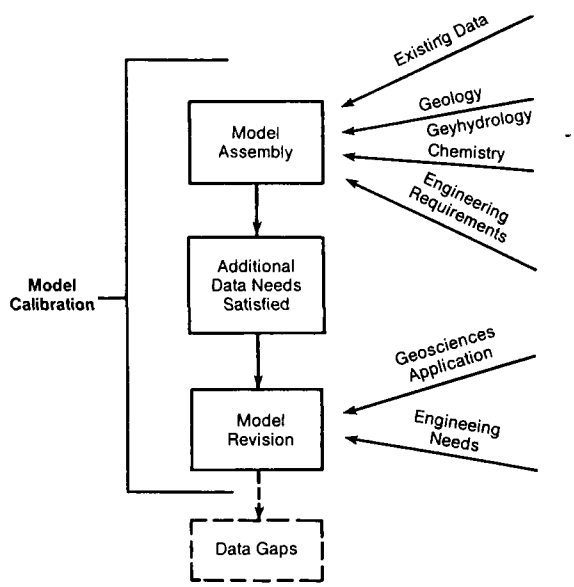

Figure 3
Groundwater Model Development

become relatively minimal. As this point is approached, acquisition of additional field information is not needed to refine the site model, and field investigation work is complete. Site conditions are now defined consistent with the set of objective criteria identified for the project. Assessment of remedial alternatives can commence.

The model assembly, identification of additional data needs and model revision work tasks identified in Figure 3 are in effect the data analysis and additional data input loop identified in Figure 2. The exercise of identification of additional data needs and acquisition and input of these data to the flow model constitute calibration of the flow model. An important distinction between this approach to use of groundwater modelling and the approach discussed in the previous subsection is that model calibration is integral to the field investigation exercise.

Finally, no (or at least very little) assumed data are needed to calibrate the groundwater model. Thus, the flow model that ultimately will be used to compare various remedial alternatives already will have undergone the rigors of development and calibration placed upon it not only by the simulation of known site conditions, but also by the technical requirements of the disciplines involved in overall problem resolution.

THE COMPUTER MODEL AND SITE INVESTIGATIONS

The principal concerns surrounding the use of computer modelling have been its availability to the project's principal investigator and the cost associated with development and operation of these models. Over the past few years, both of these concerns have been significantly diminished by the development of the desk top personal computer. Thus, the principal investigator or project manager has a significant library of groundwater models readily available to him that can be developed and exercised at a relatively inexpensive cost. In fact, the graphics capability as well as the data base management capabilities of these machines can reduce the overall project costs compared to hand manipulation and graphics development for a medium to large scale site investigation.

In the past, groundwater flow models have been misused by misrepresenting their capabilities and application. One of the common problems associated with groundwater modelling is the tendency to use the most sophisticated model available for problem resolution. This temptation is difficult for the technical community to resist, but can be managed if integration of technical skills is accomplished in the early stages of the project. This integration of the groundwater modelling expertise with the pragmatism of the engineer usually results in model development consistent with the identified objectives for the site study. This management of technical expertise must be coordinated by the project's principal investigator.

Another technique that can be used to help prevent over extension and misrepresentation of groundwater model usage is the phased implementation of a particular model's capability. For example, throughout this paper, only groundwater flow models have been discussed and solute transport models have not been strongly considered. This analysis does not say that solute transport models are not appropriate for the problems discussed herein; it does, however, say that in the early stages of model development and utilization in site investigations, the first step should be a characterization of groundwater flow hydrology. Once groundwater flow characteristics (especially velocity parameters) have been identified, solute transport models can be included. One must remember that the model only need to detailed enough to satisfy the stated objectives of the project.

The following brief example shows how various data elements can be obtained and input for site investigation modelling. The advantage of a phased field investigation program is highlighted in the example.

Existing Data Review and Model Development

During the review of existing information for a site area, data concerning the history of operation of the site, the geologic and geohydrologic conditions of the area, precipitation, surface water hydrology and so forth, are compiled. The completeness of this information depends upon the location of the site, the notoriety it has received, site management and numerous other factors. For the purposes of this paper, only that available data pertinent to development of the groundwater model will be discussed. The lack of consideration of any other data does not mean it is not needed for a site investigation nor does it mean it may not be pertinent to model development at some sites.

Figure 4 presents a map of the example site area and contains a significant amount of information. The example site is located in a river floodplain below an upland area. Thus, the aquifer of concern is more than likely alluvial in nature, probably containing a wide distribution of grain-size materials. In addition, channelization of sediments due to alluvial action is very possible. Finally, the upland area probably forms a recharge boundary for the alluvial aquifer, and the river probably forms a discharge boundary.

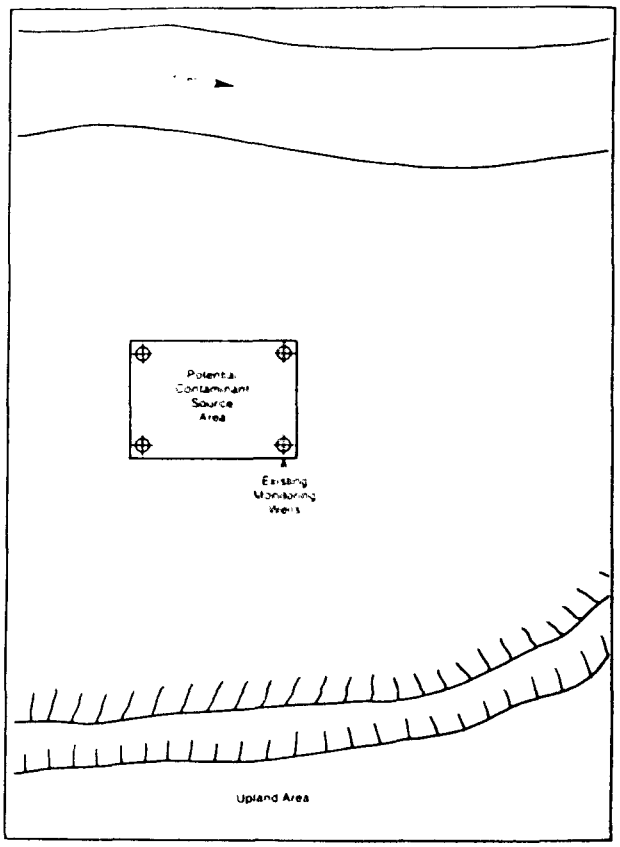

Figure 4
Example Site Area

There are four existing monitoring wells identified at the corners of the site. These wells could provide information on groundwater levels as well as the type of sediments contained in the saturated zone. Figure 5 presents preliminary geotechnical findings showing a gravel seam through the center of the site flanked by finer grained sediments. If no aquifer characteristic data is available, the existing monitoring wells could be used to conduct abbreviated aquifer tests, such as slug tests. These tests are

described by Cooper, Bredehoeft and Papadopulos[2] and Bouwer and Rice.[3] Thus, existing site information as well as readily obtainable information can provide the needed data.

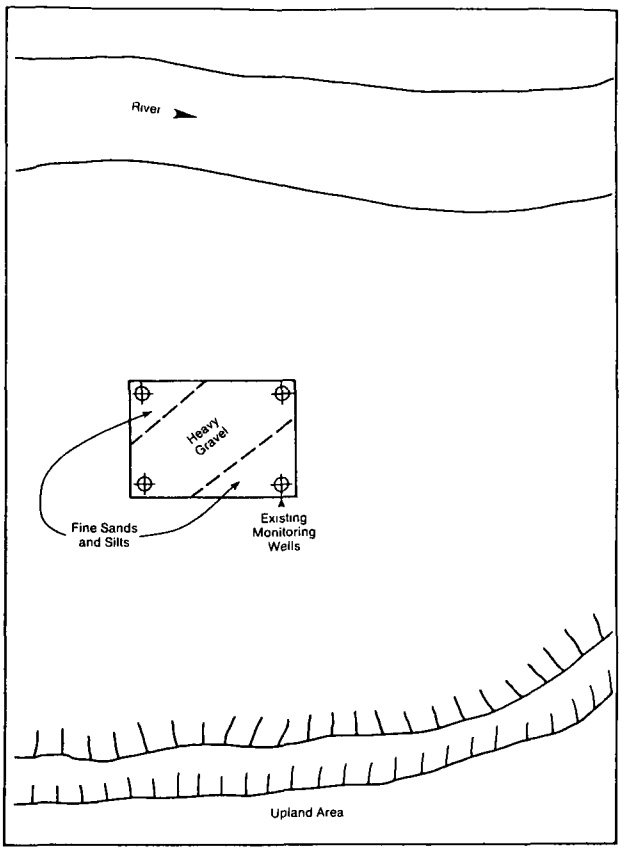

Figure 5
Preliminary Geotechnical Findings

In some site areas, no existing monitoring wells are available. In such cases, geologic and hydrogeologic reports concerning the aquifers of the area as well as the estimated permeabilities and transmissabilities would have to be utilized. In these cases, it might be advantageous to postpone initial model development until specific site information could be obtained from installation of groundwater monitoring wells. Generally speaking, sites being investigated today have a limited number of monitoring wells or soil borings available for use in the initial stages of the projects.

FIELD INVESTIGATION

Based upon the findings of the data review, it is often advantageous to conduct the field investigation work in a phased manner. That is, early acquisition of general site area information (such as aquifer characteristics determined by slug tests and geophysical data) would be advantageous to more detailed planning of the later stages of field investigation.

Figure 6 shows a probable set of conditions related to geophysical findings for the example site area. The geophysical methods employed might include determination of terrain conductivity by electromagnetic techniques. The results of this type of investigation usually are mapped so that anomolous conductivity patterns (inferred to be indicative of contaminant transport conditions) can be identified. In our example problem, it appears that the gravel seam through the site area is a preferred avenue of groundwater movement and contaminant transport. In a preferred groundwater movement area, it is likely that water levels in the gravel will be slightly lower than in the immediately adjacent less permeable zones.

Given the information obtained from the data review as well as the preliminary work conducted in the initial stages of the site investigation, a plan of overall investigation effort can be formulated. Figure 7 displays how additional data with respect to groundwater flow conditions and contaminant levels might be obtained by monitoring well installation. At the same time, the available data can be used to establish the initial conditions of the groundwater flow model. The groundwater elevations obtained from the existing monitoring wells coupled with the assumed groundwater levels associated with the gravel seam can be used to predict the findings of the investigative work. The actual data from each well would be put into the model as each well was installed and the model would be rerun to refine predictions for the remaining wells scheduled for installation. Based upon these findings, monitoring well locations would be modified to maximize data acquisition efforts. The use of the model to guide and refine the field investigation exercise can result in the elimination of monitoring wells and the early cessation of the field investigation exercise.

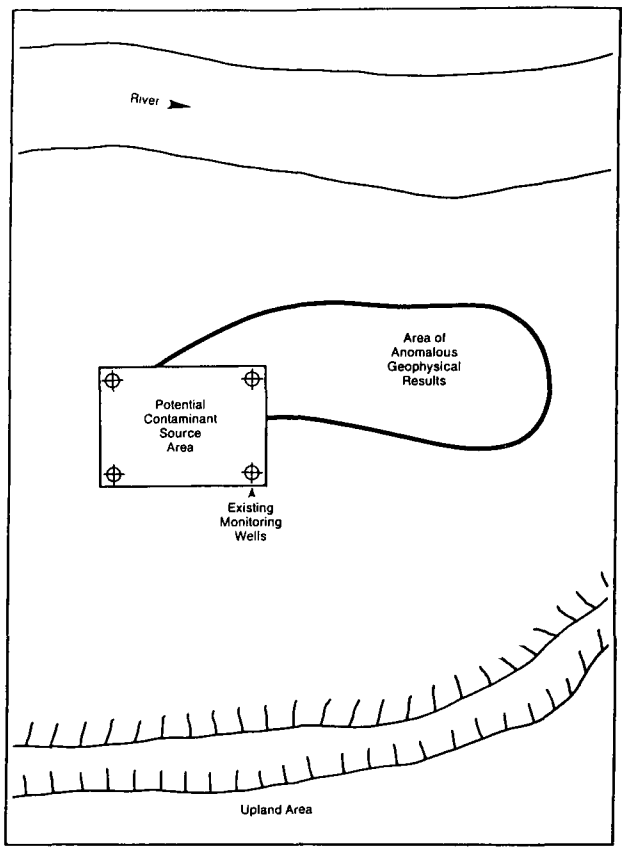

Figure 6
Geophysical Survey Findings

Simulation of Remedial Work

After the field investigation exercise has been completed and groundwater flow calibration has been accomplished, the impacts on groundwater movement due to various remedial scenarios can be simulated. In the case of the example problem, groundwater flow barrier walls intersecting the gravel zone, coupled with groundwater pumping wells, could be simulated. Groundwater pumping without barrier walls also could be modelled and the results could be compared to estimate the savings in treatment costs that could be realized due to the difference in groundwater pumpage. These simulations, as well as numerous other simulations, can be made on a consistent comparative basis through the

developed groundwater flow model. This consistency of comparison is essential to the quantitative evaluation of alternative remedial measures.

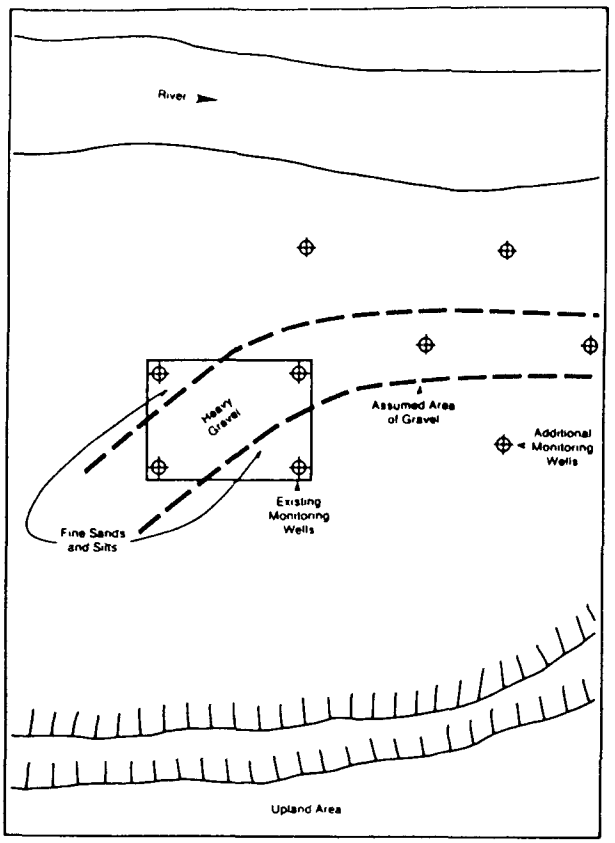

Figure 7
Additional Data Needs Definition

THE OVERALL PICTURE

Not all projects may be appropriate for application of groundwater flow models as described in this presentation. Certain site problems may be so small that a conceptual model may be sufficient and a computer model may not be warranted. The groundwater model is simply a tool that can be used to help organize and streamline the site investigation work and the process of remedial system selection.

Whenever a model is being developed during a site investigation and is intended to be used to compare and predict remedial action impacts, care must be taken to properly apply historical factors specific to the site area. For example, long-term historical precipitation patterns should be considered when designing groundwater pumpage, treatment and recharge networks. Anomolously high rainfall conditions could cause an increase in the volume of water requiring treatment or in other ways impair operation of the remedial system. Anomolously low rainfall could result in a general lowering of the groundwater table and cause flow conditions to be significantly different than those considered by the predictive model. In either of these cases, if the predictive model did not consider the long-term fluctuations in precipitation and the resultant impact on infiltration quantities, the predictive analyses compiled by computer modelling might not be valid. Mercer and Faust[4] recommend that groundwater flow models be calibrated with known historical site information and that the period of prediction not exceed twice the period of historical data used in the calibration.

When evaluating the overall factors of a site investigation and development of remedial alternatives, a general review of the work should be made to insure that it is consistent with sound technical "intuition." One of the worst mistakes that can be made in groundwater modelling is unchecked acceptance of the model results. Data cross-checking and integration are advisable with or without a groundwater computer model, but must definitely be utilized when employing models to protect against blind acceptance of computer output data.

A good conceptual understanding of the site conditions and general influences in the site area is a prerequisite to initiation of the site investigation work and utilization of groundwater modelling. Without such understanding and cross-checking of technical information, little or no integration of technical disciplines will be accomplished, the overall program effectiveness will be significantly reduced and the investigation may, in fact, become a waste of time and money.

CONCLUSIONS

Until now, groundwater models have not been extensively used as tools in the conduct of site investigations. Generally, models have been applied after completion of field investigations to predict the impact of various remedial alternatives. The proliferation of sophisticated computer equipment and the adaptation of groundwater model codes to this equipment have literally brought the groundwater flow modelling capability to the desk top of each project engineer and scientist. Thus, groundwater modelling is now a readily available tool that can be used to identify data collection requirements, evaluate these data, conduct data sensitivity analyses with respect to groundwater flow impacts and assess the long-term impacts of various remedial actions on the groundwater flow conditions.

When employing groundwater flow models, a good conceptual understanding of the aquifer and other pertinent subsurface conditions must be available as the underlying basis for model development. The extent to which these conceptual understandings backed by actual observed field conditions can be simulated by the model is the quantitative measure of the ability of the model not only to adequately represent existing field conditions, but also to predict future conditions. The ultimate responsibility to ensure both proper integration of technical talent in model development and calibration, plus proper technical usage of the model in simulating remedial activities, rests with the principal investigator or overall project manager. Proper integration of technical talent in model development and usage is key to successful site investigation and remedial action alternative analysis.

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Alternative Treatment Techniques for Removal of Trace Concentrations of Volatile Organics in Groundwater

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ABSTRACT

In response to the detection of volatile organics in wells serving the process and drinking water needs of an industrial manufacturing facility, a groundwater quality investigation was initiated for an industrial manufacturer in Maryland. The objectives of the investigation were to define the extent of groundwater contamination, to identify probable sources and to develop remedial measures to rehabilitate the affected aquifer while ensuring a potable water supply.

Field studies confirmed the sources of volatile organics to be burial trenches located 350 ft southeast of one of the affected wells. A hydraulic-control recovery system was recommended, using the affected well as a pumping center.

Several treatment techniques were identified which could treat the low-levels of tetrachloroethylene and trichloroethylene. The alternatives included aerated lagoon volatilization, spray irrigation/land application and packed-tower air stripping. Cost comparisons and treatment efficiencies for each process were evaluated. Air stripping was selected as the preferred alternative based on efficiency, cost and reuse of the treated water to satisfy the facility's water needs.

INTRODUCTION

An industrial manufacturer in Maryland depended on wells on the plant property for process cooling and drinking water. When low levels of tetrachloroethylene (PCE) and trichloroethylene (TCE) were detected in several of the supply wells, the facility installed individual granular activated carbon (GAC) cartridges at various points in the plant. In response to increasing levels of volatile organics found in the water supply, a groundwater quality investigation was initiated to determine the probable sources of the contamination and the degree of aquifer degradation, and to recommend remedial measures to rehabilitate the aquifer while ensuring a continuous potable water supply for the plant.

GEOLOGY/HYDROGEOLOGY

The plant site is located within the eastern division of the Piedmont physiographic province. The region is characterized by moderate relief, gentle slopes and rounded hills. Locally, the bedrock geology consists of folded biotite and chloritic-albite schist of the Wissahickon formation. The Wissahickon is overlain by saprolitic material maintaining parental bedding-plane structures. The saprolite consists of silty clay varying in thickness from

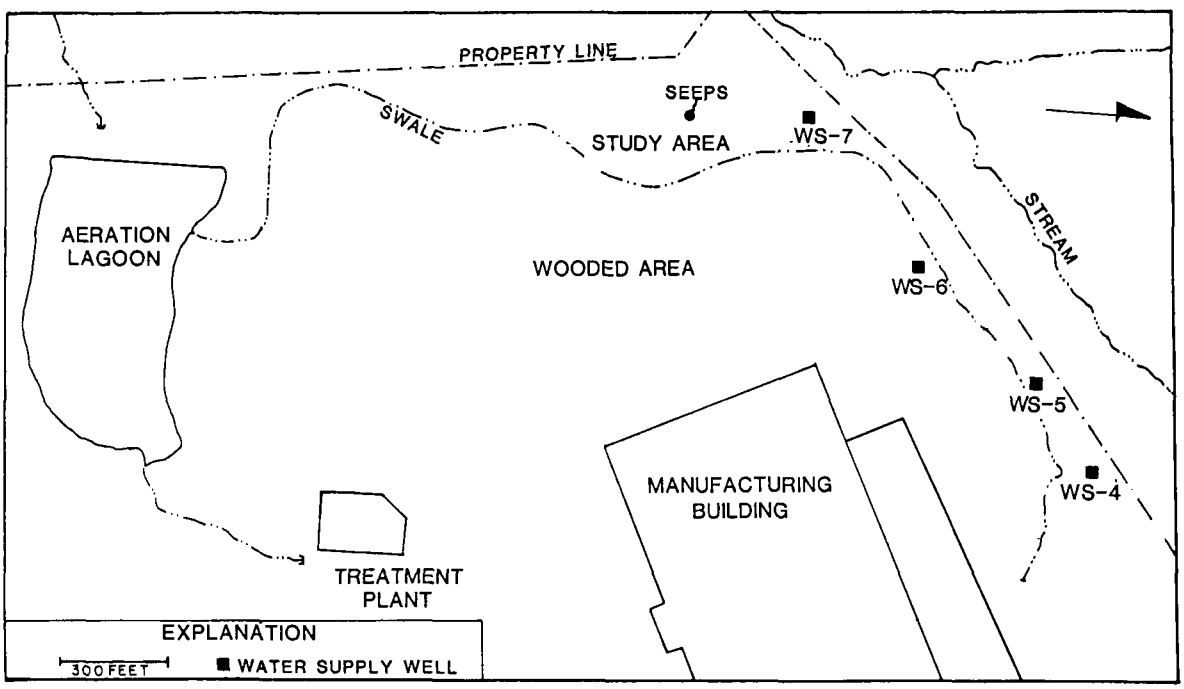

Figure 1
Site Plan of the Groundwater Investigation

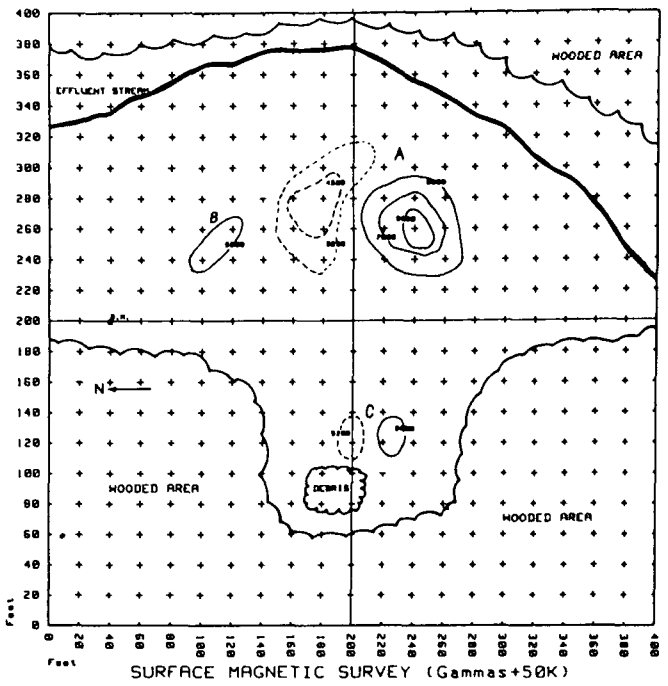

Figure 2
Geophysical Survey Results Using Magnetics Instrumentation

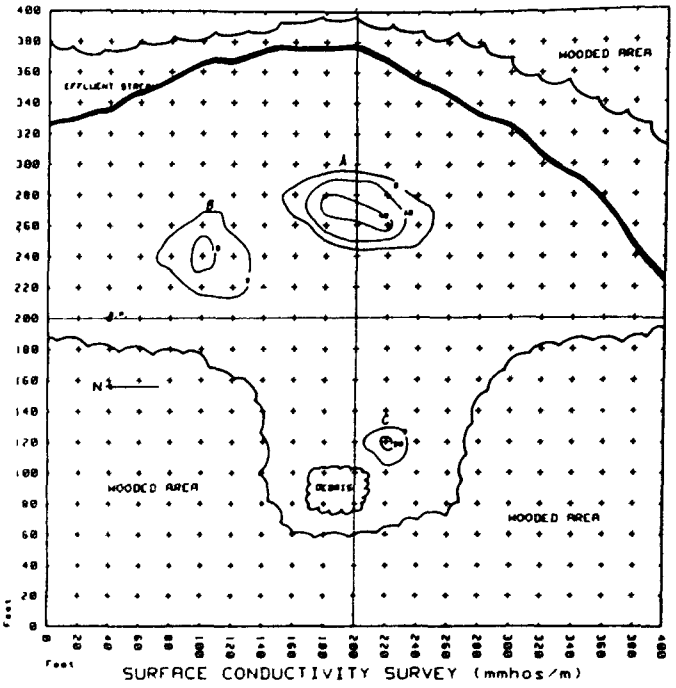

Figure 3
Geophysical Survey Results Using Conductivity Instrumentation

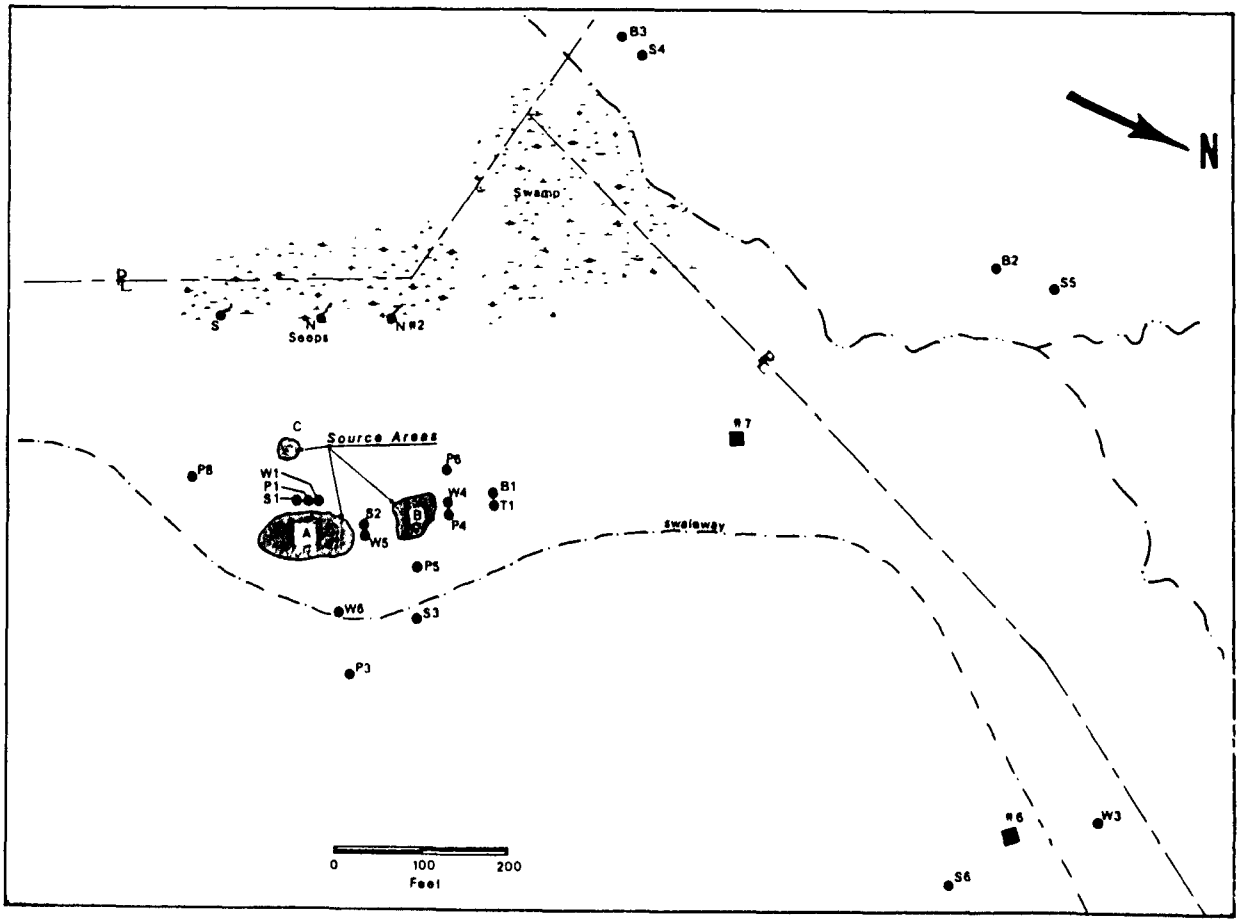

Figure 4
Well Locations and Source Areas of Contamination

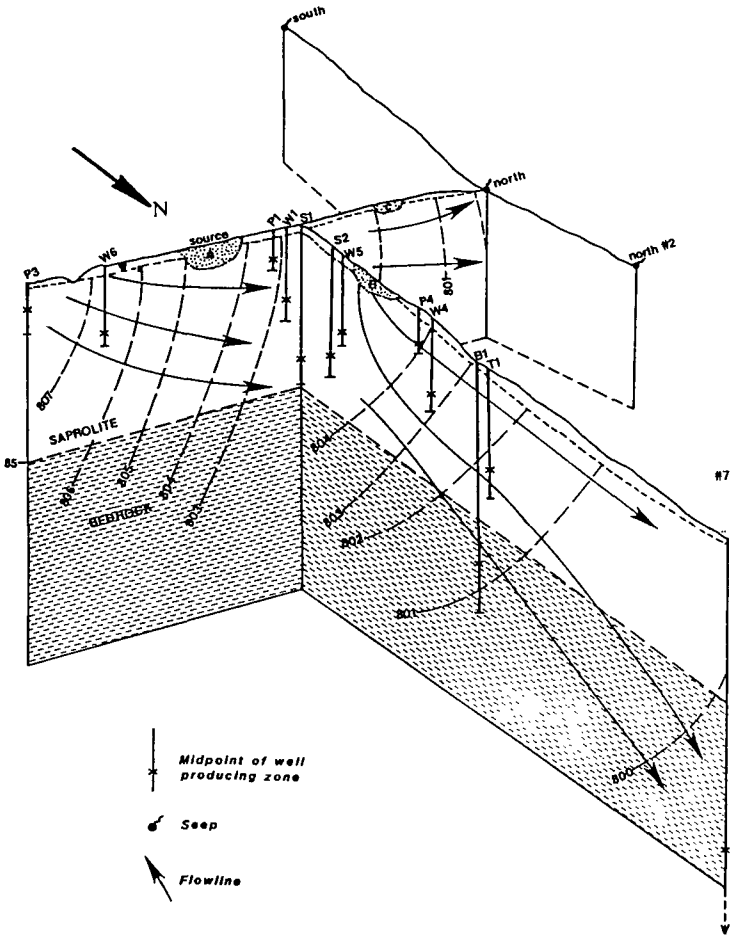

Figure 5
Geologic Cross-Section and Groundwater Flow Patterns

25 to 125 ft. Groundwater exists in both bedrock and the overlying unconsolidated deposits predominantly in fractures of bedding-plane microfractures.[1] The secondary permeability results in a wide areal variation in well yields dependent on proximity of the well to fracture zones. The facility and surrounding local populace depend on the Wissahickon formation for water supply. Wells in the area typically penetrate the bedrock from 50 to 450 ft, with well yields varying from 5 to 250 gal/min.

FACILITY DESCRIPTION

The manufacturing facility is located on top of a hill with a small stream located along the northwestern and western property boundaries. This stream locally represents the groundwater divide. On-site water-supply wells for the plant are located along the northwest property line. At the southwest corner of the facility, a lagoon collects and treats stormwater runoff from the boundary swaleway and treated wastewater effluent from the plant (Fig. 1). Water-supply well 7 (WS-7), located at the northwest property boundary, was found to contain the highest concentrations of volatile organic compounds (VOCs) with 1300 μg/l tetrachloroethylene.

SOURCE INVESTIGATION

Facility personnel tentatively identified possible VOC source areas as waste pits previously excavated in a clearing 350 ft southeast of Well WS-7. Wastes, which were suspected of being present in these pits, included process waste drums, construction debris and defective products. A surface geophysical investigation was conducted in this area using a proton precession magnetometer and terrain electromagnetic conductance instrumentation to locate buried metallic objects. Both surveys were run on common transects with 20-ft grid spacings. The proton precession method delineated three anomalous areas of low and high signals. Terrain conductance delineated three areas of anomalous signals located between the proton precession highs and lows (Figs. 2 and 3).

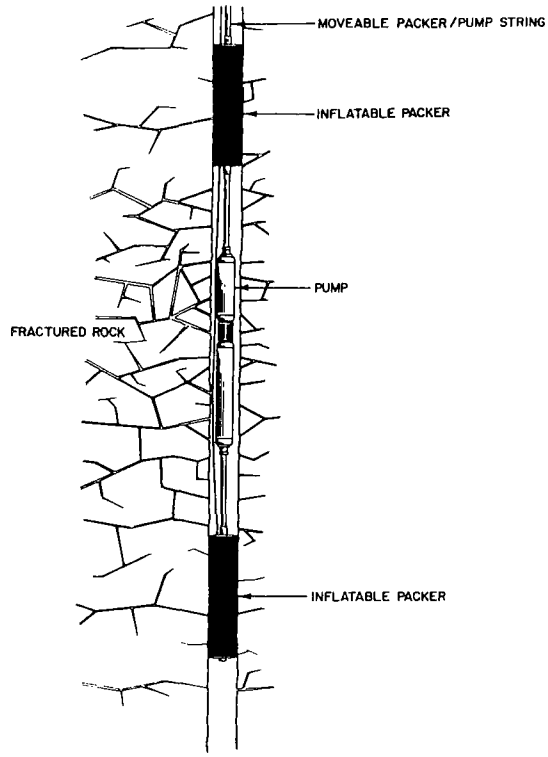

Figure 6
Straddle Packer Apparatus Used for Stressing Wells

WATER QUALITY INVESTIGATION

Subsequent to the surface geophysical work, numerous nested well clusters were installed around the major anomalies to: (1) define horizontal and vertical flow patterns and (2) determine local groundwater quality. Seventeen monitor wells were installed at discrete water-bearing intervals in the saprolite material. Wells were designated by series P, W or S, representing the first water-bearing zone (20 ft), intermediate water table (40 ft) and bedrock/overburden interface (60 ft), respectively. The well locations are shown in Figure 4.

Based on water-level measurements from the installed monitor wells, groundwater flow is directed to the west toward the small stream. In addition, three significant seeps were discovered downgradient of the area under investigation. These seeps are believed to represent surface discharge of groundwater from the first water-bearing zone. Vertically, a strong downward component of groundwater flow also exists. Groundwater samples from the wells and seeps were collected and analyzed for suspected VOCs. Based on the sampling, Anomaly B was identified as the major contributor of VOCs to the groundwater regime (Fig. 5). Wells located between Anomaly B and Well WS-7 exhibited tetrachloroethylene concentrations equal to levels discovered in the water-supply well.

AQUIFER TESTS

In an effort to better define the groundwater regime in the vicinity of Well WS-7, several aquifer test programs were initiated. A downhole pneumatic straddle packer/pump assembly was used in Well WS-7 to stress discrete intervals of the openhole well (Fig. 6). Short-term pumping was performed at various inter-

Table 1
Lagoon Disposal Cost Estimates

	Equipment		Estimated Cost Lined	Estimated Cost Unlined Swale	Basis for Estimate	Year Incurred
Direct Capital Costs (Purchase Price and Installation)	Piping		$ 4,000	$ 4,000	Means CCD	
	Swale Lining		$ 38,000	--	Means CCD	
	Recovery System Pumps		$ 3,000	$ 3,000	Means CCD	
	Three Recovery Wells		$ 15,000	$ 15,000	G&M	1
	French Drain		$ 19,000	$ 19,000	Means CCD	
	Subtotals	Costs Unique to Lagoon Treatment (UC)	$ 42,000	$ 4,000		
		Total Direct Costs (TCC)	$ 79,000	$ 41,000		
Indirect Capital Costs	Subcontracting Fees		$ 7,900	$ 4,100	10% of TCC	
	Engineering and Design		$ 6,320	$ 3,300	8% of TCC	
	Contingency Allowance		$ 15,800	$ 3,280	20% of TCC	1
	Start-Up/Shake Down		$ 3,950	$ 2,050	5% of TCC	
	Total Indirect Costs		$ 33,970	$ 16,730		
TOTAL CAPITAL COSTS			$112,970	$ 57,730		
Operating Costs	Operating Labor		$ 11,000		2 man-hrs/day	1-30
	Electricity		$ 3,000		6.25 h.p. @ 8c/kilowatt	1-30
	Monitoring				Not Included	1-30
	Administration		$ 1,000			1-30
	Maintenance Contingency Reserve		$ 1,000			1-30
TOTAL OPERATING COSTS			$ 16,000			
Costs for Presently Operating Faucet GAC System			$ 13,000			
Total Operating Costs Including Water Supply			$ 29,000			

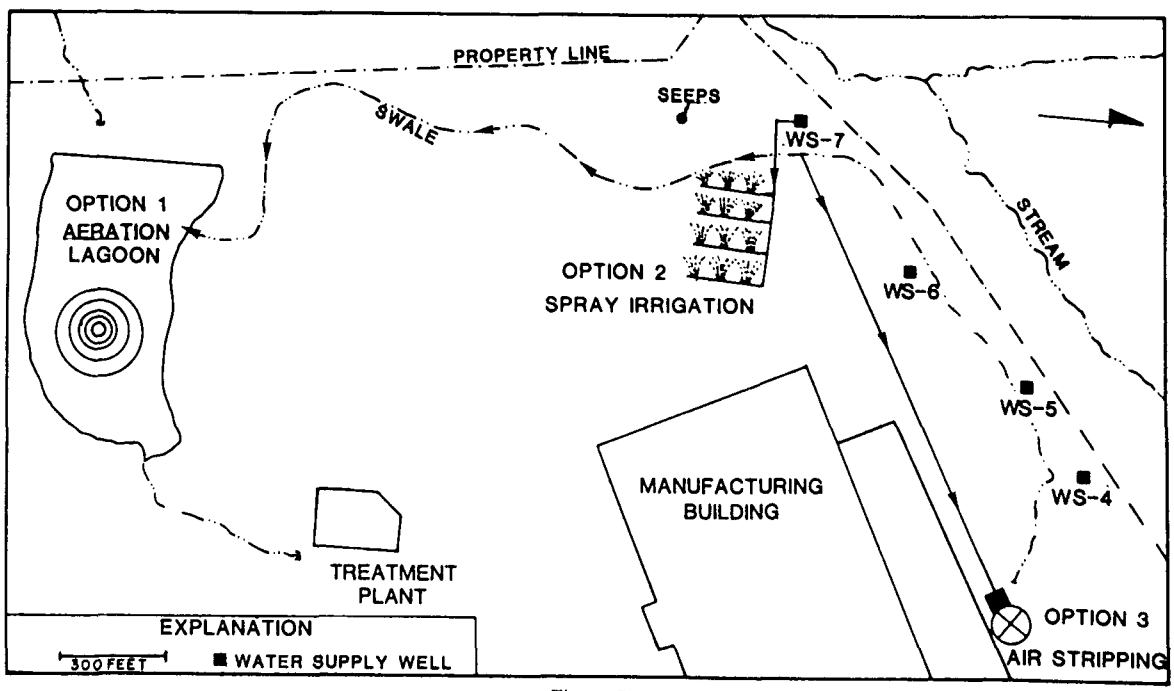

Figure 7
Treatment Options: Equipment Locations

Table 2
Slow Infiltration (Spray Irrigation) Cost Estimates

	Equipment		Estimated Cost	Basis for Estimate	Year Incurred
Direct Capital Costs (Purchase Price and Installation)	Piping (PVC)		$ 22,000	Means CCD	
	Sprinklers (18)		$ 3,000	Sprinkler Irri. Assoc.	
	Recovery System Pumps		$ 3,000	Means CCD	
	Three Recovery Wells		$ 15,000	G&M	1
	French Drain		$ 19,000	Means CCD	
	Subtotals	Costs Unique to Sprinkler System (UC)	$ 25,000		
		Total Equipment Costs (TCC)	$ 62,000		
Indirect Capital Costs	Subcontracting Fees		$ 6,200	10% of TCC	
	Engineering and Design		$ 4,900	8% of TCC	
	Contingency Allowance		$ 12,400	20% of TCC	1
	Start-Up/Shake Down		$ 3,100	5% of TCC	
	Total Indirect Costs		$ 26,660		
TOTAL CAPITAL COSTS			$ 88,660		
Operating Costs	Operating Labor		$ 10,000	Land Treatment Systems (3 man-hrs/day	1-30
	Electricity		$ 3,000	6.25 h.p. @ 8c/kilowatt	1-30
	Monitoring			Not Included	1-30
	Administration		$ 1,000		1-30
	Maintenance Contingency Reserve		$ 1,000		1-30

vals for groundwater yield, and samples were collected for VOC analysis. Results of the study include: (1) degraded groundwater is limited to specific depth intervals in the bedrock; (2) groundwater is restricted to the fractured intervals; and (3) fractures are limited to the upper 60 ft of the Wissahickon bedrock.

In addition, a 120 hr pump test on Well WS-7 was performed while continuously monitoring water levels in surrounding installed wells. Both the pumping and recovery curves for Well WS-7 contained a sharp breakpoint, which may represent changes in formation transmissivity due to aquifer inhomogenieties at some distance laterally away from the well or leakage/delayed drainage from the overlying saprolite. No response to pumping was seen in the surrounding monitor wells. Based on relative concentrations of VOCs, we felt that longer pumping tests could influence outlying wells in the direction of the identified source areas.

GROUNDWATER REMEDIATION STRATEGY

Based on the work performed, plausible corrective action strategies were developed and evaluated for technical feasibility, environmental protection, cost effectiveness and related specific needs of the facility. To halt the further introduction of VOCs to the groundwater regime, the identified anomalies are to be evaluated, excavated and redisposed in an off-site chemical waste landfill.

The contaminants already introduced into the groundwater regime can be recovered by: (1) installing a shallow gravity drain near the seeps to control overland discharge; (2) installing several overburden pumping wells north of Anomaly B; and (3) continuous pumping of Well WS-7. By stressing and treating individual water-bearing zones within both the overburden and bedrock, substantial rehabilitation will occur over a shortened time frame.

EVALUATION OF TREATMENT ALTERNATIVES

In order to evaluate the most cost-effective solution for cleanup of the contaminated groundwater, three alternatives were evaluated in detail:

- Pumping and treatment in the plant's existing aerated lagoon
- Pumping and treatment using spray irrigation
- Pumping and treatment with an air-stripping tower

The locations where each of these treatment systems would be utilized are shown in Figure 7. A discussion of each process and associated costs follows.

Lagoon Disposal

This option considered using the existing aerated lagoon for contaminant load equalization and stripping of the volatile contaminants from the groundwater. Under this option, the groundwater would be discharged to the lagoon through the existing swaleway. Since the swaleway would be used to convey contaminated groundwater over a relatively uncontaminated portion of the site and seepage effects were uncertain, this option was

Table 3
Stripping Tower Cost Estimates

	Equipment		Estimated Cost	Basis for Estimate	Year Incurred
	Stripping Tower (with blower)		$ 25,000	G&M, Tampa	
	Electrical Work Controls		$ 4,000	G&M, Tampa	
	Piping		$ 10,000	Means CCD	
	Recovery System Pumps		$ 3,000	Means CCD	
	Three Recovery Wells		$ 15,000	G&M	1
	French Drain		$ 19,000	Means CCD	
	Subtotals	Costs Unique to Stripping (UC)	$ 39,000		
		Total Capital Costs (TCC)	$ 76,000		
	Subcontracting Fees		$ 7,600	10% of TCC	
	Engineering and Design		$ 6,100	8% of TCC	
	Contingency Allowance		$ 15,200	20% of TCC	1
	Start-Up/Shake Down		$ 3,300	5% of TCC	
	Total Indirect Costs		$ 32,700		
TOTAL CAPITAL COSTS			$108,200		
	Operating Labor		$ 11,000	2 man-hrs/day	1-30
	Electricity for Pumps		$ 3,000	6.25 h.p. @ 8c/kilowatt	1-30
	Electricity for Blower		$ 2,000	3 h.p. @ 8c/kilowatt	1-30
	Monitoring			Not Included	1-30
	Administration		$ 1,000		1-30
	Maintenance Contingency Reserve		$ 1,000		1-30
TOTAL OPERATING COSTS			$ 18,000		

evaluated with and without a liner for the swaleway. Mass balance calculations were made, treating the lagoon as a continuous reactor with first-order kinetics for volatilization of the PCE and TCE. Evaluation of flow conditions in the lagoon at both maximum and average flow rates showed that there would be sufficient retention time for volatilization of PCE to concentrations below 10 $\mu g/l$ throughout the year.

Total capital costs were estimated to be $41,000 for the unlined swaleway option and $79,000 for the lined swaleway. Operational costs would be about $16,000 yearly. Cost estimates for both options are presented in Table 1.

Spray Irrigation

Treatment of the volatile organics in the groundwater also was evaluated using a spray irrigation method. With this option, groundwater would be pumped through a network of sprayers located throughout part of the wooded land located above the swaleway. It had been estimated that approximately two acres of land would be required to allow infiltration of the 100 gal/min of water. Approximately 60% of the PCE and TCE would volatilize during spraying. Water containing residual PCE and TCE would enter the swaleway and flow to the lagoon; however, we determined that some could infiltrate to deeper sediments.

Since spray irrigation for this site represented a combination of slow rate and overland flow methods (for water to the swale), the method was evaluated using both design procedures. Both design procedures confirmed that sufficient land was available at the site for this treatment option. Volatilization rates of the contaminants were evaluated using a mass transfer approach as in the lagoon option; volatilization rates compared favorably to values in the literature for similar studies by others.[2]

Estimated capital costs for the spray irrigation/recovery system were $108,200; yearly operational costs would be approximately $15,000 (Table 2). One problem with this option was that the spray irrigation system would not be operational during the months of January and February due to cold weather conditions. An additional cost consideration for spray irrigation would be the need for a pilot study to determine actual PCE removal rates and the ability of the soils to accept the sprayed fluids.

Air Stripping and Reuse of Groundwater

The last option considered was pumping and treating the groundwater using a packed column tower air stripper. Using mass transfer calculations, we calculated a 99% removal of the volatile organics (PCE and TCE). This option would involve pumping the water to be treated to the top of the aeration tower and allowing it to flow downward against a countercurrent flow of blown air. The system would be designed so that the treated water could achieve volatile organic concentrations as low as 1 $\mu g/l$ which, in turn, could be used as the water supply for the

Table 4
Summary of Alternatives, Costs and Evaluation

Option	Total Capital Costs	Annual Operating Costs	Comments
1. Lagoon Disposal w/Liner wo/Liner	$112,970 57,730	$ 16,000	If liner not necessary, could be desirable on capital costs basis
2. Spray Irrigation	$ 88,600	$ 15,000	Cold weather operation problems makes this option less attractive
3. Air Stripping/Reuse	$108,200	$ 18,000 ($ 5,060)	Option would allow for $13,000/yr. savings by eliminating in-plant GAC system.

plant. Locating the tower adjacent to the plant buildings would make it convenient to use excess steam, if available, to ensure operation of the treatment system throughout the winter.

Total capital costs for the completed stripping-tower/recovery system were estimated to be about $108,200; yearly operational costs would be $18,000. The cost estimiates are presented in Table 3. These costs assumed that the volatile organic air emissions would be permissible and that no carbon recovery system would be required.

CONCLUSIONS

The three treatment options were evaluated for effectiveness and cost (Table 4). Assuming that the only contaminants of concern are trichlorethylene and tetrachloroethylene, both the stripping tower and the lagoon systems can effectively reduce VOC concentrations in the groundwater to acceptable levels; the spray irrigation option would remove approximately 60% of the volatiles. The capital costs of the lagoon system would either be as expensive as the stripping tower or 50% less expensive, depending upon whether or not lining the swaleway would be required. However, considering the operating cost of the in-plant activated-carbon filters currently used for drinking water (which would still be necessary if the lagoon system or the spray irrigation system were used), the $18,000 per year operating cost of the stripping tower would be offset by a $13,000 savings by eliminating the existing GAC system currently installed. This option would also allow reuse of the treated groundwater in the plant, since the contaminants could be reduced to a "safe" level.

The air stripping option was recommended to the client and will be constructed for treatment and reuse of the contaminated groundwater. The lagoon treatment system, although competitive from a capital cost perspective, was eliminated from further consideration because it did not eliminate the high costs of the presently installed in-plant activated carbon system nor did it provide the water-supply advantages that resulted from the packed tower air stripping treatment system.

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Cost-Effective Soil Sampling Strategies to Determine Amount of Soils Requiring Remediation

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INTRODUCTION

Designing a sampling strategy to determine the extent of contamination in uncontrolled hazardous waste sites is not as simple as putting out some transects or an evenly spaced grid. Similarly, contouring the data should not be considered a simple exercise in running software. The spatial distribution of the data plus the statistical distribution will determine the type of sampling scheme and the type of contouring (interpolation scheme) that will represent field conditions with greatest certainty.

Sampling schemes and contouring programs are most easily designed and applied when the spatial distribution of contaminants is continuous across the field and when the statistical distribution tends toward normality or lognormality. If these two conditions are met, the certainty about the boundaries separating clean from contaminated soils will be highest. This high level of certainty also can be achieved by using a minimal sampling strategy.

Such ideal conditions of spatial and statistical distributions are rarely met on hazardous waste sites. Hazardous waste sites typically are very heterogenous. The statistical distributions most often are dominated by outliers or exist as multiple populations, and the spatial distributions usually are discontinuous across the landscape. Such non-ideal conditions reduce the efficacy of simple sampling schemes or simple contouring programs. Non-ideal conditions also increase the chances of non-optimal remediation costs; costs that are much higher than necessary considering the "true" extent of contamination.

A sampling strategy designed to overcome the non-ideal conditions will be expensive to accomplish, but the extra expense of sampling can be compensated by reducing the amount of material removed during remediation. An example of sampling scheme/remediation optimization is described in detail later in this paper.

Designing the appropriate soil sampling strategy and choosing the methods of interpolation depends on a variety of factors involving the spatial and statistical distributions of the data set as well as the expected remedial measures. These factors include: (1) the method of disposal, spatial scale of disposal areas, site history and previous sampling results; (2) chemical and physical characteristics of the contaminants and site including mobility of contaminants, soil organic carbon, water table and groundwater flow direction; (3) present spatial extent of the contamination taking into account the homogenizing effects of the environment; (4) appropriate sampling, analysis, methods and their costs considering site conditions, depth of contaminant penetration into the subsurface and anticipated compounds; and (5) most likely remedial alternatives and their costs.

Extrinsic vs Intrinsic Variability

The first three factors above can be broken into two major groups relative to the variability contributed by each factor. Extrinsic variability can be thought of as the variability applied to the system by non-natural forces (humans).

Methods of disposal, spatial scale and distribution of the disposal areas are all factors directly imposed onto the system by humans. There is no way to predict the locations or size of disposal areas from viewing the natural system. A series of aerial photos may indicate the presence of roads, process buildings, burning grounds or landfills, the location of which can be used in designing the appropriate sampling scheme. Human actions set up the heterogeneity for natural factors to homogenize.

On the other hand, intrinsic variability can be thought of as the variability applied to the system by the natural environment. Intrinsic factors such as temperature, precipitation and physicochemical characteristics of the media act in conjunction with the characteristics of the contaminant to homogenize the extrinsic variability.

When extrinsic factors are more evident than intrinsic factors, the spatial and statistical distributions tend to be non-ideal (i.e., very heterogenous). As the effects of intrinsic factors become more apparent, the distributions tend to be closer to ideal. This certainly is not always the case as evidenced by the extreme variability of contaminant distribution in naturally occurring fractured bedrock.

For an example of the intrinsic/extrinsic effects of a hazardous waste site, consider a drum storage area with some leaky drums interspersed through the area. At time zero, numerous small areas of heavily contaminated soil would exist in an area of predominantly clean soils. A gridded sampling scheme would probably miss most of the contamination, but the statistical distribution would be dominated by a few extreme outliers. The extrinsic factors dominate in this situation.

If the same site is studied 10-20 years later, the contaminants will have begun migrating vertically and horizontally through the soil. The homogenizing effects of the intrinsic factors are evident. The same gridded sampling scheme will identify more of the contaminated areas, especially at depth. The statistical distribution will not be dominated by the extreme outliers as before. The statistical distribution will tend toward lognormality (more ideal), exhibiting some outliers but not as extreme as at time zero. The spatial distribution will be more continuous than at time zero.

Factors 4 and 5 consider the economics of the total remedial effort including sampling and analysis costs as well as cleanup costs. The importance of designing an optimum sampling strategy is

minimized if the costs of the expected remedial alternatives are minimal. If one of these feasible remedial alternatives is to excavate, the number of samples to be taken can be optimized by considering the estimated volumes of soils needed to be removed considering sampling density.

OPTIMIZATION OF SAMPLING DENSITY

When the pattern of contamination is relatively simple (a contiguous contaminated area with little or no contamination outside that area) an optimal sampling density can be defined to minimize total remediation costs, including both the investigation and cleanup phases. This concept is illustrated best by considering some extreme examples. Assume that 100 m^2 of soil are contaminated. Next assume that samples were taken to define this contamination: one sample at its center and then samples on a uniform rectangular grid with a sampling interval of 100 m^2 for a total of 9 samples as in Figure 1. As has been discussed, soil contamination is extremely heterogeneous, and interpolation between data points is risky at best. It is prudent, based on the data available from this hypothetical site, to remediate all soils within the region defined by the clean samples, approximately 40,000 m^2.

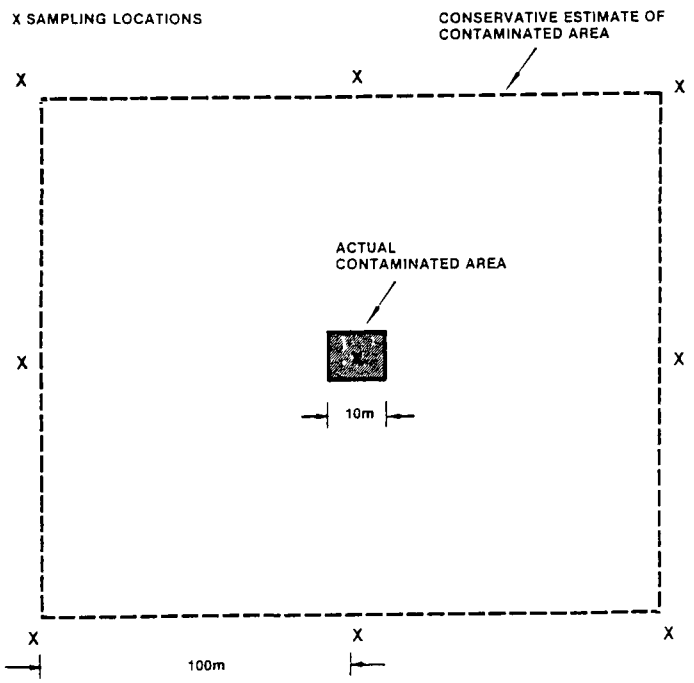

Figure 1
Example of Inappropriate Sampling Density

On the other hand, one might have started by taking a sample every meter along a similar rectangular grid. Since phased sampling frequently is not feasible, this approach would have required 40,000 samples to define the contamination distribution over the same area. Even if we had been clairvoyant, or had some independent information on the soil contaminant distribution, sampling at a density of 1 m would have required 121 samples to define a contaminated area of only 10 m^2.

Obviously these are ridiculous extremes, but they clarify an important problem. How does one define an appropriate sampling density? If we sample intensively, sampling and analysis costs could exceed the cleanup costs. If the sampling grid is too coarse, we may not accurately define the contaminant distribution. Based on a reasonable requirement to ensure the public health and safety, remediation of large quantities of clean soils may be indicated, wasting valuable resources.

This problem is resolved as a simple linear optimization problem where the objective is to minimize total remediation costs, including the wasteful remediation of clean soils and the cost of sampling and analysis. The cost of remediating contaminated soils must occur in any case and can be ignored in the analysis.

The cost of wasteful remediation is calculated as follows. It can be assumed that two rings of sample locations will define the contaminated perimeter. The perimeter of most simple shapes is 3 to 4 times the width (a circle is 3.14 times; a square is 4 times). It can be assumed approximately that the perimeter, P, is given by $P = 3.6\ W$, where W is a length scale, such as the width. The area where wasteful remediation can occur is the distance between sampling points, L, times the perimeter of the contaminated area.

The sample density, D, is the number of samples per unit area. Thus, $L = D^{-1/2}$. Combining these definitions, the area in which wasteful remediation is likely to occur is $A_R = 3.6\ WD^{-1/2}$. The cost of wasted remediation is given by a unit cost, R$, the remedial cost per unit area times the area of wasteful remediation.

The sampling and analysis costs will be simply the S&A costs per sample, SA$, times the number of samples, N. The number of samples is given approximately by $N = DW^2$ (sample density times area). The total costs thus are given by:

$$\$ = SA\$\,(W^2)\,D + R\$\,(3.6\,W)D^{-1/2} \quad (1)$$

The solution of the optimization problem is derived by differentiating with respect to sample density and setting the derivative to zero. This will define the sample density at which total costs are minimized. The result is given by:

$$D = \left[\frac{1.8\ R\$}{(W)\ SA\$}\right]^{2/3} \quad (2)$$

Consider the following example:

SA$ = $1,000 per sample
R$ = $900/$m^2$
W = 75 m

Then $D = 0.069$ sample/m^2.

The sampling interval, $L = D^{-1/2} = 4$ m, and one sample every 4 m would optimize overall cost. Approximately 400 samples would be indicated with a sampling program cost of $400,000. Contrast this with the cost of wasted remediation, estimated in this example to be $810,000, even though a relatively dense sampling grid is employed. If the sampling interval were 20 m, the sampling costs would be reduced to $15,000, but the cost of wasted remediation would increase to $4,000,000. Total costs would be approximately $3,000,000 higher than the optimal response.

By inspection, Equation 2 indicates that a lower sampling density (greater spacing between samples) is optimal if the contaminated area is large (large W) or if remedial costs are less than in the example. If remediation is inexpensive, then overdoing it is less costly than sampling so there is less need to define the contaminated area precisely.

GEOSTATISTICS

Geostatistics are best applied to normal populations that are spatially continuous. As normality and continuity criteria deteriorate, geostatistics become less optimum in ability to interpolate. Somewhere between ideal and non-ideal data sets, interpolation schemes such as method of triangles, inverse distance weighting and kriging become useless.

Kriging is a valuable interpolator because, unlike other geostatistical methods, kriging produces an error value for each interpolated value. By paying close attention to the errors, the user can

determine when kriging becomes a liability in determining extent of contamination. There is no easy way to tell when other interpolators fail to produce accurate estimates.

The Semi-Variogram (SV) is the tool within kriging that identifies the expected ability of this interpolator to work. A combination of SV characteristics and goodness-of-fit values helps identify the usefulness of kriging before interpolation even begins. Goodness-of-fit values are typically called jackknifing errors[1] and have been the standard method of determining the usefulness of the kriging system and its SV.

Characteristics of the modeled SV are as valuable or more valuable than jackknifing errors as indicators of the ability of kriging to produce optimum estimates. The important SV characteristics include the nugget value (y-intercept), sill value and shape (value of gamma where the SV levels out) and noise. The ideal SV has a nugget value of zero, a well defined flat sill and minimal noise. The noise can be defined as the variability of the SV data points about the fitted model.

Pitfalls of Using Geostatistics

User knowledge of SV characteristics and the Cumulative Density Function (CDF) is vital to be confident that the kriging algorithm actually is producing optimum estimates.

Using jackknifing errors alone may be misleading. Certain hazardous waste site characteristics tend to result in problems if kriging is to be used as the interpolator. The problems are evidenced by SV or CDF characteristics.

Waste sites consisting of numerous small waste spills interspersed through generally uncontaminated soils most likely will result in a statistical population dominated by outliers. The CDF would be heavily skewed. The effects of the outliers also will be noticeable as significant noise and/or a significant nugget value on the SV. Sometimes the SV is so noisy that a model cannot be fit to it.

Log transformation is the simplest remedy for this situation but, depending on the extremity of the outliers, it does not always work. The transformation will usually smooth the SV, enough to be modeled, but rarely affects the nugget value.[2] Transformation removes the extreme variance caused by the outliers but does not remove the baseline variance between the majority of points. In one case, log transformation reduced the noise but resulted in a pure nugget (horizontal SV) indicating that the sampling scheme was not of sufficient density to identify spatial variability.

Kriging this system will tend to greatly overestimate the extent of contamination. The peak true contamination values will be reduced while the true extent of contamination will be overestimated. The interpolation scheme will not generate any new peaks in the field but will incorrectly increase the extent of low level contamination especially around the measured outliers. This becomes significant when the cleanup criterion is near background.

Another waste site characteristic that causes problems is one that contains several lagoons or larger areas of contamination interspersed through relatively uncontaminated soil. A grid system of points covering this site most likely would show a bimodal distribution, one peak of near background values and another peak of high values. The SV may show a poorly defined sill or possibly even two sills representing the effects of the two populations of values. If the true SV model cannot be well estimated, one of the populations will be overemphasized causing a severe over or under estimate of the true extent of contamination. One solution to this problem is to work with the two populations individually to calculate individual SVs and then use both SVs as a comparison for interpolation.

Waste sites characterized by basin environments are conducive to kriging. In a basin, the extrinsic variability is decreased by the intrinsic factors involved with seasonal flooding. Each time the system floods, the contaminants disperse somewhat creating a more continuous spatial distribution and decreasing the extreme outliers to create a more lognormal population. These spatial and statistical distributions are more ideal than those found on other types of hazardous waste sites.

Case Histories

The following example shows how information about extrinsic and intrinsic factors can be used to optimize the utility of kriging. The site is a basin environment, so the values are dominated by intrinsic variability. Boundaries of expected contamination were identified from previous investigations (extrinsic variability) and used to help locate the sampling grid (Fig. 2). The results from this first phase are not available yet, so we've described one of the probable outcomes. We assume that the eastern third of the site was uncontaminated while the samples up to the western boundary were contaminated. Our confidence along the western half boundary is bolstered by the previous information on the location of the perimeter (extrinsic factors). There is less need of sampling along this boundary since it is more certain. The dashed line, P_2, represents the line of proposed phase 2 sample locations based only on seeking a precision of 35% in estimation of contaminated soil areas. This line would encompass 1.35 times the area circumscribed by P_1. This precision of estimation of contaminated soil lies in the requirement under recently issued CERCLA Guidance[4] that feasibility study cost estimates be accurate to within +50% or −30% of the actual costs. Where the perimeter extends beyond line P_2, an additional line of samples is proposed (P_3) which again would encompass an area 1.35 times larger than the previous area.

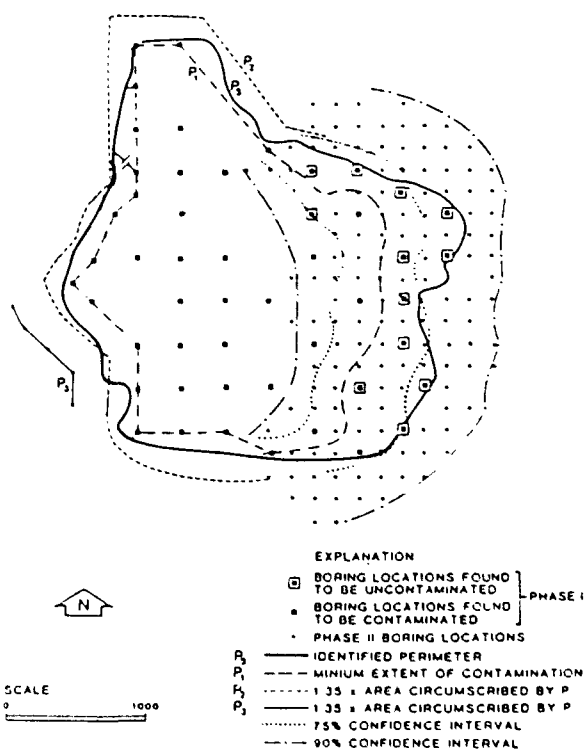

Figure 2
Sampling Scheme for Hazardous Waste in a Basin Environment

We have less confidence in the boundary along the eastern half of the site since it is completely estimated. A parameter, C, has been used to help locate subsequent sample locations.[3]

Parameter C is defined as follows:

$$C = [(\text{Criterion}) - (\text{Est} + (\text{Conf})(\text{KE})]/\text{Standard Deviation} \quad (3)$$

Where:

Criterion = Cleanup criterion
Est = Interpolated value
Conf = Confidence interval (1.28 for 90% confidence)
KE = Kriging error associated with interpolated point.

The 75 and 90% confidence intervals about the boundary of minimum extent of contamination were drawn using parameter C. It is obvious that many more samples are required to identify this boundary than the western boundary due to increased uncertainty in this area.

Parameter C is unique since it combines the cleanup criterion with the kriging error to arrive at the most likely Phase 2 sampling locations. Areas that are significantly above or below the criterion are eliminated from further consideration even if uncertainty is large in those areas. The use of kriging error alone to indicate future sampling areas discriminates based only on uncertainty rather than boundary locations which can be misleading.

Kriging was used in conjunction with a phased sampling scheme on another site and reported by Tucker *et al.*[3] Parameter C was used here to identify confidence intervals for the whole site since the expected extent of contamination was not well known on this site. This site was not a basin area as described previously, so it had less than ideal spatial and statistical distributions. Log transformation of the data eliminated SV noise resulting in a smoother curve. The uncertainty of boundary locations was still significant however, and caused a large portion of the site (1/3 of the area) to be considered for Phase 2 sampling. This level of uncertainty was caused mostly by a few outliers in the data set and resulted in the need of a significant Phase 2 effort.

CONCLUSIONS

With the advent of user-friendly computer contouring packages, there will be an increased tendency to misuse kriging or overemphasize the positive benefits of kriging when used on inappropriate data. Kriging along with other geostatistic methods should not be used as standard procedure at all hazardous waste sites. The data must be examined for statistical and spatial distribution patterns before initiating geostatistics. Geostatistics become more valuable as the spatial distribution tends to be continuous and the statistical distribution tends to be normal or lognormal. Both patterns are relatively rare on hazardous waste sites since extrinsic factors usually dominate intrinsic factors in controlling site variability. Extrinsic factors tend to result in discontinuous spatial data exhibiting statistical outliers.

Kriging is more useful than other interpolators since it produces an error term with each estimated value. This error can be used to plan a second phase of sampling using Parameter C when the data from Phase 1 sampling are less than ideal. This error also may indicate that kriging or other interpolators are not useful on that particular site.

Finally, sampling schemes can be designed to optimize the total costs of remediation (sampling costs + remediation costs) by optimizing the relationship between the number of samples taken and analyzed versus the costs of soil remediation. By examining this relationship mathematically, it appears that costs of extra sampling can be easily overcome by reducing the final costs of soil remediation.

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Land Treatment of Wood Preserving Wastes

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ABSTRACT

Numerous wood preserving plants currently are evaluating disposal alternatives for sludges and contaminated soils generated at these plants. Land treatment is a potentially environmentally sound and cost-effective means of treating these wastes on-site. Results of four pilot-scale studies completed at wood preserving plants in California, Montana, Minnesota and the northeastern United States are summarized. The land treatment studies involved a detailed evaluation of the degradation, adsorption and toxicity reduction of the hazardous constituents present in these wastes.

INTRODUCTION

This paper presents a description of on-going industry sponsored studies concerning the land treatability of sludges and contaminated soils resulting from wood preserving operations. The objectives of this paper are to:

- Identify the types of field and laboratory studies being conducted in this area
- Identify the methods being used in the treatability studies
- Present preliminary results of the on-going studies

Background

Of the estimated 400 wood treating plants in the United States, over 80% use creosote and/or pentachlorophenol as wood preservatives. These plants may generate sludges and contaminated soils containing the above preservatives as a result of spills, leaks and settled material from wastewater impoundments. Many of the wood preserving plants are regulated under RCRA or are on the National Priority List and must identify alternative means for disposal of sludges and contaminated soils.

This paper briefly discusses four current laboratory and field studies concerning the land treatability of wood preserving wastes. Table 1 summarizes the location at each study and the types of wastes involved. All the studies have been designed to meet the objectives of a land treatment demonstration under RCRA as defined in 40 CFR 270.20. These objectives are to:

- Accurately simulate proposed full scale conditions including soils, climate and design and operating conditions
- Demonstrate that the wastes can be degraded, transformed and immobilized within the treatment zone of the land treatment facility

The four studies described in this paper will provide valuable data in determining whether land treatment of wood preserving wastes can successfully meet RCRA standards. It should be emphasized that additional studies concerning the land treatability of wood preserving wastes have been completed. These include but are not limited to studies by Sims[1], Sims and Overcash[2], Umfleet *et al.*[3], Umfleet,[4] Edgehill and Finn,[5] Baker and Mayfield[6] and McGiniss.[7] Laboratory studies also are being conducted under the sponsorship of the U.S. EPA Robert S. Kerr Laboratory in Ada, Oklahoma.

CASE STUDY A

The objective of this study was to develop design and operating criteria for full scale on-site treatment of creosote-contaminated soils at a wood treatment plant in Minnesota. The study included both bench scale and pilot scale evaluation of several performance, operating, and design parameters. These parameters include:

- Soil characteristics
- Climate
- Treatment supplements
- Reduction of organics, phenolics and PAH compounds
- Toxicity reduction
- Effect of initial loading rate
- Effect of reapplication

Soil Characteristics and Climate

The study soil is a fine sand which comprises the upper 2 ft of the bottom of a RCRA impoundment previously used for the storage of wastewater from a tie treatment plant. The soil is contaminated with creosote constituents which primarily consist of PAH and phenolic compounds. Total benzene extractable hydrocarbons in the contaminated soil range from approximately 8 to 12% by weight.

The soil has a natural pH of approximately 6.5 and, therefore, no pH adjustments were necessary prior to initiating the studies. Specific conductance values and metal contents of the soil are generally within the range of values reported for natural soils. The carbon to nitrogen (C/N) ratio of the contaminated soil is high, and nutrient additions were necessary to reduce the C/N ratio to a range which promotes microbial growth.

Because the natural soils are fine sands and extremely permeable, it was decided that the full scale system would include a liner and leachate collection system to prevent leachate break through. To replicate the proposed full scale conditions, the pilot studies consisted of five lined, 50 ft^2 test plots with leachate collection. Table 2 shows the experimental conditions for each of the test plots.

The field studies were conducted from July 25 through Oct. 30, 1984. Average ambient temperatures generally exceeded 50° F during this period. July and August were exceedingly dry months,

Table 1
Summary of Land Treatment Studies

Facility	Location	Type of Study	Type(s) of waste	Principle Contaminants
A	Minnesota	L,F	Creosote contaminated soil and sludge	PAH, T. Phenol
B	California	L,F	Creosote and pentachlorophenol contaminated soil	PAH, clorinated phenolics
C	Montana	F	Creosote contaminated soil and sludge	PAH, T. Phenol
D	North East	L	Creosote and pentachlorophenol contaminated soil	PAH, chlorinated phenolics

L—Laboratory Study
F—Field Study

and the field plots required weekly watering to maintain them near field capacity. October was a very wet month, and the plots were near saturation during this period. The active degradation period appears to extend through the month of October at this site.

Treatment Supplements

The studies were designed to maintain soil conditions which promote the degradation of hydrocarbons. These conditions include:

- Maintain a pH of 6.0 to 7.0 in the soil treatment zone
- Maintain soil carbon to nitrogen ratios of 25 to 1
- Maintain soil moisture near field capacity

In addition, the studies evaluated the effect of seeding the soil with commercially available microbes adapted to hydrocarbon.

The soil pH was within the desired range at startup and no lime additions were necessary. Soil pH decreased below 6.0 in most of the plots after 2 months of operation. Subsequent additions of 1.0 to 1.5 tons/acre of agricultural grade limestone raised the pH of the test plots to the desired range and no subsequent drops in pH were observed during the test period.

The equivalent of 10-20 tons/acre of 10:10:10 fertilizer (10 lb nitrogen, 10 lb phosphorous and 10 lb potassium per 100 lb fertilizer) were added to all the plots at the beginning of the study based on the estimated carbon content of each plot. The fertilizer additions successfully reduced the carbon to nitrogen ratios of each plot below 25:1. Residual ammonia levels following the fertilizer application were fairly high, however, creating a concern about possible ammonia toxicity problems.

All the test plots were watered based on the results of daily rainfall and pan evaporation data as well as daily soil tensiometer reading. Soil irrigation was necessary on a weekly basis during most of the study. The monitoring and irrigation program successfully maintained the soil near field capacity. No significant reductions in organics were observed in the plot which was not watered. These data illustrate that maintaining the soil near field capacities is a critical operational parameter for obtaining successful degradation. Field capacity of the fine sands appears to be approximately 10% moisture by weight.

No significant advantages in organic degradation can be attributed to seeding the plots with the adapted microbial culture used in the study. It is hypothesized that an active natural soil microbial population exists in the contaminated soil. Due to the length of time the soil contamination existed, the existing soil microbes are well adapted to the contaminants present in the soil.

Reduction of Organics, Phenolics and PAH

Reductions of benzene extractable hydrocarbons were fairly similar between all the field plots. Similar reduction trends were observed in the laboratory reactors, however, at lower rates. Percent removal efficiencies and first order kinetic rate constants were fairly similar for all the field plots. Average removals for all field plots over the 4 months were approximately 40% with a corresponding first order kinetic constant (K) of 0.004.

The greatest mass of benzene extractable removals was associated with the highest initial loading rates. Total removals over the 4-month test period on the basis of pounds of organics removed/ft^3 of soil/degradation month are presented in Table 3.

Table 2
Experimental Specifications for Test Plots

Test Plot	Soil Specifications	Initial Oil[1] Content (%)	Fertilizer[2] (lb)	Cultivation Frequency
1	Contaminated soil and clean sand; Hydrobac CL	10	50	Weekly
2	Contaminated soil and clean sand: Hydrobac CL	5	24	Weekly
3	Contaminated soil and clean sand, no microbial seed	5	25	Weekly
4	Contaminated soil and peat moss, Hydrobac CL	5	25	Weekly
5	Visibly non-contaminated soil, Hydrobac CL	3	15	Weekly

[1]Benzene Extractable Hydrocarbons.
[2]10-10-10 Fertilizer.

Table 3
Total Benzene Extractable Removals in Field Plots

Plot Number	Initial Benzene Extractable Content (percent by weight)	Total Benzene Extractable Removals (lbs/ft^3 of soil/month)
1	8.83	0.94
2	4.00	0.56
3	4.06	0.34
4	10.59	0.91
5	1.73	0.20

These removal rates can be compared to data from petroleum refinery land treatment facilities.[8] Typical removal rates at well operated refinery facilities range from 0.1 to 1.0 lb of oil removed/ft^3 of soil degradation month with the lower end corresponding to a "low" initial concentration (such as in Plot 5) and the high end corresponding to "high" initial concentrations such as Plots 1 and 4. The data, therefore, are in good agreement with removals documented at refinery land treatment facilities.

Phenol removals did not exhibit the same linear relationship over time as the benzene extractable contents. Phenol removals were observed over the first three months followed by a market increase in the phenol content of the soil in the fourth month. The trends observed may be partially a result of analytical variability but also may be affected by the breakdown of complex organic compounds releasing phenolic constituents.

First order rate kinetic constants for PAH were fairly similar between the field and laboratory studies with the exception of 4+ ring compounds in test runs 1 and 4. The laboratory tests had higher first order rate constants than the field plots for these compounds.

Table 4 compares the first order rate constants for benzene extractables and PAH compounds between the laboratory and field studies which had an initial benzene extractable content of 4 to 5% and the laboratory and field studies which had an initial benzene extractable content of 8 to 10%.

The median kinetic values (of the 4 to 5% studies and the 8 to 10% studies) are approximately equal for all the parameters. The most notable variance is for the 4+ ring PAH compounds. The 4 to 5% initial loading rates resulted in slightly higher kinetic rates for these compounds as compared to the 8 to 10% initial loading rate. The kinetic rates appear independent of the initial loading rate within the range of loading rates tested.

Table 4
Comparison of the Range and Median
Kinetic Values at Two Initial Loading Rates

	4 to 5 percent		8 to 10 percent	
	Range	Median	Range	Median
	(K, day^{-1})		(K, day^{-1})	
Benzene Extractables	0.001-0.007	0.003	0.002-0.004	0.003
2 Ring PAH	0.021-0.024	0.023	0.013-0.033	0.023
3 Ring PAH	0.014-0.017	0.016	0.013-0.023	0.016
4+ Ring PAH	0.002-0.007	0.004	0.000-0.005	0.001
Total PAH	0.008-0.011	0.009	0.006-0.013	0.008

Toxicity Reduction

A battery of toxicity assays was completed on 3 test plots (1, 2 and 5) at the completion of the 4-month study as well as on creosote sludge and contaminated soils which approximately represented the start up conditions in plots 1 and 2 at the beginning of the study. The battery of assays included:

- Microtox
- Ames mammalian mutagenicity
- 96-hour static acute fish bioassay

The battery of assays resulted in the following observations:

- Test plots 2 and 5 were non-toxic after 4 months
- Test plot 1 showed intermediate toxicity after 4 months
- Both contaminated soils and the creosote sludge were toxic to all the bioassays

The microbial assays (microtox and Ames test) on the contaminated soils would have suggested that the initial concentrations in test plots 1 and 2 would have resulted in a toxic response to the soil microorganisms and therefore no significant degradation would occur. The results from these plots, however, have shown significant degradation. This indicates that an acclimated microbial population existed in the contaminated soil prior to the initiation of the studies. The creosote constituents (within the range of initial concentrations tested) do not result in toxic effects to the acclimated soil microorganisms used in the toxicity tests.

From an environmental toxicity standpoint, however, the toxicity tests show that the toxicity of the contaminated soil has been decreased through the treatment process. Complete toxicity reduction appears to fall between 2.5 and 5% benzene extractable content. Complete toxicity reduction was achieved after 4 months in plot 2.

Effect of Initial Loading Rate

First order rate constants were fairly similar between all the loading rates. The intermediate loading rate (4 to 5% benzene extractionables) may demonstrate a slightly higher removal of high molecular weight PAH compounds. Toxicity reduction also appears to occur at a faster rate for a 4 to 5% initial loading rate than at the higher initial loading rates.

The higher loading rates, however, showed the greatest mass removals and a clear detoxification trend. The studies suggest that all the loading rates tested are feasible. The selection of an initial loading rate should balance additional land area requirements against time requirements for completing the treatment process. Moderate loading rates (5%) will result in a faster detoxification whereas higher loading rates will decrease land area requirements.

Effect of Reapplication

Greater kinetic rates were observed after waste reapplication to a treated soil. The results suggest that average loading of 1 lb of benzene extractable/ft^3 of soil/degration month to a treated soil can be treated effectively when the application does not exceed 3.0 lb/$ft.^3$ The first application should occur after the initial application has been shown to be successfully treated.

Operating and Design Criteria

The studies have successfully developed operating and design criteria for a full-scale system at this site. These criteria include:

- Treatment period can be extended through October
- Soil moisture should be maintained near field capacity
- Soil pH should be maintained between 6.0 to 7.0
- Soil carbon:nitrogen ratios should be maintained at 25:1

- Fertilizer applications should be completed in small frequent doses
- Initial benzene extractable hydrocarbon contents of 5 to 10% are feasible
- Bioassays can be used to determine treatment effectiveness
- Waste reapplication should occur after initial soil concentrations have been effectively degraded
- Waste reapplication rates of 2 to 3 lb of benzene extractables/ ft^3 of soil/2 degradation months can be effectively degraded

The studies completed have shown that the visibly contaminated soil at the site can be effectively degraded and detoxified. The data indicate that the organic content of the visibly contaminated soil present in the upper two feet of the RCRA impoundment can be degraded to levels similar to the organic content of the soils beneath the visibly contaminated soils. The data also indicate that the treatment is effective in detoxifying the waste.

CASE STUDY B

This study involves a field pilot program to evaluate the feasibility of land treatment of contaminated soils from a wood preserving plant in California. Principal hazardous constituents include polynuclear aromatic hydrocarbons (PAH), pentachlorophenol, dioxins and furans. The studies were initiated in the summer of 1985 and may be continued through the fall of 1986.

Treatment Medium Soils

The test plot soils are located east of a spray irrigation field which is proposed as the full-scale treatment area. The general characteristics of the surface soils at the spray field and the test plots nearby are characterized as clayey silts which grade to silty clays with depth. Depth to groundwater in the area is generally 30 to 40 ft beneath the ground surface. Specific soil characteristics of the test plots based on core samples to greater than 7 ft show the soils to be relatively homogeneous with depth. The soils through the test plots are characteristic of a brown silty clay, tight to very tight, with small gravel clasts to 1 in.

Field Plot Experiments

Three experimental field plots were constructed at the facility near the spray irrigation field. The plots were graded to a 1% slope and earth berms were constructed between the plots. Runoff is completely collected at the low slope position of each plot. The collection areas for the plots are sized to collect the run-off from the 25-year, 24-hour storm (i.e.: approximately 4.5 in).

Also included in the plot design was the installation of soil-pore liquid samplers. The samplers are used to collect water from the unsaturated zone for the purpose of determining if hazardous constituents are migrating out of the treatment zone. The plots were fitted with three types of lysimeters per plot: a commercially available vacuum lysimeter, a fabricated glass block lysimeter and a gravity flow trench lysimeter. During the course of the study, the vacuum and glass block lysimeters have proven to be severely limited in extracting water for analysis. The trench lysimeter has worked effectively in collecting macropore flow through the treatment zone which is the most critical factor in determining if hazardous constituents are moving through the treatment zone.

The plot design also included the installation of tensiometers. Tensiometers are important in monitoring soil suction or the force that determines which way moisture will move in soil. For the study, tensiometers are used to measure moisture in the zone of incorporation and at 18 in. to determine irrigation scheduling and at 5 ft to monitor soil moisture movement through the treatment zone of the three plots.

Startup

After the plots were constructed and the treatment area was readied, the contaminated soil was spread and mixed in place with native soil to achieve an approximate benzene extractable content of 2% in plot 1 and 3000 ppm of pentachlorphenol in plot 2. Sewage sludge was applied at a rate of 20 tons/acre to Plots 1 and 2 to increase the organic matter of the contaminated soil as well as reduce the carbon:nitrogen:phosphorous ratio to a range to promote microbial growth. Also, agricultural lime was spread as a step to raise soil pH to 6.0 to 7.0. The final step of startup activities was the mixing of contaminated soil, fertilizer and lime with a tractor mounted rototiller to a depth of 6 to 8 in.

Table 5 summarizes the operational activities conducted during the pilot scale studies. These activities included test plot cultivation, irrigation, sampling and on-site climatological and subsurface monitoring.

Table 5
List of Operational Activities

Activity	Frequency
Test Plot Cultivation	Weekly
Lime Additions	As necessary to maintain pH 6-7[1]
Fertilizer Additions	As necessary[1]
Moisture Additions	As necessary[1]
On site monitoring	
-soil temperature	Daily
-pan evaporation	Daily
-rainfall	Daily
-soil suction	Weekly
-soil moisture	Weekly

[1]Determined from monitoring data.

Soil and Water Sampling

Soil samples were collected from Plots 1 and 2 at 2-week intervals for the first 6 weeks of the study and then monthly until the end of the study. Each plot was subdivided into three subplots for sampling purposes. The subplots were each 12 ft by 16 ft with 1-ft grid spacings for a total of 192 grid squares per plot. Four subsamples were collected in each subplot during each sampling event. These four subsamples were then composited into one sample for each subplot. Each subsample was collected from one of the grid squares. The four grid squares sampled in any one event were selected from a random number table. Each grid square was sampled only once during the course of the study. The randomized sampling was recommended as part of quality assurance procedure to account for field variability.

Also, during the study, nine grab samples were taken from one subplot during one sampling event as well as the normal composite sampling. This sampling was done to compare composite sampling versus grab sampling.

Soil core sampling was conducted prior to waste application, 60 days and 90 days after waste application. Cores were taken in each subplot including the control plot. The cores were collected every 1 ft to a depth of 7.5 ft.

Two water samples were taken during the study. Runoff samples were collected from each plot in September, and trench lysimeter samples were collected from each plot in December. All samples were shipped in coolers packed with ice under standard chain-of-custody procedures. Sampling equipment was decontaminated with deionized water and methanol after each sampling round.

Table 6
Range of PAH Kinetic Constants

Subplot	2 Ring	3 Ring	4 Ring	Total
1A	0.020	0.200	0.006	0.010
1B	0.014	0.014	0.007	0.009
1C	0.035	0.029	0.027	0.028
2A	0.019	0.027	0.017	0.019
2B	(1)	0.020	0.012	0.013
2C	(1)	0.018	0.001	0.004

(1) not detected at startup.

Organic Reduction Rates

Complete analytical results for the study were not available during the preparation of this paper. Preliminary results, however, indicate that benzene extractable removals in each of the subplots ranged from 34-66% for the 4-month time period with a corresponding first order kinetic constant (K) ranging from 0.003 to 0.009.

Table 6 summarizes the first order kinetic constants computed from the preliminary analytical results for various ring classes of PAH compounds. The following compounds are listed under the noted ring classes:

2 Rings	3 Rings	4+ Rings
Naphthalene	Fluorene	Fluoranthene
Acenaphthylene	Phenanthrene	Pyrene
Acenaphthene	Anthracene	Benzo (a) anthracene
		Benzo (a) pyrene
		Benzo (b&k) flouranthene
		Chrysene
		Benzo (ghi) perylene
		Indeno (1,2,3-cd) pyrene
		Dibenzo (a,h) anthracene

Considerable variability was observed in the pentachloraphenol (PCP) data. Table 7 summarizes the measured values over the course of the study and the corresponding calculated removal rates. The PCP data are non-conclusive and continuations of these studies into 1986 are necessary to draw any treatability conclusions.

As a byproduct of PCP production, furans and dioxins may be present at variable concentrations. Tetra and 2378 furans and dioxins were not detected at startup in Plot 1 and were below 5 ppb and 1 ppb for the Tetra and 2378 furans and dioxins respectively in Plot 2. The remaining furans and dioxins (Penta, Hexa, Hepta) show removals after 4 months between 75 and 95%. The octa furans and dioxins have the least percentage removals with values ranging from 0-81%.

In summary, significant removals of furans and dioxins were observed over the 4 month period, and initial startup concentrations were relatively low in comparison to PCP and PAH startup concentrations.

The studies may be extended through 1986 to evaluate long-term performance of the plots and evaluate the immobilization of the contaminants.

CASE STUDY C

This study is an on-going RCRA land treatment demonstration for a proposed full scale land treatment facility in Montana. The wastes being evaluated are creosote contaminated soils and sludges resulting from the closure of a RCRA surface impoundment. The proposed full scale land treatment facility will be used to treat and detoxify the wastes removed from the impoundment at closure. Design parameters for the field studies were developed based on results of Case Study A.

Soil and Climate

The treatment area soils consist of loamy silts and silty sands. The caution exchange capacity of the surface soil is approximately 20 milliequivalents/100 g of soil and the organic matter content of the surface soil is approximately 1.5%.

The climate of the area is semi-arid. Annual evapotranspiration exceeds annual precipitation and there is limited recharge to the groundwater resulting from precipitation and run-off. Monthly ambient temperatures exceed 50° F approximately 6 months of the year.

Description of Study

The soil and climatic conditions at the site are considered highly favorable for attenuation of the creosote contaminants. Therefore, unlike Case Study A, this system is not lined. The results

Table 7
Summary of Pentachlorophenol Removals in Plots 1 and 2

	Concentration (ppm) at Time (t) Days					Percent of Removal at Time(t) Days(1)			
	Date					Date			
	7/12/85	8/16/85	8/27/85	10/10/85	11/11/85	8/16/85	8/27/85	10/10/85	11/11/85
Plot	t=0	t=35	t=46	t=90	t=122	t=35	t=46	t=90	t=122
P1A	120	110	260	54	210	8	0	55	0
P1B	130	95	120	44	110	27	8	66	15
P1C	160	69	150	48	11	57	6	70	93
P2A	6800	5300	8200	1500	310	22	0	78	95
P2B	1400	5200	5700	2300	1000	0	0	0	29
P2C	1700	4200	5600	1900	480	0	0	0	72

(1) Percent Removal at Time (C(O)-C(T)/C(O))100.

of Case Study A, however, were used to select the design parameters for the study including waste application rate and treatment supplements.

Waste Application Rate

Waste application rates are based on gross organic loading as defined by benzene extractable hydrocarbons. The loading were selected on the basis of results from Case Study A and involved initial loadings of 2% and 5% benzene extractables. The 2% plot includes subsequent bi-monthly applications of 2% benzene extractables to evaluate the effect of waste re-applications. The 5% plot does not include waste re-application in order to evaluate the effect of one batch loading.

Treatment Supplements

To minimize the need for replicate plots and minimize the analytical costs of the study, certain management practices were selected as "good management practices" for the study and were applied consistently to all the plots. These "good management practices" are anticipated to optimize treatment (based on literature data) and include:

- Maintain surface soil pH between 6.0 and 7.0
- Maintain a soil carbon:nitrogen ratio of 25:1
- Maintain soil moisture near field capacity through irrigation
- Apply manure or organic amendments to provide nutrients and increase the organic carbon content of the surface soil
- Till the soil once every 2 weeks
- Prevent storm water run-on from entering the plots and capture run-off

Construction of the Plots

The field plots were constructed in June 1985. One plot is a control where no wastes have been applied but all the "good management practices" are implemented. The other two plots are for the two waste loading rates being evaluated.

Each plot is 12 ft x 50 ft with a defined treatment depth of 5 ft. The plots are separated by earthen berms which prevent run-on from entering the site. Each plot is graded to a 1% slope, and a lined run-off collection sump capable of handling two 25-year, 24-hr storm events is present at the toe of the slope. The entire study area is fenced:

Three types of soil-pore water collection devices were installed in each plot. These include:

- A vacuum lysimeter capable of placing a suction on the surrounding soil
- A pan lysimeter constructed from a hollow glass block approximately 1 ft^2
- A trench lysimeter consisting of a 10-ft long 6-in. diameter PVC drain, placed at the bottom of the treatment zone

In addition soil tensiometers were placed at 3 ft and 5 ft. These tensiometers in conjunction with a hand tensiometer used to take soil suction readings at the surface are used to evaluate the hydraulic flux through the soil.

Monitoring

Monitoring at the site includes monthly sampling of the zone of incorporation to evaluate the degradation of specific organic constituents and bi-annual sampling of soil cores, soil pore water and groundwater to evaluate contaminant immobilization.

Table 8 presents the analytical parameters evaluated in each medium. The principal hazardous constituents being evaluated are polynuclear aramatic hydrocarbons PAH. These constituents are monitored on a monthly basis along with indicator parameters such as benzene extractable hydrocarbons and total phenols. In addition, nutrients, soil electrical conductivity and soil pH are monitored on a monthly basis to evaluate the need for treatment supplements. Soil moisture is checked on a weekly basis to evaluate the need for supplemental irrigation. The relative toxicity of the surface soil is evaluated through monthly microtox analyses.

Table 8
Analytical Parameters, Site C

Parameter/Method	Medium
-Benzene Extractables/Soxhlet extraction	Z
-Metals/ICAP	C
-Total kjeldahl nitrogen/automated titrimetric	Z
-Ammonia nitrogen/automated titrimetric	Z
-pH/combination electrode	Z,C,L
-Conductivity/conductivity bridge	Z,C,L
-Total organic carbon/combustion or oxidation	L
-PAH/Method 8270	Z,C
-Base neutrals/Acid extractables	C,L
-Microtox/Toxicity Analyzer System	Z,L
-Fish bioassay	Z

Z zone of incorporation soil samples.
C = core soil samples
L lysimeter water samples.

Bi-annual soil core sampling includes collection of soil cores in 1 ft increments down to the bottom of the treatment zone (5 ft). The soil cores, groundwater and lysimeter samples are analyzed for indicator parameters and for a complete scan of base neutral and acid extractable organics using GC/MS techniques. Inorganic metals also are included in the analyses using ICAP techniques.

All sampling and analyses include triplicates from each plot to determine statistical variability. The startup of the study was in July 1985, and it is scheduled to be completed in 1986. Insufficient analytical data were available at the time of this writing to evaluate degradation trends. However, the soil core, lysimeter and groundwater analyses have not detected any migration of hazardous constituents from the treatment zone.

CASE STUDY D

This project involves a detailed laboratory study using creosote and pentachlorphenol contaminated soils from an abandoned wood preserving plant in the northeastern United States. The study was initiated in December 1985 and is scheduled to run for 8 months.

The laboratory study program evaluating land treatment is divided into the following three areas:

- Evaluation of leachate movement through soil columns and contaminant volatilization
- Examination of contaminant degradation rates in soil pans
- Development of soil/water partition coefficient for PAH and pentachlorophenol associated with the site soil

Soil Column Evaluation

The studies outlined below are designed to evaluate the rate and extent of treatment, including biodegradation and retardation. A mass balance of selected constituents will be determined by taking into consideration the initial loading rate, the concentration of constituents in the leachate for the duration of the 8-month experiment and the concentration of constituents in the soil core at the termination of the experiment.

The soil treatment process will be evaluated using 4-in. diameter, 5-ft long glass column reactors packed with clean soils to represent actual site conditions. The columns contain the same

soil profile materials that exist at the site. Native soils were collected in 6-in. intervals and packed into the columns in the same order as obtained in the field to obtain a representative soil column profile.

Before any contaminated material was applied to the soil columns, chloride tracer studies, using sodium chloride, were performed. This work was completed to determine the proper hydraulic loading rate once contaminated material is applied.

Actual contaminated soil from the site was mixed into the upper 6 in. of the clean soil in a porportion to give approximately 5% benzene extractables. Common commercial fertilizer and manure also were added and the soil pH was adjusted to and maintained between 6-7 by lime additions. The columns are to be operated for approximately 8 months with only one initial waste application. Watering of the columns is to be done with its pH adjusted to approximately pH 4. The pH adjustment is done to simulate the existing pH of rain water for the area. In addition to routine watering, the columns are to be watered with the equivalent of a 25-year, 24-hr storm event in January and May during the study. The soil is to be tilled every other week. Volatile emissions are to be addressed as part of the column work.

For QA/QC purposes, two duplicate columns containing the waste material are operated. A third column containing only clean soils serves as a control and is operated in the same manner as the columns with contaminated material. All three columns are to be sampled periodically for analyses.

Soil Pan Reactor Evaluation

In conjunction with the operation of the soil columns, a soil pan study phase is to run for approximately 8 months with degradation rates of specific compounds addressed. Four soil pan reactors are operated. The soil pans are constructed of aluminum, have a surface area of approximately 1.5 ft^2 and contain approximately 6 to 8 in. of soil. The soil is a mixture of contaminated material and clean surface soil from the site in a proportion to give a concentration of approximately 5% benzene extractables. Fertilizer and manure have been added to give a C:N:P:ratio of approximately 50:2:1, respectively. Manure was applied corresponding to a loading rate approximately 10-20 dry tons per acre. This is the same soil misture that is to be used in the column reactors. The soil pH is maintained within a range of 6-7 by lime addition as needed, and the soil moisture is maintained within 50% of field capacity by laboratory tap water adjusted to a pH of 4. During the course of the experiment, hand tilling is to be done every other week.

For QA/QC purposes, three duplicate pans containing the soil waste material lime, fertilizer, manure are to be set up. Two of the pans are to be maintained in a moist environment by water applications as needed. The third pan is not to be watered and is to serve as a contaminated soil control. A fourth pan, containing only clean soil, is to be operated in the same manner as the contaminated soil pans.

Soil/Water Partition Coefficient Development

Soil/water partition coefficients are to be developed for pentachlorophenol and PAHs as these compounds specifically relate to the contaminated site soils. For this work, different solution pHs are to be evaluated to examine the effect of pH on the leachabilities of PAHs and pentachlorophenol.

This information is needed to develop a better theoretical understanding between pentachlorophenol and PAH attenuation by the soil matrix.

CONCLUSIONS

Land treatment is a potentially technically effective and economic means of treating and disposing of wood preserving wastes from sites currently regulated under RCRA or CERCLA. Rigorous 2-year studies are currently under way to determine appropriate engineering design features for these systems. The data from those studies will provide a sound scientific basis for evaluating the feasibility of this technology at other wood preserving sites.

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Method for Determining Acceptable Levels of Residual Soil Contamination

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INTRODUCTION

With the exception of PCBs, regulatory standards or established numerical criteria that define acceptable levels of soil contamination at hazardous waste sites do not exist. However, numerical criteria are readily available for air and water. In contrast to air and water, soils are not fluid and are more readily subject to property rights. People experience little direct exposure to contaminated soils. For example, adults inhale approximately 17,000 l/day and ingest roughly 2 l/day of water, but they generally are believed to accidentally ingest less than 0.00005 l of soil per day. For these and other reasons, Congress has not enacted the "Clean Soils Act," and soil quality standards have not been implemented.

The extent of human exposure to residual contamination in soils can be extremely variable, depending on such factors as climatic factors and soil properties. The most important variable is land use. Contaminated soils in a backyard playground and subsistence garden (common in many residential areas) pose a much greater health risk than in a paved shopping mall development.

Consequently, it is reasonable to determine acceptable levels of residual soil contamination on a site-specific basis, considering the probable (or possible) future uses of the land during the period that it will remain contaminated. Many feasibility studies for remediation of contaminated sites and remedial actions implemented at sites reflect this concept. On the other hand, implications of this concept have been addressed only implicitly or qualitatively in many Remedial Investigation/Feasibility Studies (RI/FS) conducted to date. Systematic and quantitative implementation of this concept can be accomplished with multimedia exposure and risk assessment procedures that are readily available and well documented.

The purpose of this paper is to present these procedures in the context of the endangerment assessment process as they currently are implemented by the authors. The methods used by the authors are similar to the PPLV method developed by Dr. David Rosenblatt and co-workers of the U.S. Army Medical Bioengineering Research and Development Laboratory; the interested reader should consult Rosenblatt and Dacre[7], Rosenblatt, *et al.*[8] and Small[9] for further discussion of their procedures. Following the presentation of the method, a few examples will be presented to illustrate some features of its implementation.

APPROACH

Establishment of acceptable residual soils concentrations often will be an essential element of the endangerment assessment process. Endangerment assessment links the remedial investigation to the feasibility study in two ways:

- The process results in determination that an endangerment or public health risk exists. If the determination is positive, it virtually rules out the no-action alternative and demonstrates the need for the feasibility study.
- The endangerment assessment should clearly identify the environmental quality criteria that would be required for the CERCLA alternative; that is criteria which, if met, would substantially eliminate the endangerment.

The establishment of acceptable levels of residual soils contamination contributes to both objectives of the endangerment assessment. Endangerment may be suspected if the "endangerment criteria" are exceeded. The role of "endangerment criteria" in the RI/FS process is presented in Figure 1.

The recommended approach for determining acceptable levels of residual soils contamination is presented in Figure 2. Results of the remedial investigation will identify the contaminants of concern for the site. Inputs from the endangerment assessment team will be useful at an early stage in the remedial investigation to refine the list of contaminants of concern to focus RI resources on the "riskiest" contaminants. Further refinement and screening undoubtedly will be required as the RI data are acquired and reviewed. In some circumstances a formal hazard ranking system may be useful to screen contaminants, and applications of a formal screening model may be a component of the uppermost "box" of Figure 2.

Once contaminants of concern have been identified, investigations proceed along two parallel and simultaneous paths which interface at intermediate points in the process as well as in the integrative final steps. The two paths are contaminant fate (down the right in Fig. 2) and contaminant toxic effects (down the left).

Effects

First, the available toxic effects data for the contaminants of concern are reviewed. It is important to identify any particularly sensitive subpopulation (e.g., children, women of childbearing age, aquatic species or age classes). Considering this information on sensitive subpopulations and site-specific factors (e.g., industrial site where children would not be exposed) permits the identification of populations at risk. Populations at risk are those potentially exposed populations who also are sensitive to the contamination. The most sensitive population at risk normally will be considered as the basis of the endangerment criteria. However, if the number of individuals in the most sensitive population at risk is likely to be very small, it may in some instances be reasonable to base the criteria on another sensitive population while allowing for special or auxiliary protection of the special, rare subpopulation.

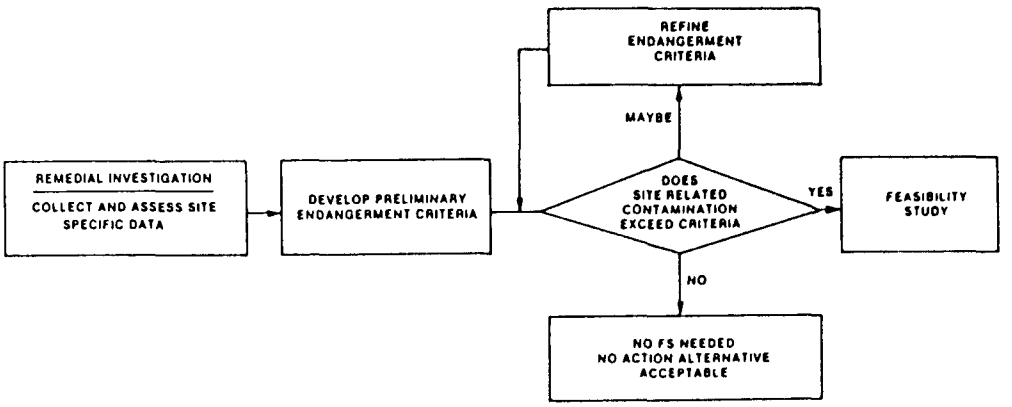

Figure 1
Role of "Endangerment Criteria" in RI/FS Process

The next step in the effects side of the process is to determine acceptable exposure levels for the sensitive population at risk. Determination of an acceptable exposure level is often the most controversial step in the process depicted in Figure 2. Much of the effort, techniques and procedures frequently referred to as carcinogenic or quantitative risk assessment are almost exclusively devoted to this element of the process. Later in this paper, it will be shown that other aspects of the process also introduce substantial uncertainty and variability in estimates of acceptable residuals levels. For carcinogenic contaminants, this step also introduces the controversial issue of acceptable risk: recent policy guidance from the U.S. EPA indicates that a 10^{-6} lifetime individual cancer risk level should be evaluated as a cleanup goal at CERCLA sites, consistent with its guidance for groundwater Alternative Concentration Limits, a site-specific standard setting mechanism under RCRA. Alternative cleanup standards resulting in lifetime individual cancer risks in the range of 10^{-8} to 10^{-4} also should be considered.

Land Use Scenario

As illustrated in Figure 2, a critical requirement of the soil criteria setting procedure recommended here is the need to define an exposure scenario. As used in this discussion, an exposure scenario is a characterization of the behavioral patterns of the population at risk that could result in, or reduce, exposure to the contaminants at the site. The critical element of the exposure scenario will be the land use scenario used in the analysis.

Depending upon the degree of conservatism that may seem warranted to affected parties, and the persistence of site-related contaminants, the exposure scenario may be based on: (1) the existing land use, (2) probable future land use over a specified future period, based on existing or predicted patterns of land development and (3) the use (of all possible future uses) that leads to the greatest potential for exposure. The choice among these alternative scenarios is not strictly a technical decision, but the technical implications of selecting among these alternatives can be addressed by a technical specialist. Ultimately, the selection of a land use scenario for the analysis and the selection of an "acceptable risk" are political/regulatory decisions, not technical ones. It will be shown later that these decisions can affect the ultimate soils criteria by factors of a thousand or more.

Environmental Fate

Parallel to and simultaneous with the review of toxic effects data, the environmental physical chemical properties of the contaminant are reviewed in the context of the environmental setting of the contamination/soils to evaluate the site-specific environmental behavior of the contaminants.

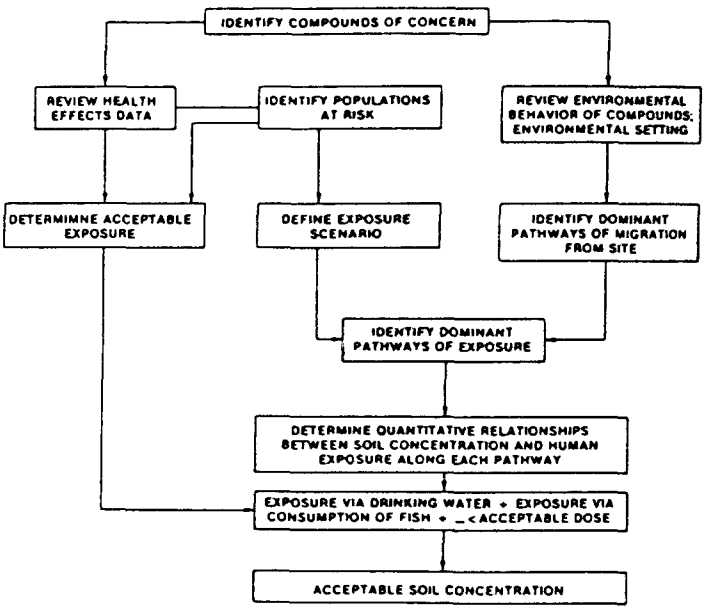

Figure 2
Determination of Acceptable Soil Concentrations by Exposure and Risk Assessment

Dominant pathways of migration from the site are identified by screening level analyses and calculation. Screening level analysis procedures are diverse, and flexibility must be maintained in their application in order to derive the most information possible from the available data, while conserving "level of effort" resources. Identification of the dominant migration pathways usually can be deduced on the basis of the judgment of senior environmental scientists familiar with the site. Occasionally, formal screening level calculations as represented, for example, by methods of Enfield, *et al.*[9] or Tucker, *et al.*[10], can be applied at this step.

Integrating the information from the exposure scenario with the dominant migration pathways yields the dominant pathways of exposure. These are the pathways, from soil to an exposed member of the population at risk, that are capable of carrying

and delivering a significant dose of contamination. An example of an exposure pathway would be "surface run-off erodes surficial soils and carries both dissolved and adsorbed soil contaminants to a nearby estuary; fish and shellfish bioconcentrate the contaminants from the water, and the organisms are harvested for human consumption."

Once the dominant exposure pathways are identified, each is expressed as a mathematical equation relating the dose (exposure) via the pathway to the soil contaminant level. These equations are representations of actual processes and are designed to express the relationship conservatively (inferring a higher-than-expected exposure for a given soil concentraton) to favor protection of public health. The most important pathways should be evaluated with the greatest degree of sophistication to make their exposure estimates more reliable.

Finally, the exposures via all of the individual pathways are added together, and the sum (total exposure) must be less than the acceptable exposure. This step links the exposure assessment with the toxic effects evaluation to produce the risk assessment-based criterion. Each pathway is defined as a factor times the soil concentration, and the acceptable exposure and the factors are known. Consequently the equation may be inverted to derive the acceptable soil concentration.

APPLICATIONS OF THE PROCEDURE

In most applications of this procedure conducted by the authors, the following pathways of exposure have required consideration:

- Incidental direct soil ingestion
- Dermal absorption
- Uptake by plants in the human food chain
- Leaching by infiltrating rainwater leading to contamination of shallow water table aquifer
- Groundwater or surface run-off discharge to surface water bodies supporting a fishery
- Resuspension of contaminated soil particles to the atmosphere by wind erosion or mechanical entrainment associated with earth moving activities

Consequently, the assumptions related to exposure via the processes and the uncertainty associated with procedures used to quantify these processes, become critical issues in determining acceptable levels of residual soil contamination.

Importance of Land Use Scenario

The land use issue can be investigated with reference to these processes by contrasting the assumptions involved for a residential land use scenario vs. an alternative land use. Consider a hypothetical example: rural land now used for lumber production has been determined to be contaminated. Assume it has been estimated that the contaminants may persist in soils for 50 to 200 years. If the existing land use is maintained for that period, then the exposure potential is very low. Workers involved in lumbering will be exposed to soil contamination via dust inhalation, incidental direct soil ingestion and dermal absorption. Small[9] recommended the use of 10 mg/m^3 as a reference exposure level for this situation. Since levels higher than 15 mg/m^3 are not permitted in the workplace, this is a useful conservative estimate. Actual levels may be much lower. Depending on the importance of this pathway relative to others, a more realistic estimate considering level of activity, soils and climatic factors may be warranted. Exposure to airborne dust also depends on the pulmonary ventilation rate. Data are presented in Anderson, *et al.*[1] and Small.[9]

Adults probably ingest very little soil. Soil ingestion occurs as a result of contamination of food and food wrappers, dirt on hands (especially prior to eating) and ingestion of inhaled particles trapped in the upper respiratory tracts. Definitive data on typical or extreme rates of soil ingestion among adults are not available. Small[9] recommends the use of 100 mg/day, an estimate consistent with Ford and Gurba[4] recommendations. Although there is very little basis for this estimate, it is commonly used. General support for the estimate relates to studies of juvenile soil ingestion that indicate ingestion rates from 100 to 1,000 mg/day.[2] It is generally accepted that most adults ingest less soil than most children.

A basis for estimating dermal absorption exposure to contaminated soils was presented recently by Layton, *et al.*[6] Their analysis indicates that it is conservative to assume that adults are exposed to the contamination contained in 43 mg of soil per day via this exposure pathway. Alternative approaches to estimating dermal absorption are available, but few address the details of absorption from contaminated soils, so the Layton, *et al.*[6] method is a useful basis for screening level analysis.

The information presented above may be combined to estimate the total dose experienced by the individual as follows:

Incidental Ingestion		Airborne Dust	Dermal Absorption

$$\text{Dose} = [0.1\ \text{g/day} + 17\ \text{m}^3/\text{day}\ (0.01\ \text{g/m}^3 + 0.043\ \text{g/day}]C_{soil} \quad (1)$$

Expressed in terms of the soil concentration:

$$\text{Dose}\ (\mu\text{g/day}) = 0.31\ \text{g/day} \times C_{soil}\ \mu\text{g/g} \quad (2)$$

To determine the acceptable soil concentration, ACS, we simply require that the actual dose be less than or equal to the acceptable dose:

$$\text{Dose} = 0.31\ \text{g/day} \times \text{ACS} \leq \text{Acceptable Dose} \quad (3)$$

$$\text{implying ACS} \leq \frac{\text{Acceptable Dose}}{0.31\ \text{g/day}} \quad (4)$$

To complete the hypothetical example, insert an acceptable dose for a 70 kg adult of 2,000 μg/day. Then the acceptable soil concentration is 6,450 μg/g.

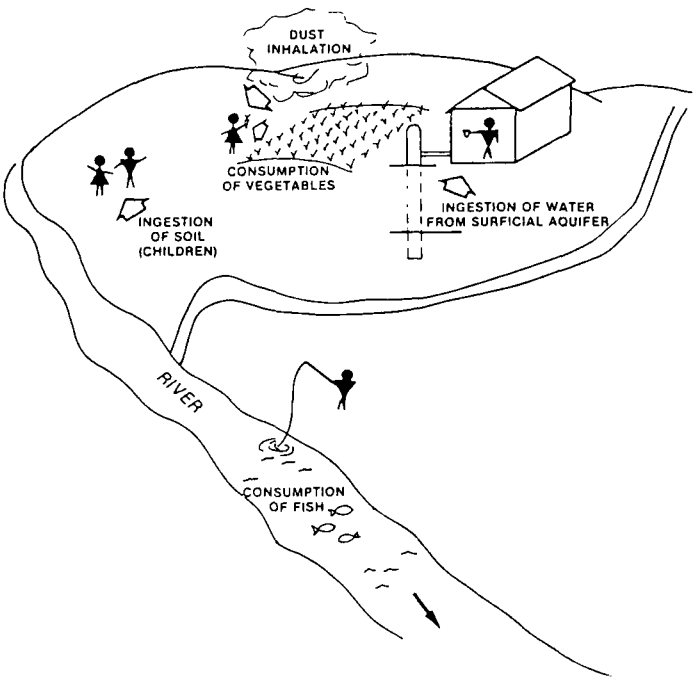

Figure 3
Characteristic Elements of a Residential Land Use Scenario

The recommended residual contamination level would have to be much lower if it were anticipated that the land would be developed residentially. Figure 3 illustrates some of the exposure pathways operating under a residential land use. It must be assumed that children may spend most of their time playing on contaminated ground. Subsurface contamination can be exposed during normal residential landscaping which also may resuspend dust into the air. Families may derive a significant fraction of their diet from a backyard garden. The residential water supply may be derived from shallow individual wells, depending on local hydrogeologic conditions and the availability of community water supplies. These factors can lead to substantially higher exposure, especially for children.

Assume that the population at risk is children ages 1 to 3 having a typical body weight of 12.5 kg. Their acceptable daily dose for the (same) contaminant would be 350 μg/day. Based on the data presented by Binder, *et al.*,[3] it seems likely that the average child ingests 100 to 200 mg of soil per day and a value of 150 mg/day will be used in this sample calculation. Kolbye, *et al.*[4] provide estimates that a 2-year-old ingests 0.4 l/day of water and 125 g of potatoes and other vegetables per day (20 g/day, dry weight); while Layton, *et al.*[5] estimate that a child is exposed to the contamination found in 41 mg of soil per day, by the dermal absorption route. These exposure factors will account for the major exposure pathways to children in a residential setting. To relate these exposure factors back to the soil concentration, it is necessary to establish the relationship between soil concentrations and: (1) plant concentrations (plant bioconcentration factor) and (2) groundwater/drinking water concentrations.

The best method for estimating plant bioconcentration factors will depend on the combination of contaminant and plant(s) and the data available for that combination. Assume that Small's[6] guidance has been used to indicate that plant concentration on a dry weight basis will be approximately five times soil concentration.

Groundwater/drinking water concentrations may or may not be related to soil concentrations. However, if the shallow water table aquifer yields water of acceptable quality and quantity for residential potable use, then it usually would be assumed to be the source of drinking water. Further, and for the sake of simplicity in this example, if the contaminated land is situated at a groundwater divide, then the quality of water in the wells will be similar to the quality of the soil solution in equilibrium with the contaminated soils. Then the concentration in drinking water will be:

$$C_w^{mg/l} = \frac{C_{soil}\ \mu g/g}{K_d} \qquad (5)$$

where: K_d is the adsorption coefficient. Assume that $K_d = 125$ for the contaminant in site soils. Combining this information for the various pathways, the total dose for the 1-3 year old children comprising the population at risk can be calculated in proportion to the soil concentration.

$$\text{Dose} = \underset{\text{ingestion}}{C_{soil}\,(0.15\ g/day} + \underset{\text{water}}{0.4\ l/day\ \frac{1,000}{kd}} + \underset{\text{vegetables}}{20\ g/day \times 5} \times \underset{\text{absorption}}{0.041\ g\ day)} \qquad (6)$$

Expressed in terms of the soil concentration:

$$\text{Dose}\ (\mu g/day) = 103\ C_{soil}\ (\mu g/g)$$

97% of the dose (100/103) is calculated to come from the garden vegetable pathway.

To calculate an acceptable soil concentration (ACS), the dose must be less than the acceptable dose.

$$\text{Dose} = 105\ g/day\ C_{soil} \leq 350\ \mu g/day$$

$$ACS \leq 3.4\ \mu g/g$$

Comparing this value with the ACS for the lumber production land uses scenario (ACS $\leq$ 6,450 μg/g), it is seen that the land use scenario assumption can affect the recommended soil criterion by more than three orders of magnitude. This degree of sensitivity to assumptions is apparently at least as important as the uncertainty regarding toxic effects and quantitative carcinogenic risk assessment procedures.

Refinement of Exposure Factors/ Reduction of Uncertainties

The results of any predictive method, such as the one presented here, always will be uncertain. In multimedia exposure and risk assessment, the number of variables and uncertainty in each results in large uncertainties. A traditional response to uncertainties in environmental assessment has been a reliance on conservative estimates. The true situation is unknown, but estimates and decisions are based on extremely adverse assumptions.

The simple predictive methods presented in the examples above can be refined by acquisition of more data or application of more sophisticated predictive methods. As the estimates become more reliable, the degree of conservatism can be reduced. This process usually will result in a less stringent, yet more firmly based, recommendation.

As an example, consider the basis for estimating inhalation exposure for the lumber production scenario. It was assumed that air concentration of dust that had been stirred up from contaminated areas could be as high as 10 mg/m³. The basis for that estimate was conservative: if levels were higher, the workers would wear respirators. This estimate could be refined either by sophisticated wind erosion/fugitive dust modeling or by measuring air concentrations under the conditions of the exposure scenario. Assuming that fixed air monitors were placed in a similar, though uncontaminated area, and that personnel monitors also were employed in a 1-month study of worker exposure to nuisance dust, a more realistic dust concentration of 0.4 mg/m³ was determined. Applying this finding, the previous analysis can be refined. The dose is now estimated to be:

$$\text{Dose} = \underset{\text{ingestion}}{C_{soil}\,(0.1\ g\ day} \times \underset{\text{inhalation}}{17\ m^3\ day} \times \underset{\text{dust}}{0.0004\ g\ m^3} + \underset{\text{absorption}}{0.043\ mg\ day)} \qquad (7)$$

$$= 0.15\ mg\ day\ C_{soil}\ (\mu g/g)$$

and the acceptable soil concentration would be:

$$ACS = \frac{2,000\ \mu g\ day}{0.15\ g\ day} = 13,400\ \mu g/g$$

Such refinements almost invariably should result in a relaxation in the recommended criterion, as long as uncertainties always are resolved with a conservative assumption.

CONCLUSIONS

A method for determining safe levels of residual soils contamination as a component of the endangerment assessment process for hazardous waste sites has been presented. The method presented is based closely on the PPLV approach developed by Dr. David H. Rosenblatt and co-workers at the U.S. Army Medical Bioengineering Research and Development Laboratory, Ft. Detrick, MD.[7-9] The method has been restated here, using slightly different terminology, to illustrate its relationship to the endangerment assessment process.

Development of a hypothetical example illustrates the sensitivity of the recommended criteria to the exposure assumptions adopted, particularly those relating to the future land use of the site. The land use scenario adopted for the analysis affected the recommended acceptable soils concentration by more than three

orders of magnitude in the example problem. It is possible to construct alternative scenarios that affect the criteria by even greater amounts. Thus, uncertainty regarding future land use and the assumptions adopted in the face of that uncertainty can influence the endangerment assessment, the evaluation of the no-action alternative and the costs of remedial action just as severely as uncertainties regarding the "toxic effects/quantitative risk assessment" aspects of the problem. The exposure assumptions are readily understood and thus readily debated by all concerned parties, and so they can and should receive a thorough airing during the RI/FS. Decisions regarding appropriate future land uses for the site are quintessentially political, rather than technical decisions. Affected parties should be consulted, and these decisions should be made by regulatory authorities and/or affected parties.

The second major conclusion of the paper is based on an analysis in which one of the criteria was refined by acquisition of additional data. This allowed a more realistic analysis and the discarding of an excessively conservative assumption. More sophisticated theoretical analysis frequently can achieve a similar result. To develop criteria in the face of great uncertainties, it frequently is prudent to adopt conservative assumptions. This affords the decision-maker the certainty that the criterion level is safe and that concentrations below the criterion do not pose an unacceptable risk. The converse, however, is untrue: levels above the derived criteria are not necessarily unsafe. The refinement of estimates presented bears this out: with a conservative assumption, applied in lieu of site-specific data, it was determined that soils having 6,450 μg/g of contaminant "X" were "safe" and presented no endangerment. Upon acquisition of additional data, it became apparent that soils as high as 13,400 μg/g can be left in place. This does not contradict the previous analysis. Before acquisition of the new data, the analysis indicated that 6,450 μg/g was a safe level. The new analysis confirms this conclusion. Generally, the public and their representatives interpret results of this type to mean that soil contamination at 6,500 μg/g, or any level above 6,450 μg/g, is harmful. Drawing this interpretation from the conservative analysis would be inappropriate and should be avoided.

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Objective Quantification of Sampling Adequacy and Soil Contaminant Levels Around Point Sources Using Geostatistics

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ABSTRACT

This paper describes the events and conclusions resulting from a study focused on two lead smelters within the Dallas city limits. These smelters were implicated as the sources of elevated concentrations of lead in the surrounding soils. The presence of high lead is of considerable concern to nearby inhabitants.

This report focuses on the application of geostatistical techniques to sampling around point sources. The application of geostatistical methods to smelter contamination had not been previously attempted. Many of the questions concerning applicability of geostatistics, geometric and spatial structure of the contaminant plume, modeling of the area, sampling strategies and generalization to future sites have been resolved. Geostatistical techniques have proven to be very useful in the resolution of these questions.

INTRODUCTION

Increased environmental awareness dictates that virtually any type of industrial "smokestack," either existing or planned, is subject to public scrutiny. Coal-burning power plants and steel mills are being blamed for acid rain problems. Other heavy metals such as uranium that are emitted from coal-powered plants also are causing concern. These emissions pose a threat to nearby plant and animal life. Insights gained from modeling heavy metal airborne contamination hopefully can improve models in these other situations or provide a starting point for understanding these unique problems.

The results and conclusions of the Dallas Lead Project have provided analytical tools and valuable insights into the nature of contamination at other locations. This information then can be applied to future modeling projects.

This paper discusses the techniques applied to the modeling of the Dallas project in detail as well as the insights that have been gained by the authors. The U.S. EPA commissioned this study as an experiment to determine applicability of geostatistical techniques in an attempt to develop more objective procedures. The following conclusions are reached in the paper:

- Geostatistical methods are very objective and effective in modeling contamination around smelters. Two separate smelters in the Dallas area have been studied. Both sites have produced excellent results and nearly identical geostatistical models indicating that other sites may follow a similar pattern.
- Geostatistical modeling has many advantages over traditional estimation techniques. Its Best Linear Unbiased Estimator (BLUE) property provides more objective answers to questions that are difficult to provide otherwise. Results of studies such as this one influence decisions in cleanup phases that affect human health and safety and should be made based on the best possible data. The results also will have significant legal ramifications and are subject to close scrutiny in courts of law. Thus the need for objectivity and reproducibility becomes increasingly important as issues enter the courtroom.
- Modeling with regionalized variable techniques permits the earth scientist to isolate different phenomena acting simultaneously within the same geographic area. Different patterns of dispersion from the smelter can be recognized and isolated from other sources. Trivial contributions from secondary sources (e.g., auto emissions) can be identified. In this way liability can be correctly assessed.
- Objective methods to determine sampling sufficiency easily can be defined. Sufficient grid sizes to model and assess the area with an acceptable level of confidence can be obtained with minimum sampling. If too many samples already have been taken, sampling can be reduced to determine sufficient levels for obtaining both variograms and desired accuracy as a starting point for future projects. The technique known as the composition of extension variances has been applied and discussed with respect to overall precision.

The results can be applied to the design of future smelters; they also provide a method of limiting liability in environmental impact situations by isolating sources; finally, the results can be used by the environmental and legal professions to further the cause of public health and safety within a framework of cost consciousness and objectiveness.

BACKGROUND: THE DALLAS LEAD PROJECT

During the last quarter of 1980, a sampling team from the University of Texas at Arlington, under contract with the U.S. EPA's regional office in Dallas, Texas, collected samples of soil, house dust, paint and tap water from a number of private residences and schools. These sample locations were situated near and in the general vicinity of two lead smelters and one battery plant in Dallas, Texas. In addition to the two smelter sites and the battery plant, a fourth site identified as the Reference area (REF) also was selected as a control area for sampling. The purpose of this initial phase of the investigation was to determine whether additional effort was warranted, i.e., did a problem exist?

All four sampling sites were located within the Dallas city limits and all except the REF site were geographically located in the city's western section. Figure 1 shows the location of the two lead smelters: RSR Corporation (RSR) and the Dixie Metal Company (DMC). General Battery Corporation (GBC) is located near the intersection of Bengal and Amelia Streets. The GBC site was not analyzed in the geostatistical portion of the study, however. The

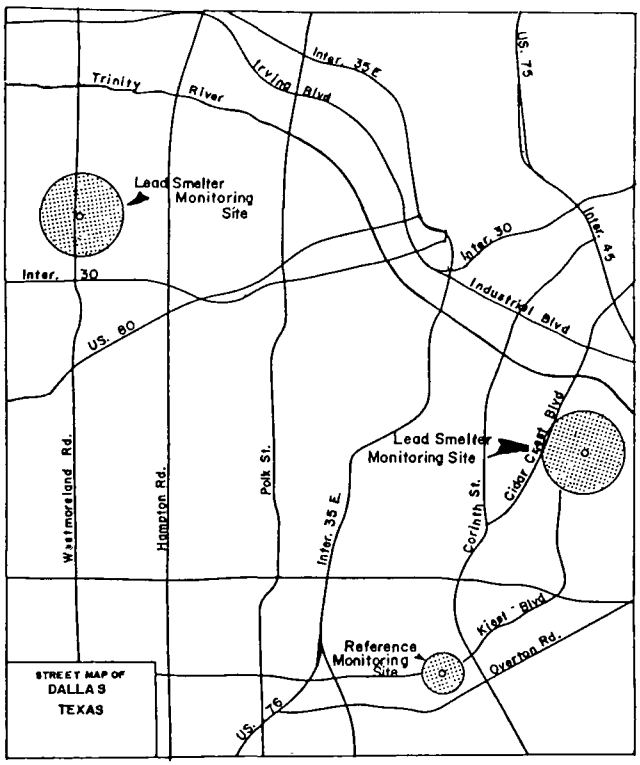

Figure 1
Location of the DMC & RSR Smelters and the Reference Area

REF site was selected for its similarity to the RSR, DMC and GBC sites in automotive emissions, population and ethnic background.

SAMPLING

Data collected by the University of Texas at Arlington have shown some soils in the immediate vicinity of the Dixie Metal Company (DMC) and the RSR Corporation (RSR) to have lead levels that exceed 1,000 ppm, believed to be the critical danger level for exposure. Due to the presumed behavior of airborne lead from smelting facilities such as these, the sampling area was confined to a 2-mile radius around each site. To better evaluate the degree of contamination of these two industrially exposed areas, a site known as the Reference area (REF) was selected.

The sampling scheme, except for the total number of samples collected in the reference area, was identical to that used at the DMC and RSR sites. In addition, a 2-mile area surrounding a third site, the General Battery Corporation (GBC), was sampled using the same scheme.

SAMPLING AND GRID DESIGN

The information collected in sampling phase 1 (20 data points) was used to construct a variogram for each of the three study areas. The calculated and recommended sampling scheme to identify the geographical extent and level of soil lead contamination for phase 2 of the project was as follows:

- The dimensions of the square grid should be 750 ft x 750 ft.
- The total area covered by the grid should be contingent upon the minimum lead concentrations of concern.
- The grid should be oriented along the axis of the plume.
- The grid used in the REF area should be identical to that used in the DMC and RSR areas.
- Soils within a radius of 100 ft of each grid intersection should be sampled using procedures identical to those described in phase 1.
- Six samples should be collected for each site to be composited into a single sample.
- Duplicate samples should be collected at 5% of the grid locations.
- Samples should be separated into three "splits" at 5% of the grid locations and sent to different laboratories.

During the summer of 1980, the U.S. EPA collected more than 3,000 individual core samples that were composited into more than 500 grid samples throughout the three study areas. These data are the foundation of the subsequent geostatistical analysis and mapping portion of the project.

STRUCTURAL ANALYSIS

Variograms of the Ln-transformed soil sample values were computed in each of the three areas. In each case, an average variogram and four directional variograms were produced. The four directional variograms have been calculated along the east-west (0°), north-south (90°), northeast-southwest (45°) and northwest-southeast (-45°) directions. For each directional variogram, an angular tolerance window of 22.5° (total width of window) around the given direction was allowed. A distance lag separation of 800 ft also was used. For the average variogram, which considers all points, the angular tolerance was 180°.

The results of the calculations were very good. Salient features of the variograms include the following:

- All the variograms show some kind of continuity between holes. They all tend to increase with distance until they reach a sill value.
- Continuity in the DMC and RSR areas shows very similar patterns when compared to the reference area. Modeled range and sill values bear this out.
- As expected, the REF area shows a much lower sill and a lesser degree of continuity.

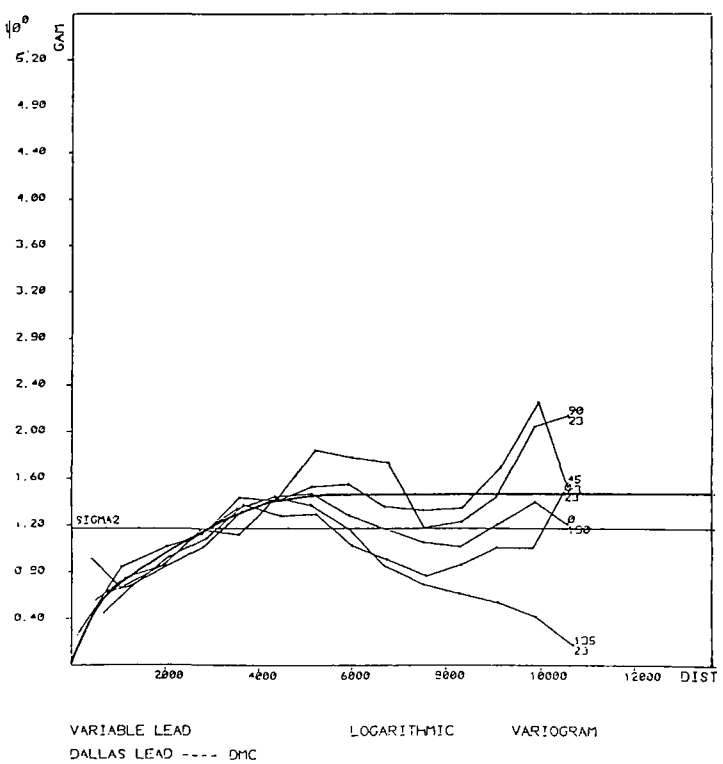

Figure 2
DMC Variograms of Ln-Transformed Lead Values for Phase 2

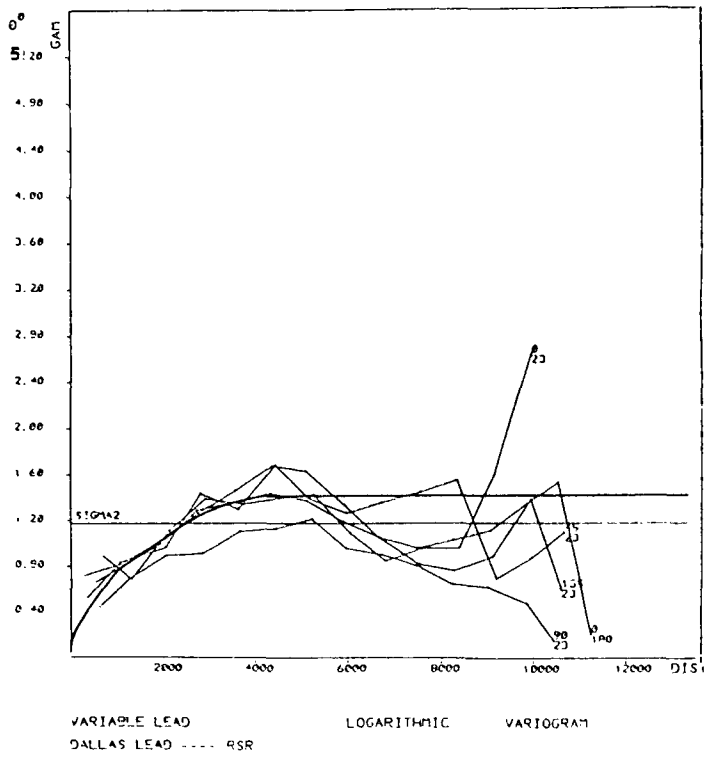

Figure 3
RSR Variograms of Ln-Transformed Lead Values for Phase 2

Isotropic spherical models have been fitted to the experimental average variogram curves. In all cases, they are the sum of a small nugget effect (calculated from the duplicate samples) and one or two spherical structures of varying ranges. The curves of the fitted models are shown as a solid line in Figures 2 to 4.

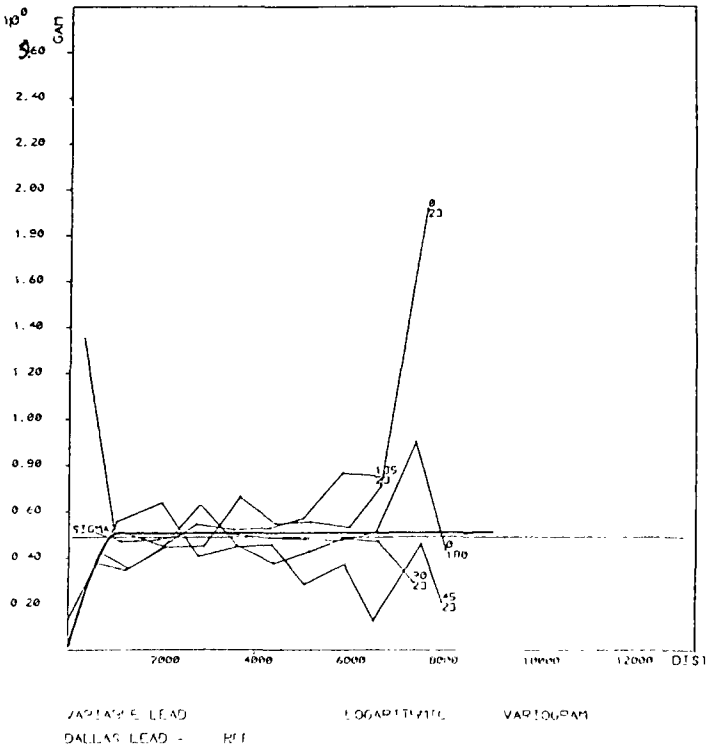

Figure 4
REF Variograms of Ln-Transformed Lead Values for Phase 2

Finally, one anticipated problem in the calculation of the variograms did not arise. This "non-problem" was the possible presence of a drift or a trend. A drift is defined in geostatistical terms to be a systematic increase or decrease in the data along given directions. This drift causes problems in the variogram. Modeling such a structure is difficult and also causes problems in the kriging process. Special forms of kriging (universal, generalized IRF) have been created just to handle this problem. Although the possibility of a drift seemed reasonable, one did not arise.

MODELING THE AREAS: KRIGING LEAD VALUES

The soil sample data were kriged in each of the three areas using their respective variograms. The kriged area has been made large enough to include three reference locations of geographic interest. These locations have been used for map orientation.

The contour maps resulting from the kriged grid are shown in Figures 5 to 7. The round symbol in the center represents the lead smelter. The contour lines show the estimated soil lead concentration in ppm. In the DMC area (Fig. 5), a highly visible concentration or plume has developed around and to the north and east of the source. The large number of concentric contours encircling the smelter shows a steep gradient of rapid change in a short distance between a low of 200 ppm outside and a high of 3,000 inside.

The effects of flooding by the Trinity River are well defined (to the north) as a distinct area of low lead concentration which can be seen along the flood plain of the river. On either side of the river, the concentrations are noticeably higher. Several possible anomalous sample values also occur to the north of the river. In at least one case a sample whose concentration was 10,400 ppm contamination was found later to have been exposed to automotive contamination.

In the RSR area, the smelter is located within the major contaminant plume that disperses rapidly east-west and more slowly north-south (Fig. 6). The southern end of the plume also contains

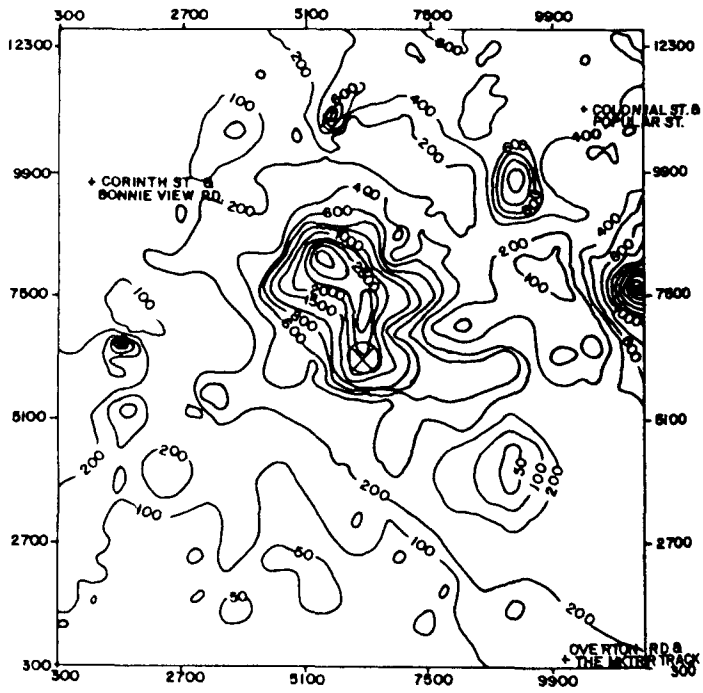

Figure 5
Isomap of Estimated Lead Values in the DMC Area

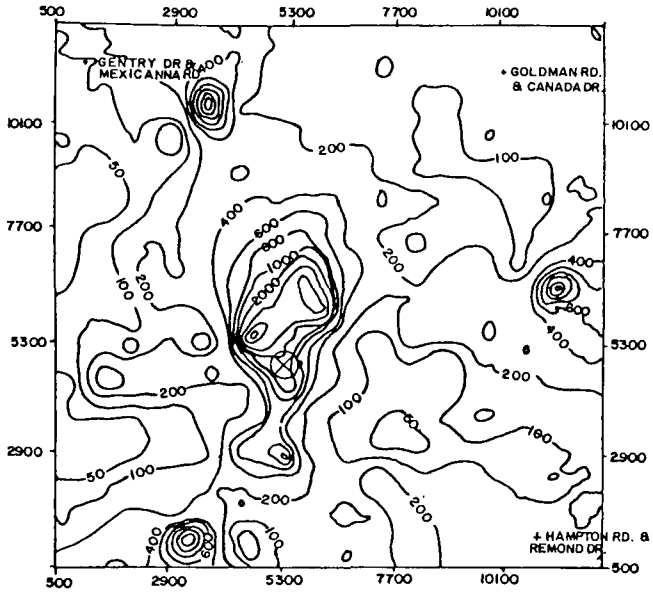

Figure 6
Isomap of Estimated Lead Values in the RSR Area

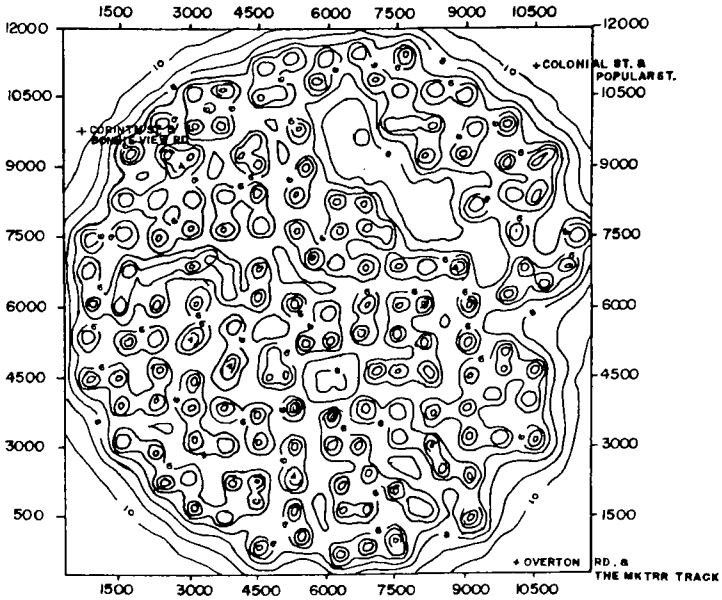

Figure 8
Isomap of the Estimation Variance in the DMC Area

a possibly anomalous value that has the effect of extending the plume in this direction. This finding suggests that the true dispersion nature of the plume is primarily north and slightly west from the smelter.

As expected, the REF area shows no systematic areas of lead concentration (Fig. 7). Local highs and lows fluctuate randomly and at considerably reduced levels overall from those seen in the DMC and RSR sites. There is no evidence to suggest that this is anything other than a background lead level map.

Accompanying each isopleth map is a second contour surface that contains isovalues for the kriging standard deviation (Figs. 8 to 10). The values shown are the logarithmic kriging deviation multiplied by a factor of ten (to facilitate plotting). The "swiss cheese" effect noted here is common for cases such as this where the sample grid spacing is a relatively large percentage of the range of the variogram. Because the quality of estimation is solely a function of geometry and the variogram, estimates are better as they approach a sample point.

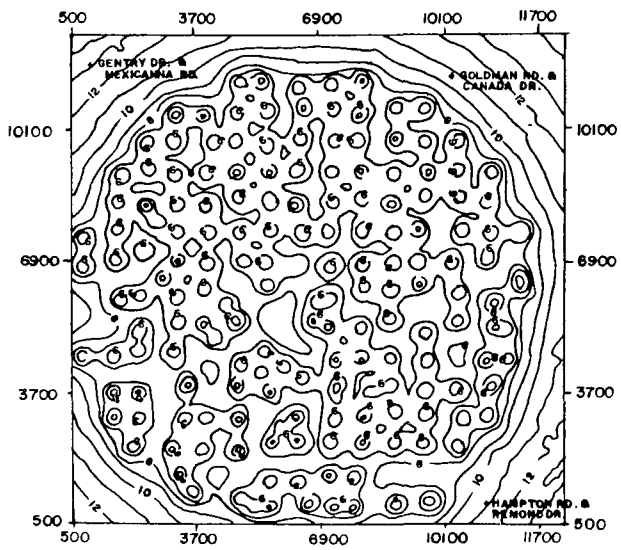

Figure 9
Isomap of the Estimation Variance in the RSR Area

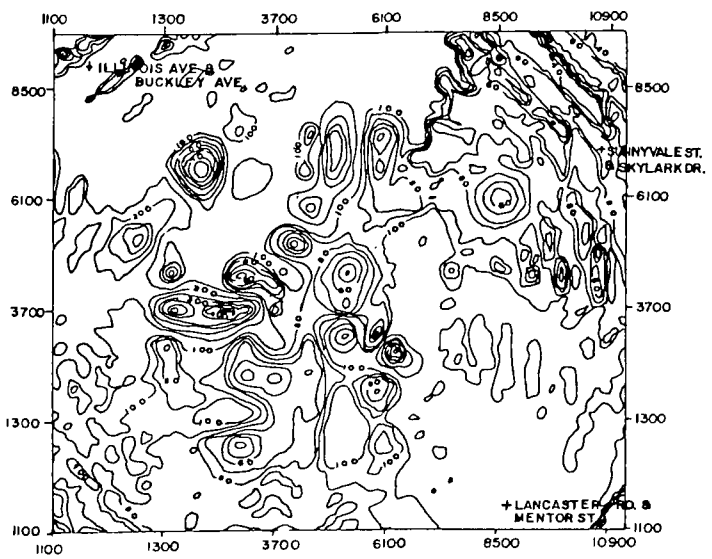

Figure 7
Isomap of Estimated Lead Values in the REF Area

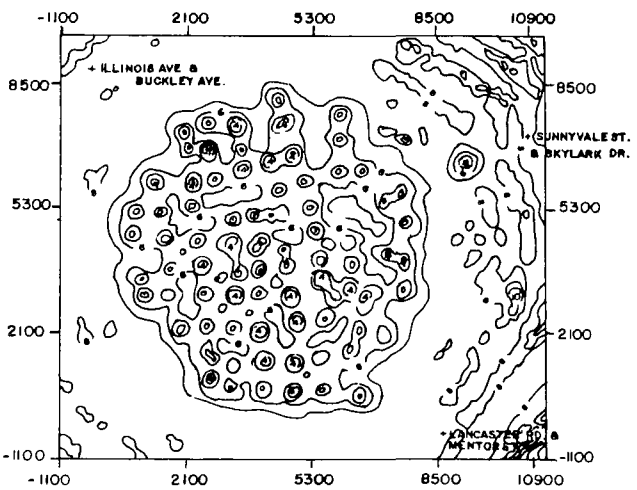

Figure 10
Isomap of the Estimation Variance in the REF Area

SAMPLING SENSITIVITY: REDUCED SAMPLE SIZES

The results of this first mapping stage proved that kriging and geostatistical techniques apply very well to soil data and point source contamination. The second stage of this study addressed the concerns of the U.S. EPA and others as to the adequacy of sampling: have enough samples been taken to assure reasonable level of certainty? Also, what changes might be made in future studies of similar phenomena? These questions will not be addressed.

The techniques used to answer these questions will be the analysis of extension variance and the use of reduced data sets to determine the effects on the variogram. The results of the preliminary geostatistical analysis provided models of the spatial continuity structure in each area through their respective variogram models. These models will now be assumed to be the "true" underlying spatial structure. The data sets of 206 and 208 samples in the DMC and RSR sites respectively will be taken as the "universe" of data.

The procedure, then, is to reduce the level of sampling in the areas of study and to recompute the variograms using a smaller data set. Multiple data sets will be produced and analyzed at each level of reduced sampling to minimize any possible selection bias. The new parameters of the variograms then will be compared to the "true" values to see how accurately the subset can predict the "real" structure. This information from small data sets can be used to design future two-phase sampling schemes.

The two smelter areas have been divided into equal sized grid cells from which one sample per cell has been taken at random. This random selection has been done by computer to eliminate human bias. Since the "true" variograms are isotropic (equal zone of influence in all directions), the sampling grids were designed to be isotropic (square) so that this relationship can be honored.

From the variograms, it is possible to quantify the variances of polygonal (block) extension errors and then combine them, since they are the variances of independent variables. This has been used as a check on total precision.

Small sample subsets were selected in both the DMC and RSR areas on grids of 11 x 11, 7 x 7, 5 x 5 and 4 x 4. These represent sample sizes of approximately 100, 50, 25 and 16 respectively. The 11 x 11 grid was selected as the first grid size with the idea that subsequent sizes would be enlarged or reduced as needed depending upon the outcome of this first attempt. Ten sample subsets were taken using the same ten random seeds in both smelter areas. The ten new data sets in each area then were variogrammed, their sample locations were plotted and their histograms were plotted.

The 20 variograms then were modeled. The results showed remarkable similarity to the original data sets both visually and in variogram parameter comparison. The results of the 11 x 11 grid data were so successful that the data set was again halved by using a 7 x 7 grid. Excellent variograms were produced although more variation was noticed in the model parameters. The RSR models tended to have a lower sill than the true one, but the ranges were generally the same as for the true model. The DMC models showed on the average the same sill but generally showed a shorter range. Because the object of this exercise was to determine sampling grid sizes from small initial data sets, the range was the most important parameter. For this grid size, both areas provided accurate ranges with the DMC models being a little more conservative.

Again the data set was halved by going to a 5 x 5 grid. At this level of sampling, the directional variograms had deteriorated to such a point that they were valueless. A lack of data was the cause. However, the average variogram still could be used to advantage as good structures still were found. Sill variance showed a much greater fluctuation, with a number of low-valued variances where sampling failed to pick up high values near the smelters. Ranges generally were shorter than the "true" ranges. This corresponded to the shorter range found in phase 1 of the sampling where only 20 samples were taken. A few very long range values did appear, but they resulted mainly from an attempt to fit a good model at short distances where the variance rose quickly for a time and then slowly crept toward the sill.

The final level of sampling was produced on a 4 x 4 grid. Again directional variograms were of no value. The sill values in the RSR area showed a large fluctuation, but the ranges were quite stable and not too far from the "true" parameters. In the DMC area, sills were generally near or above the "true" parameters and the ranges were at or below those expected. Overall, this grid produced about the same quality estimates as the 5 x 5 grid and showed slightly better stability of ranges.

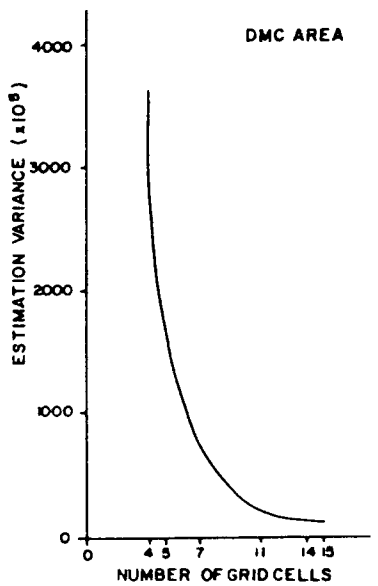

Figure 11
Global Precision vs. Sampling Density in the DMC Area

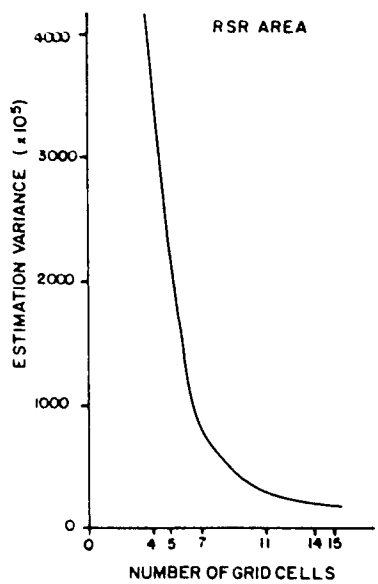

Figure 12
Global Precision vs. Sampling Density in the RSR Area

GLOBAL PRECISION

An estimate of global precision provides a measure of the certainty with which the global mean is known. This value is analogous to the "standard error of the mean" in classical statistics. In the geostatistical sense, obtaining a high value for precision of the global mean suggests that local estimates also will remain quite accurate. This condition is not strictly true in all local cases but offers a starting point for decision making.

The precision for symmetric grids of sides 4 through 15 have been calculated and have been plotted in Figures 11 and 12. The 14 x 14 and 15 x 15 intervals represent the precision when considering a full sample set of 206 or 208. The graphs show that in terms of global estimates the sampling has reached the point of diminishing returns. Both figures indicate that further sampling is unnecessary. What also is critical here is that variograms have been produced for even the smallest of data sets.

CONCLUSIONS

Geostatistical techniques have proven to be an extremely valuable tool in the analysis of pollutant contamination. A strongly identifiable plume of lead is associated with smelter source. No such structure is found in the REF area. The plume is marked by a central core of concentrated high values, generally within 1 mile of the source, with a continual decrease in lead values to the borders of the areas. It appears certain that these two smelters were indeed the source of the contamination and that automobile emissions are of negligible contribution.

The smelter areas have been adequately sampled with the 800-ft grid. The range of the variograms was five to seven times this sampling interval and proved quite sufficient to model the spatial continuity of the lead values.

Global estimates of precision for the second stage sampling campaign are very conservative and indicate that additional sampling would have been of little value. Variogram parameters remain surprisingly constant down to extremely small levels of sampling.

Two-stage sampling, though already in regular use in the environmental industry, can be greatly enhanced by the use of geostatistical technique. Optimal sampling geometries can be developed for a variety of situations and constraints. As a result, cost benefit curves can be produced to select development drilling grids. These analyses will provide a measure of confidence and objectivity.

Innovative Application of Chemical Engineering Technologies for Hazardous Waste Treatment

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ABSTRACT

Regulatory and public pressure are creating an increasing demand for more innovative methods of hazardous waste management. In response to this need, some proven technologies are being adapted to provide alternatives to the more classical remediation techniques in certain applications. This paper reviews the site-specific parameters that need to be considered before selecting one of these alternatives. The operational details of the candidate technologies are discussed, and specific examples of applications are given.

INTRODUCTION

Application of the RCRA and CERCLA statutes often creates the need for corrective action, particularly with regard to groundwater treatment and surface impoundment closure. Of particular interest to industries are the on-site treatment alternatives due to the cost and liability factors of land disposal and the lack of convenient incineration options.

This paper concentrates on proven treatment solutions available to meet the needs of corrective action situations. Particular emphasis is placed on those technologies offering the opportunity for cost-effective, on-site treatment or waste volume reduction. Included is a review of technologies utilized in mobile and/or in situ applications.

PROBLEM DEFINITION

Unfortunately, no single treatment technology is going to be universally applicable for all corrective action situations. A thorough evaluation of the site-specific parameters involved is necessary in order to choose the most technically suitable and cost-effective treatment technology for the job. Because major corrective action programs, especially those involving aquifer restorations, are likely to take several years to accomplish, the investment of time and effort to properly evaluate the situation initially will more than pay for itself in the long run.

Among the major site-specific parameters that should be defined are those discussed below.

Contaminant Composition and Concentration

An accurate analysis of the site contamination is important. The contamination could be a single component from an underground solvent storage tank leak or a wide variety of components from a disposal site leachate. The level of contamination could range from low µg/l to several hundred mg/l. The treatment costs of technologies such as carbon adsorption and oxidation are dependent on concentration and type of compound, while costs for technologies such as air stripping are more closely related to the treatment rate and desired removal efficiency.

Desired Cleanup Criteria and Effluent Disposition

Stringent cleanup criteria (e.g., drinking water standards for aqueous streams) will eliminate some technologies from consideration immediately, but it must be recognized that different levels of cleanup are likely to be required for many remedial programs. The ultimate disposition of the effluent for aqueous treatment will have significant bearing on the required effluent quality. If the treated stream can be discharged to the sewer for further treatment by a municipal waste facility (POTW), effluent guidelines are likely to be less strict than if the stream is to be recharged to an aquifer or discharged directly to a surface water source under an NPDES permit.

Volume to be Treated

Treatment volumes for remedial programs can vary widely. A small volume may be treated best by a technology with low capital costs and high operating costs, while economic remediation of a larger magnitude is more likely to be accomplished utilizing a technology with low operating costs. An evaluation of treatment options should include consideration of leasing equipment to treat small volume sources.

Fate of Treatment Byproducts

Local requirements for disposition of treatment byproducts will have a major impact on the economics and viability of various treatment technologies. Air stripping can be an extremely cost-effective technology if the organic-laden air can be emitted directly to the environment; but strict air emissions standards may require that air stripping be followed by a vapor-phase adsorption system, significantly increasing treatment costs. Similar considerations exist with the generation of potentially toxic byproducts from chemical oxidation processes and the possible need for nutrient removal (phosphorus and nitrogen) from the effluent of biological oxidation processes. The economics of activated carbon adsorption (especially on a throwaway carbon basis) can be affected by the accessibility of an approved disposal site for the contaminated carbon.

Utilities Availability and Cost

The selection of certain technologies will be influenced by the availability of utilities such as steam at the treatment site. Likewise, some processes such as UV-catalyzed oxidation can require a substantial source of electrical power. The energy-intensive processes are likely to be more attractive in the southern part of the country where electrical costs are approximately $0.05/kWh than on the West Coast where costs can approach $0.15/kWh.

A clear definition of the goals of a remedial action program along with an understanding of the above site-specific parameters

and the technical limitations of the technologies under consideration will allow selection of the most cost-effective treatment option.

TECHNICAL EVALUATION

A number of technologies are potentially applicable to remediation programs. Some are best suited for specific applications and others may be eliminated from widespread consideration because of the inability to meet stringent discharge standards or other technical limitations. In this section, the technologies with the greatest potential in remedial actions are identified and specific applications are discussed.

Incineration

Incineration, or thermal destruction, is an effective way to destroy organic liquids and sludges and organics in a solid matrix. It can be used for a relatively broad waste profile depending on the type of incineration system utilized. Incineration is defined generally as a controlled, high-temperature, oxidation reaction. The end products of the incineration reaction are generally carbon dioxide and water from hydrocarbon wastes; but industrial and hazardous wastes also can generate hydrogen chloride, sulfur dioxide and less desirable combustion byproducts depending on the nature of the wastes, the operating features of the specific incineration system and the compatibility of the waste profile and incineration system.

The technology of high-temperature incineration is in widespread use, both at private and commercial installations. It often is considered in remedial action alternative evaluations, but the waste volume must be substantial to justify the expense of permitting and building an on-site unit. For more limited volumes, commercial incineration facilities offer the advantage of destruction of the wastes involved.

Thermal Desorption

Thermal desorption removes organic chemicals from soil and solids by heating the soils to temperatures sufficient to convert the organics to vapors and then holding the soil at that elevated temperature long enough for the removal process to occur. Desorbed organic and water vapors can be recovered by solvent scrubbing or condensed and collected in an accumulator where the water and organics are separated into their respective phases. Water can be treated with activated carbon before discharge, while the organics phase can be sent to a commercial incinerator or treated chemically or photolytically.

Thermal desorption is effective for any organic contaminant, with more volatile compounds such as solvents, being more readily removed. The types of compounds for which this technology is expected to be applicable range from chlorinated solvents and gasoline/fuel components to phenols, aromatic hydrocarbons, PCBs and dioxin. The concentration of the contaminant does not have a significant influence on the applicability. Although the soil characteristics will impact the operating rate and process design requirements, thermal desorption is amenable to a wide range of soil/site conditions.

IT has developed and demonstrated thermal desorption in bench scale and pilot scale equipment. Laboratory testing has been performed on a variety of soil types containing such chemicals as Agent Orange (containing chlorinated dioxins), pentachlorophenol and creosote materials (PNAs). Pilot scale work, conducted as part of the Air Force's Environmental Restoration Program, will be reported at an upcoming American Chemical Society meeting.[1] Briefly, a pilot plant was assembled to treat up to 100 lb/hr of soil contaminated with 2,3,7,8 TCDD from Agent Orange. The desorber was operated at 460 to 560 °C. The vaporized contaminants were captured by a solvent scrubber and destroyed in a UV photolysis reactor. Soil analysis showed a greater than 99% reduction in the TCDD concentration and residual soil concentrations of less than 1 ppb.

The thermal desorption process offers several advantages, as compared to thermal oxidation, for decontamination of organically contaminated soil. These advantages include lower temperature operation resulting in less energy consumption and simpler design criteria, relative ease of regulatory approval due to classification as a physical/chemical treatment process and the ability to easily skid or truck mount the equipment for mobile treatment.

UV Photolysis

Ultraviolet light can catalyze normal chemical oxidations by creating a supply of "free radical" species. IT has applied this technology to the destruction of dioxin at the Syntex Agribusiness plant in Springfield, Missouri.[2] The dioxin destroyed was in a distillation residue which was a byproduct of previous production of hexachlorophene by the Northeast Pharmaceutical Company. The process involved extraction of dioxin from the residue using a common solvent and then destruction of the dioxin in reactors equipped with 10-kW, high intensity ultraviolet lamps. Approximately 13 lb of dioxin were destroyed using this process.

Chemical/Biological Oxidation

Oxidation technologies use chemical or biological means to completely oxidize organic contaminants to carbon dioxide and water, or partially oxidize them to non-toxic intermediates. Most of the oxidation options are best suited to specific applications.

Chemical oxidation accomplishes detoxification of waste streams through the addition of chemical oxidation agents. Nearly all chemical oxidation processes use either chlorine or oxygen as the oxidizing agent.

Chlorine oxidation is of questionable value in most remedial applications because of the difficulty in assessing the impact of potentially toxic chlorinated byproducts. Oxygen itself has very limited effectiveness but may be of use in the form of ozone or hydrogen peroxide.

As an example of an application of chemical oxidation, IT has utilized hydrogen peroxide to successfully treat a sizeable spill of formaldehyde. The spill resulted from a leak in an underground pipeline and had contaminated both the subsurface soil and the groundwater. Because the spill contamination was below a shipping and receiving area, common cleanup techniques involving excavation would have caused an expensive disruption of plant operation. Instead the formaldehyde was chemically oxidized in situ by injecting a hydrogen peroxide solution into the contaminated zones. Formaldehyde contamination levels in the soil, originally as high as 8% (80,000 ppm), were reduced to 15 ppm or less by this method.

Biological oxidation uses active microorganisms to biodegrade organics to acceptable forms. The two major forms of biological treatment are aerobic (which produces carbon dioxide and water) and anaerobic (which produces carbon dioxide and methane). Biological treatment is getting increased attention as a remedial alternative because of its potential for in situ treatment. Bioreclamation basically is the use of indigenous soil bacteria to degrade organic contaminants. Nutrients, such as oxygen, and specific biological cultures can be added to enhance the degradation.

Vandalism of a rail car parked on a railroad siding in Ukiah, California resulted in an opportunity for the application of biological oxidation to an emergency situation. Twenty thousand gallons of a strong formaldehyde solution drained from the rail

car into and through the rail-track ballast and into the associated drainage system. Initial efforts focused on containing and isolating the spill.

Once the spill had been controlled, the more difficult task of decontamination of the affected area was addressed. The railway company was vary concerned that normal excavation procedures would disrupt rail service on the adjacent mainline track. Thus, IT developed an alternative approach which initially involved treatment of the area with alkaline hydrogen peroxide. This chemical oxidation process was successful in reducing the formaldehyde concentrations to a level where biological oxidation could be used.

The biological process made use of a portable aeration tank, a spray system and the railroad ballast itself. Liquid was pumped from a sump dug next to the ballast, passed through the aeration tank and sprayed back onto the ballast. The system was inoculated with a specially cultured microorganism that degraded formaldehyde but was free of pathogens. The ballast, being composed of coarse rock, supported the growth of the biological medium in a manner similar to a trickling filter. Nutrients were added to the system as needed. Over a 25-day period, the system successfully reduced the formaldehyde concentration from several hundred ppm to less than 1 ppm.[3]

Carbon Adsorption

The use of activated carbon adsorption for aquifer restoration programs has drawn widespread attention. Several literature sources point to its ability to achieve exceptionally good effluent quality, and the U.S. EPA has endorsed it as the preferred treatment method for meeting drinking water standards. This section discusses three basic ways in which carbon can be used:

- Throwaway carbon
- Thermal regeneration
- Nondestructive regeneration

Throwaway Carbon

One way to consistently ensure good effluent quality is to use activated carbon absorption on a once-through carbon basis. Virgin carbon is capable of removing a broad range of organic contaminants to low ug/l levels. A once-through carbon adsorption system is easy to operate, requires a minimum of operator attention and its capital cost requirements are relatively low.

Unfortunately, carbon replacement costs associated with once-through carbon adsorption systems are very high. The large treatment volumes and/or high concentrations usually associated with remedial programs result in a high carbon consumption rate. In addition, hazardous substances, when loaded onto activated carbon, make the carbon a hazardous waste, requiring disposal in an approved hazardous waste facility.

Thermal Regeneration

The most common regeneration technique for activated carbon is thermal oxidation, usually accomplished in a multiple hearth, fluidized-bed or rotary-kiln furnace. A thermal regeneration unit can be built at the treatment site, but the level of carbon consumption associated with most remedial programs usually makes it more economical to utilize an off-site thermal regeneration service.

The advantages of activated carbon adsorption with a thermal regeneration service are low capital requirement and ease of operation, as with throwaway carbon, but the disadvantages of thermal regeneration are numerous. Using a thermal regeneration service basically amounts to "renting" the carbon. However, in many cases, the cost per pound of carbon for thermal regeneration is only slightly less than that for purchasing virgin carbon. Additionally, carbon losses associated with thermal regeneration are typically 5 to 10% per cycle due to handling losses and carbon that is destroyed during the regeneration process. However, thermally regenerated carbon can be expected to have different performance characteristics and reduced removal efficiency as compared to virgin carbon.

A major problem associated with thermal regeneration is that many hazardous substances cannot be thermally regenerated for one reason or another. Because the hazardous substances are desorbed from the carbon and destroyed in an afterburner during thermal regeneration, air permits for thermal regeneration systems often contain restrictions on the types of materials that may be accepted. Consequently, thermal regenerators often refuse to deal with carbon that has been used to adsorb toxic materials such as PCBs.

Nondestructive Regeneration

There are three basic ways that granular activated carbon can be nondestructively regenerated:

- Using pH shift for weak acids or bases
- Using steam for volatile organics
- Using a solvent for a wider variety of organics

Steam regeneration, which would be applicable in many remedial situations, is accomplished by passing steam through a spent adsorber to a condenser and then to a decanter where the condensate and immiscible organics are separated. Carbon losses associated with nondestructive regeneration are significantly less than those associated with thermal regeneration. The carbon is not physically altered by the nondestructive regeneration process, and if the carbon adsorbers are made of the proper material, the regeneration can be accomplished in situ, eliminating carbon handling losses.

The process is relatively easy to operate and the nondestructive nature of the process allows organic recovery, if desired. Even if recovery is not desired, the disposal requirements are reduced from several thousand pounds of contaminated carbon to a few gallons of organic material.

IT has evaluated the applicability of carbon adsorption systems with nondestructive regeneration in a variety of remedial situations. A recent feasibility study compared air stripping, air stripping with vapor-phase adsorption, adsorption using virgin carbon, adsorption using steam-regenerated carbon, steam stripping and chemical oxidation using UV peroxide for an aquifer restoration. The critical design parameters were: a contaminated groundwater concentration of 30 mg/l or halocarbons including EDB (1,2-dibromoethane); a maximum flow of 200 gal/min and an average flow of 100 gal/min; and a mandated effluent concentration of <1 µg/l of each halocarbon present.[4]

Details on the result of this evaluation can be found in the referenced paper. Based on these design parameters, the costs of air stripping and steam-regenerated carbon adsorption were basically equal and fell in the range of $300-400/day of system operation. Subsequent laboratory work, using samples of the actual groundwater, verified that carbon adsorption with steam regeneration could achieve acceptable effluent quality and maintain a stable working adsorption capacity.

Laboratory evaluation of the air stripping option was postponed until the issue of exhausting the vaporized organics to the atmosphere could be resolved. This issue is frequently a restriction in the application of air stripping.

Air Stripping

Air stripping is a contaminant removal technique based on concentration differentials between a liquid phase and a contacting gas phase. As air is contacted with a wastewater stream in a stripping tower, the concentration differential drives the organic con-

taminant from the liquid to the gas phase. The major advantage of air stripping is its low overall treatment cost. Both capital and operating costs requirements are low compared to most other technologies.

The key to air stripping's low overall treatment cost is the assumption that it can stand alone as a treatment technology. In many cases, however, air emission standards will require that air stripping be used in conjunction with a vapor-phase adsorption unit, significantly affecting the cost-effectiveness of the technology.

Air stripping is most applicable to compounds of a volatile nature with relatively low solubility in water. Chlorinated organics such as trichloroethylene, 1,1,1 trichloroethane and aromatic compounds such as benzene and toluene are good examples of chemicals that can be successfully removed by air stripping. The overall applicability of the technology can be expanded to compounds with lower Henry's law constants by preheating the water prior to its entering the stripping column.

IT has evaluated air stripping a number of times in treatability evaluations for a wide variety of clients. In a study conducted for the American Petroleum Institute, IT engineers conducted side-by-side, bench-scale evaluations of air stripping and carbon adsorption with steam regeneration to remove dissolved gasoline components from groundwater.[5] Air stripping effectively removed the aromatic gasoline components from groundwater even at the normal groundwater temperature of 50°F. However, as would be expected, air stripping was ineffective in removing more soluble components of gasoline such as tert-butyl alcohol.

MOBILE TREATMENT

As the expense and regulatory limitations of waste disposal become increasingly important factors, the innovative option of mobile, on-site treatment has become an important remedial alternative. Many of the technologies described above can be, and have been, adapted to mobile applications.

The U.S. EPA and a limited number of commercial firms currently operate mobile incineration systems. A number of aqueous treatment technologies have been mobilized for on-site remediation including activated carbon, air stripping and ion exchange. In addition, mobile equipment is available to dewater sludges and reduce the volume of material that ultimately must be sent to disposal or destruction facilities. These options include mobile centrifuge and mobile belt filter press equipment.

CONCLUSIONS

A number of technologies exist and have been proven in remedial action situations. Experienced, knowledgeable personnel in the hazardous waste field are able to efficiently evaluate options for corrective action programs, but, in order to do so properly, they must evaluate the site-specific parameters involved and fully understand the constraints, options and goals of the program.

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Field Studies of In Situ Extraction and Soil-Based Microbial Treatment of an Industrial Sludge Lagoon

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ABSTRACT

Over a period in excess of 10 years, several industrial sludges were disposed of by landfilling in a surface impoundment. The resulting lagoon contains more than 30,000 yd^3 of sludge. Leachate from the sludges has impacted the local groundwater, thus requiring remediation. Laboratory studies indicated that in situ extraction with aqueous sodium hydroxide is a viable method for removal of organic materials from the sludges. Treatment of recovered extract was accomplished through use of a soil-based microbial treatment system. Sequential aerobic and anaerobic biodegradation in the laboratory reduced TOC by greater than 99.5%.

A field, pilot-scale treatment system has been designed, constructed and operated to demonstrate feasibility of the proposed renovation program. Field results indicate that exhaustive extraction of the sludges is possible. Up to a 50-fold increase in the rate of removal of contaminants over natural processes can be achieved. Biodegradation treatment efficiencies in excess of 95% have been demonstrated.

INTRODUCTION

Over a decade or more, several sludges were disposed of by landfilling in a surface impoundment. During this period of operation, the composition and rate of deposition of sludges varied. The resulting lagoon contains more than 30,000 yd^3 of sludge. The principal sludges in the lagoon are primary (lime neutralized) and secondary (biological) sludges from treatment of effluent from diverse chemical manufacturing operations. The sludges range from solid to gelatinous in physical state and are layered in the lagoon. Leachate from the sludges has impacted the local groundwater.

Cleanup of the lagoon is viewed as two interrelated problems. The first problem is the removal of contaminants from the lagoon without major excavation. The second problem is treatment of the stream containing the stripped contaminants, including both organic and inorganic species. To achieve these goals, a process consisting of in situ extraction of the sludges followed by on-site treatment of recovered extract has been developed.

Laboratory results have indicated that exhaustive leaching of the sludges with an alkaline aqueous extractant (sodium hydroxide) is possible.[1] Natural leachate and the sludge extracts can be treated effectively for total organic carbon (TOC) removal through use of a soil-based aerobic/anaerobic microbial treatment process employing an acclimated mixed microbial population in a soil matrix.[2] Aerobic biodegradation occurs near the soil surface where oxygen is available. Anaerobic biodegradation occurs at greater depths. Conversion of organic solutes to carbon dioxide and methane is the ultimate result. Treatment efficiencies in excess of 99% were attained.[1]

Preliminary design estimates for implementation of these processes indicated that renovation of the lagoon could be accelerated to a period of less than 5 years with substantial cost reductions compared to traditional treatment technology. Thus, a field pilot plant was designed, constructed and operated for demonstration of the process.

PILOT-PLANT DESIGN

The pilot system consisted of several sequential process steps (Fig. 1). The first process step is the extraction of sludges present in a representative section of the lagoon. Sodium hydroxide solution is mixed batch-wise in a 200 gal process tank (Tank 1). This solution is applied to sludges present in the Extraction Bed. The solution either can be applied to the surface of the Extraction Bed through perforated pipe or injected into the sludges through six well-points. Extract is recovered from the Extraction Bed through Wells 1 and 2. Extract removed from each well is pumped through a basket strainer and cartridge filter and into a 1,000 gal storage tank (Tank 2).

The second process step is adjustment of pH, dilution if necessary and addition of nutrients to extract stored in Tank 2. This process occurs as a continuous process in Tank 3 which is a 200 gal process tank, divided into four equal sections by two overflow baffles and one underflow baffle. Extract is pumped from Tank 2 to the first chamber of Tank 3. Carbon dioxide is bubbled through the extract to adjust the pH to between 7.0 and 7.5. Extract passes under an underflow baffle to the second chamber of Tank 3. In the second chamber, floc created by the recarbonation process is allowed to settle. Clarified extract passes over an overflow baffle into the third chamber of Tank 3. In the third chamber, dilution with recycle or potable water and addition of nutrients occurs. Finally, extract underflows into the fourth chamber from which it overflows and is applied to the surface of the Treatment Bed.

The third process step is treatment of the modified extract (effluent from Tank 3) through an aerobic/anaerobic soil-based microbial treatment process. The treatment process consists of a soil bed in which an aerobic microbial population is maintained in the upper region and an anaerobic microbial population is maintained in the lower region.[2] Extract applied to the surface of the Treatment Bed percolates through the soil bed where it is biodegraded. Effluent from the Treatment Bed is recovered through Well 3. Recovered effluent is pumped to a 500 gal storage tank (Tank 4) from which it can be recycled onto the Treatment Bed, recycled to Tank 1 or discharged.

The entire process was designed to be sufficiently flexible to compensate for fluctuations in either the extraction or treatment processes as well as weather conditions. Ranges of expected conditions and flow rates for each process step are presented in Table 1.

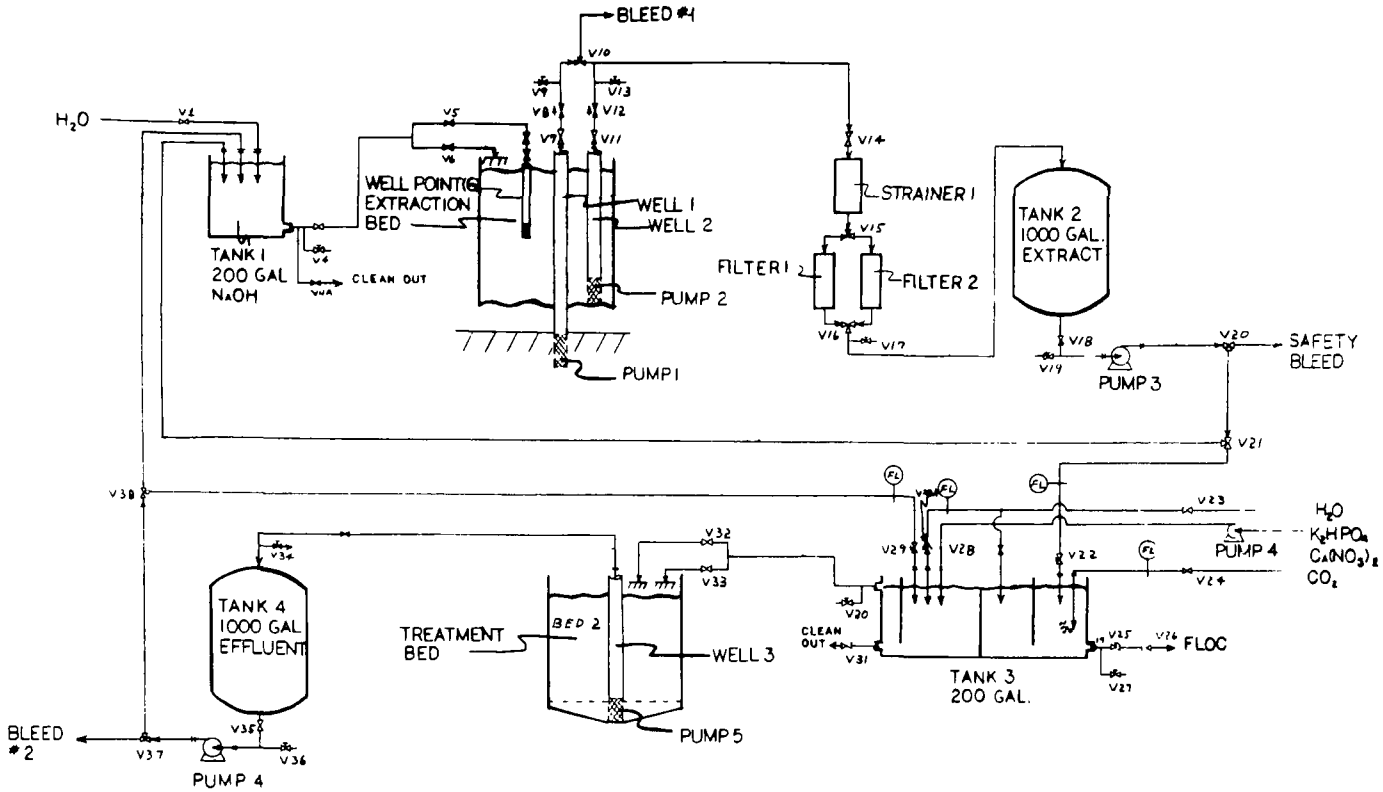

Figure 1
Process Flow Diagram for Extraction of Organics from Sludges

Table 1
Expected Process Conditions and Flow Rates

	pH		TOC (mg/l)	TDS (mg/l)	Volume (l/day)
Extraction Bed					
Influent	7	13	< 100	< 4000	< 1000
Effluent	7	12	<15000	<30000	< 1000
Treatment Bed					
Influent	7.0	7.5	<5000	---	< 500
Effluent	5	8	< 100	---	< 500

Table 2
Boring Log for Well 1

Depth (ft)	Observations
0- 2	Black sludge, dry
2- 4	Black sludge, dry
4- 6	Upper 6 in. black sludge and fill; lower 4 in. mixed brown and gray sludges
6- 8	Mixed brown and black sludge
8-10	Upper 1 ft brown sludge with gray mixed; lower 1 ft black and brown sludge mixed
10-12	Mixed fill, black and brown sludge, some soil
12-14	Brown and gray sludge
14-16	Upper 10 in. brown and gray sludge; lower 14 in. orange shale

Extraction Bed Design

The Extraction Bed was designed to test in situ extraction of the sludges present in the lagoon. A representative 10 × 10 ft section of the lagoon was isolated from the remainder of the lagoon by interlocking, water-tight steel sheet piling (Fig. 2). This sheet piling extends from approximately 2 ft above the lagoon surface to approximately 1 ft into the lagoon bottom.

Initially, extractant was applied to the surface of the Extraction Bed through two parallel 1-in. perforated PVC pipes. Subsequently, extractant has been injected into the sludges present within the Extraction Bed through six 2-in. diameter, 24-in. long screened well-points. The well-points are located on radii approximately 3 ft from Wells 1 and 2 and screened at a depth of approximately 11 to 13 ft from the lagoon surface (Fig. 2).

Extract is recovered from the Extraction Bed through Wells 1 and 2. Each well was constructed from a 6-in. diameter PVC casing with a 2-ft long, 100-slot stainless steel screen. Well 1 was screened approximately 1-ft into the bottom of the lagoon. Well 2 was screened near the bottom of the sludge within a deposit of secondary sludge. During the drilling of Well 1, continuous split spoon samples were taken; results are presented in Table 2. A stainless steel deep well pump, a low water level sensor and a high water level sensor are located within each well. Extract recovered from each well is pumped through a basket strainer and a cartridge filter and into Tank 2.

Treatment Bed Design

The Treatment Bed was constructed immediately adjacent to the Extraction Bed. The perimeter of the Treatment Bed consists of steel sheet piling interlocked with the sheet piling of the Extraction Bed (Fig. 2). Sludge within the perimeter of the sheet piling was excavated to a depth of 8 ft and removed to an alternate location within the lagoon. The inside of the sheet piling and the bottom of the resulting pit were lined with 0.5-in. plywood. Six inches of sand were placed on the bottom, and the entire pit was lined with a continuous PVC liner. Six inches of sand were also placed inside the liner, and a 6-in. diameter well (Well 3) was

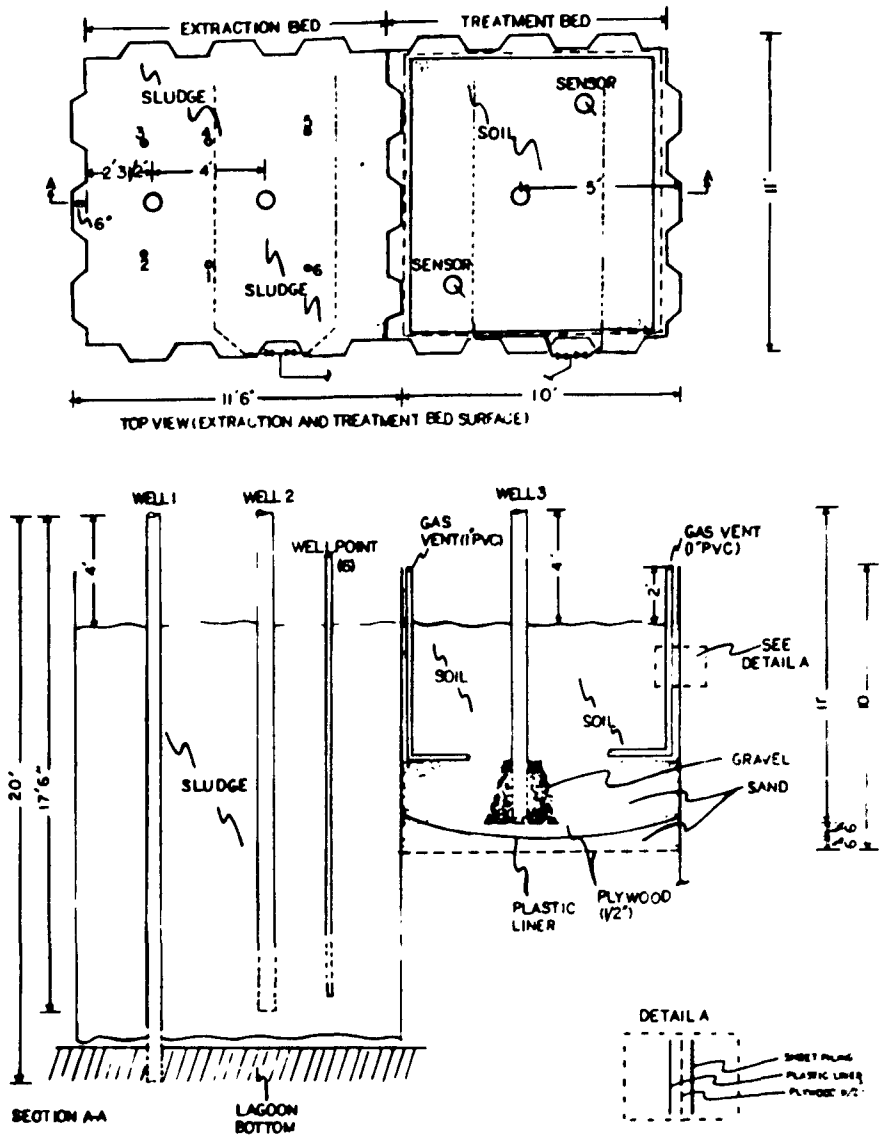

Figure 2
Extraction and Treatment Bed Construction

placed in the center. An additional 2 ft of sand were backfilled around the well. Two 1-in. methane vents were installed on top of the sand, and the remainder of the bed was backfilled with 5 ft of soil mixture.

The soil mixture used to backfill the Treatment Bed consisted of local top soil, sand and granular activated carbon 15:1:1 by volume, respectively. The soil mixture was mixed on-site by a bucket loader prior to backfilling.

Modified extract is applied to the surface of the Treatment Bed through two 0.5-in. perforated PVC pipes. Two water level sensors are located on the surface of the bed to prevent flooding. Effluent from the process is collected through Well 3 which contains a stainless steep deep well pump, a low water level sensor and a high water level sensor. Water collected from Well 3 is pumped directly to Tank 4.

Process Area Design

The Process Area consists of a 30 × 35-ft compound located on top of shale fill approximately 100 ft east of the Extraction and Treatment Beds at an elevation of approximately 10 ft above the surface of the lagoon (Figs. 3 and 4). Tanks 1, 2, 3 and 4, a storage shed for CO_2 cylinders and nutrient solution, electrical power supply and controls, a wash basin and safety shower are located within the compound.

Interconnections between tanks and the Extraction and Treatment Beds consist of PVC solvent-cemented pipe. All piping, where possible, is buried in shallow trenches approximately 1 ft deep and backfilled with top soil. The surface of the compound is covered with roadstone.

Process Controls

The process controls consist of four operationally independent controllers. Three of the controls are identical units, i.e., one pump controller each for Wells 1, 2 and 3. The well pump controls are a high water level sensor and a low water level sensor (float switches) in each well. Liquid rising to the level of the high water level sensor activates the pump in that well. When the liquid level falls below the level of the low water level sensor, the pump is deactivated. The actual operating time of each pump is accumulated on a timer located on the control panel.

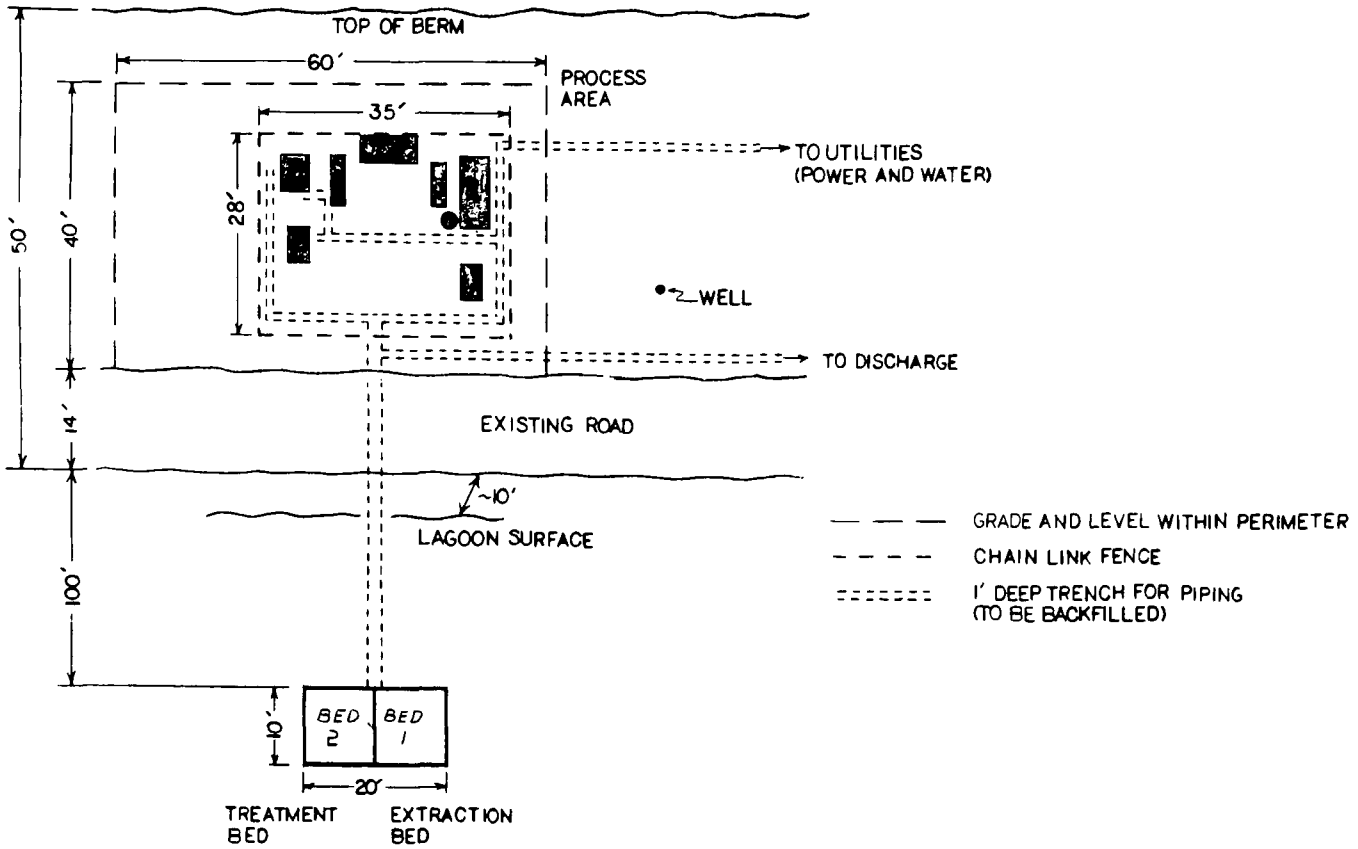

Figure 3
Pilot Plant Layout

The fourth controller controls operation of pumps, valves and sensors associated with Tanks 2, 3 and 4 and sensors on the surface of the Treatment Bed. Tank 1 is operated manually, only. The primary function of the fourth controller is to regulate application of influent to the Treatment Bed. A master 24 hr/7 day timer regulates operation cycles for application. When set on automatic, the controller will activate whichever of the Tank 2, 3 and 4 valve and pump combinations are set on automatic during the preset cycle. These combinations include:

- The actuation valve and pump on Tank 2 (extract feed to Tank 3 or Tank 1)
- The actuation valve and pump on Tank 4 (recycle to the third chamber of Tank 3, Tank 1 or discharge)
- The valve controlling potable water for dilution in the third chamber of Tank 3
- The pump for addition of nutrients to the third chamber of Tank 3
- The valve controlling recarbonation in the first chamber of Tank 3
- The valve controlling floc removal from Tank 3

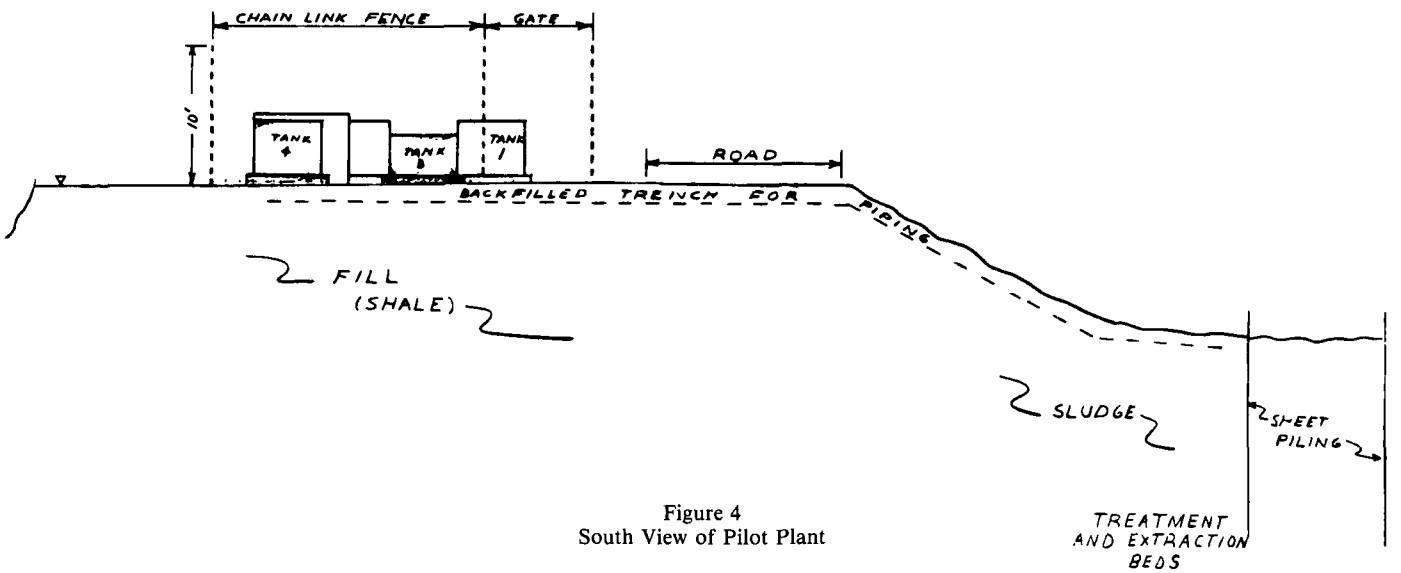

Figure 4
South View of Pilot Plant

The system will be shut off when set on automatic when:

- A sensor on the surface of the Treatment Bed indicates flooding
- A sensor in Tank 2 or 4 indicates the tank is empty, if the valve/pump combination for that tank is set on automatic
- An application cycle is completed

In addition, each pump and valve combination can be activated or deactivated manually. The system includes accumulating timers to monitor operating time for each pump in the system. A main power disconnect is provided for this controller, also.

PILOT-PLANT CONSTRUCTION

Construction of the pilot-plant began in May 1985. Brush was cleared from the surface of the lagoon in the area proposed for placement of the Extraction and Treatment Beds. Approximately 1-2 ft of cover were scraped from the lagoon surface. The resulting surface was leveled. In addition, an area on top of shale fill on the eastern portion of the lagoon was leveled for placement of the Process Area.

Wells 1 and 2 were installed on May 24 and 25, 1985. Three borings were conducted before an appropriate location for placement of the Extraction Bed was found. It was considered important to locate the Extraction Bed in a section of the lagoon that was filled continuously with sludges rather than in an area containing semi-continuous lenses of shale fill. Sheet piling was installed around Wells 1 and 2 between June 10 and 13, 1985. Construction and water batching of the pilot-plant was completed on July 15, 1985.

PILOT-PLANT OPERATION

The pilot-plant has been inspected either daily or every second day during operation. Field crews consist of at least two trained workers. Routine maintenance and inspection of the pilot-plant includes:

- Recording of elapsed time on the control timers for each pump
- Recording of the liquid levels in Tanks 2 and 4
- Visual inspection of the Extraction and Treatment Beds
- Measurement of the water level elevation in Wells 1, 2 and 3
- Mixing NaOH solution in Tank 1 and feeding the Extraction Bed, if required
- Adjusting feed stream controls and timers for Tank 3
- Sampling Wells 1, 2 and 3, and Tanks 2, 3 and 4 at times required

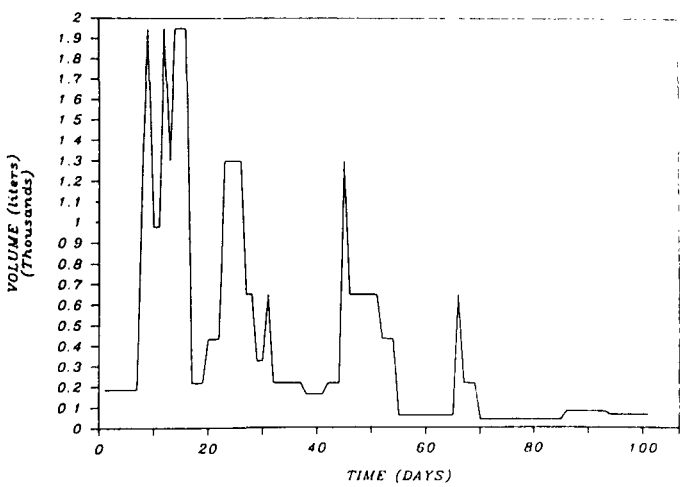

Figure 5
Extraction Bed Influent Volume

Routine maintenance and inspection usually requires 1 to 2 hours of site work per day.

Extraction Bed Operation

Recovery of leachate from Wells 1 and 2 began on July 17, 1985. Application of potable water to the surface of the Extraction Bed began on July 23. The purpose of the potable water addition was to test the application system from Tank 1 and the hydraulic response of the Extraction Bed. It was indicated that the apparent hydraulic response of the bed was greater than several days.

On July 31, influent to the Extraction Bed was changed to 0.005 N NaOH. Throughout August, low infiltration and recovery rates of extractant were observed (Figs. 5 and 6). Ponding frequently occurred at the sludge surface. In response to this problem, six well-points were installed in the Extraction Bed to effect subsurface injection of extractant. Installation of the well-points was completed on August 30 (Day 40). Subsequently, sodium hydroxide solution was injected through the well-points and applied to the surface of the Extraction Bed. Substantial increases in extract recovery were observed (Fig. 6). On Sept. 19 (Day 60), influent to the bed was increased in strength to 0.1 N NaOH. This change was made in an attempt to increase TOC concentration and quantity of extract recovered. Recent data indicate the permeability of the Extraction Bed is increasing.

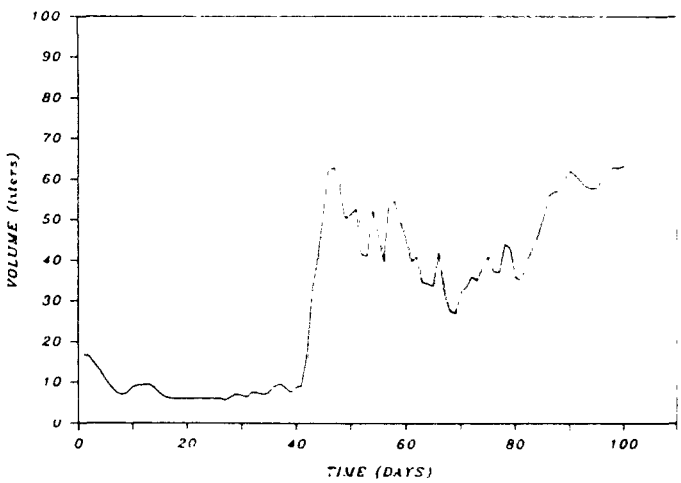

Figure 6
Extraction Bed Effluent Volume

Treatment Bed Operation

Addition of potable water to the Treatment Bed surface began on July 15. This application continued until field status of the soil system was established. On July 19, influent to the Treatment Bed was changed to a nutrient solution containing dextrose as the primary carbon source (Table 3). Inoculation with an activated sludge culture occurred on July 24.

Table 3
Makeup of Nutrient Solution Applied Beginning July 19

50	g/l	Dextrose
8	g/l	NH_4Cl
45	g/l	$Ca(NO_3)_2 \cdot 4H_2O$
0.3	g/l	K_2HPO_4

This solution is diluted approximately 100:1 in Tank 3

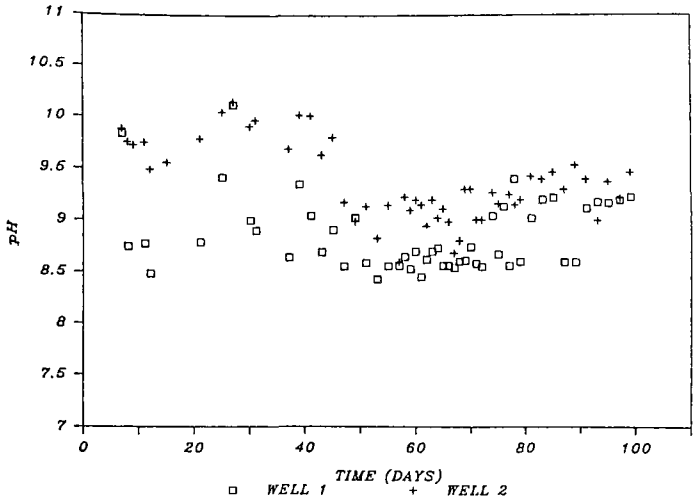

Figure 7
Extraction Bed Well 1 and 2 (pH)

Operation with nutrient solution as influent continued until adequate quantities of extract for treatment had been accumulated in Tank 2. Treatment of extract began on Sept. 13. The target TOC concentration for influent to the Treatment Bed (effluent from Tank 3) was 1,000 mg/l. The nutrient solution composition during this phase of operation included 45 g/l $Ca(NO_3)_2$ and 0.3 g/l K_2HPO_4. This solution was diluted by a factor of approximately 100:1 in Tank 3. The target influent rate to the Treatment Bed during this phase of operation was 1 in./day. The typical application cycle was 4 hr/day.

On Oct. 17, the flows to Tank 3 were adjusted to the target Treatment Bed influent TOC of 2,000 mg/l. The target influent rate of application was reduced to 0.5 in./day. These changes were made so that operation at a similar mass loading with a different hydraulic flux and influent concentration could be examined. Target flow and concentration were difficult to control because of variability in water pressure.

RESULTS

Extraction Bed

Influent and effluent volumes for the Extraction Bed are presented in Figures 5 and 6. Initially, influent volumes exceeded the volume recovered through Wells 1 and 2 by considerable amounts. These differences are attributed to several factors. Initially, the Extraction Bed was unsaturated and a large volume of liquid was required to saturate the sludges. Leading to the difference between the two flows were losses through the joints of the sheet piling. Although the area for leakage was considered small, a significant hydraulic gradient may have existed across the joints. Losses through the Extraction Bed bottom also accounted for more liquid loss.

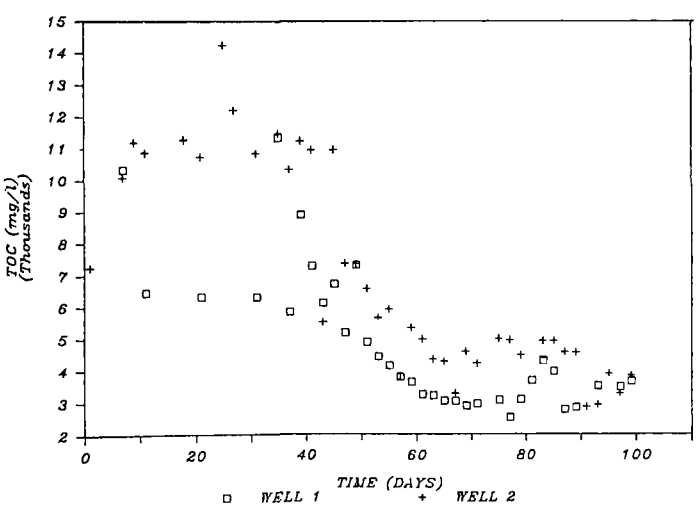

Figure 8
Extraction Bed Well 1 and 2 (TOC)

Recently, increases in the volume of extract recovered from Wells 1 and 2 have been observed. These increases correlate closely to the installation of the well-points for subsurface injection of extractant. Additional increases have been observed, most likely the result of increased sludge permeability occurring from the addition of more concentrated sodium hydroxide solution. Current influent application rates are approximately 0.5 in./day; current effluent recovery rates are approximately 0.3 in./day. Both influent application rates and effluent recovery rates are increasing. During the interval between Days 60 and 100, extract recovery was approximately 60%.

Effluent pH, TOC and TDS for the Extraction Bed are presented in Figures 7, 8 and 9. Initially, all three quantities were high. The TOC and TDS of extract recovered from Well 2 were approximately 11,000 mg/l and 28,000 mg/l, respectively; the pH was 10. However, all three parameters decreased between Days 40 and 60. On Day 60, the TOC and TDS of extract recovered from Well 2 were 5,200 and 11,000, respectively; the pH was 9.2. Initial high pH and TDS values are attributed to lime previously applied to the sludges in the Extraction Bed. Decreases in these parameters between Days 40 and 60 are considered to be the result of the lime dissolution and removal from the sludges.

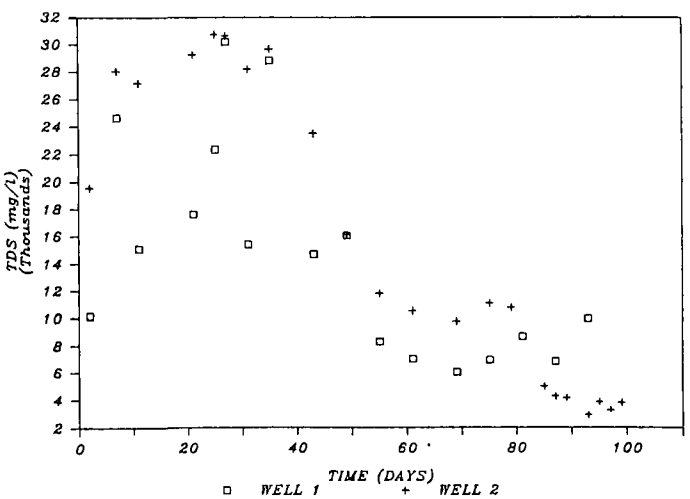

Figure 9
Extraction Bed Well 1 and 2 (TDS)

Treatment Bed

Extract was accumulated in Tank 2 until a sufficient quantity was available to operate Tank 3 and the Treatment Bed. Effluent pH, TOC and TDS values from Tank 3 are presented in Figures 11, 12 and 13. These values represent the influent to the Treatment Bed, also. Operation of Tank 3 was controlled to maintain an effluent pH between 7.0 and 7.5

Influent and effluent volumes for the Treatment Bed are presented in Figure 14. These figures are not corrected for rainfall and evaporation. Hydraulic response has been rapid, and recovery of influent has been almost quantitative throughout the period of operation. Decreases in volumetric flux after Day 70 are

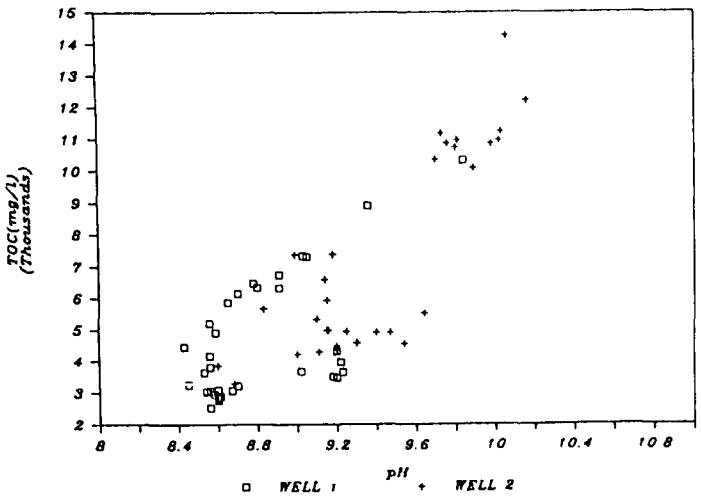

Figure 10
Extraction Bed - Well 1 and 2

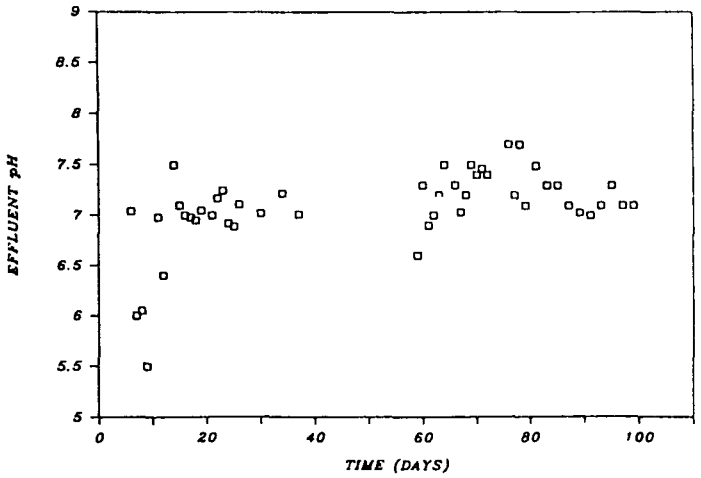

Figure 11
Nutrient Tank - Tank 3

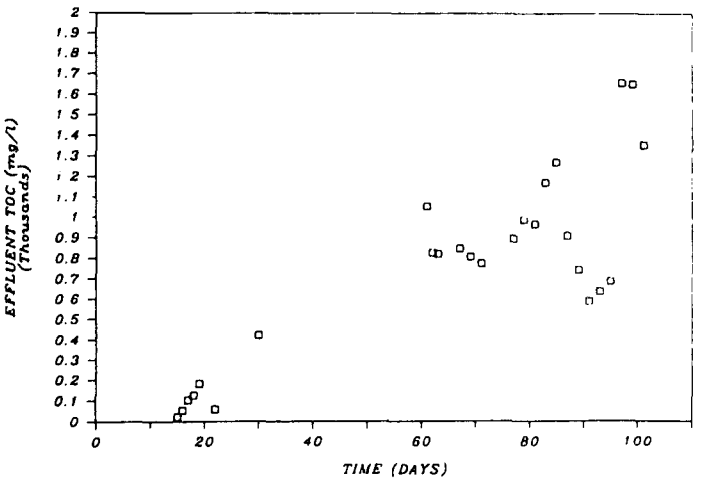

Figure 12
Nutrient Tank Tank 3 (to Treatment Bed)

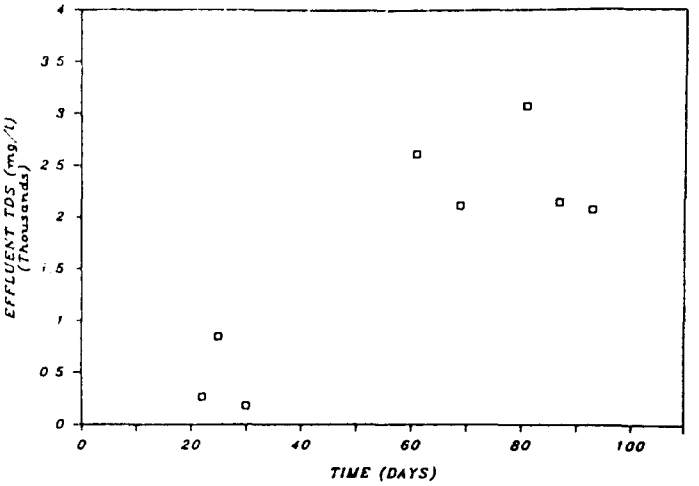

Figure 13
Nutrient Tank Tank 3

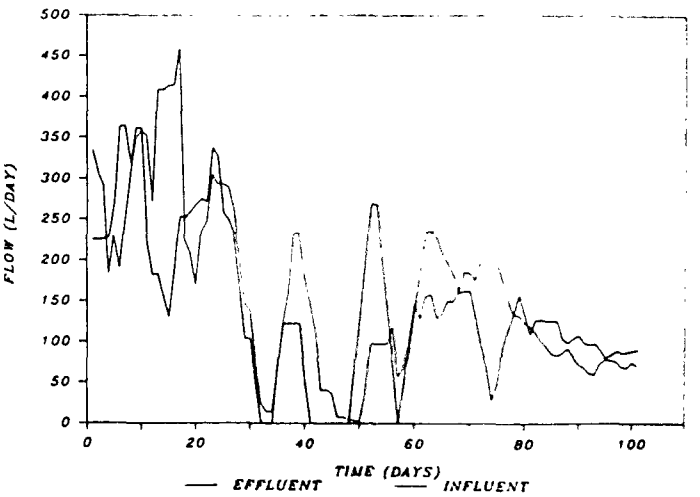

Figure 14
Treatment Bed (5-Day Avg.)

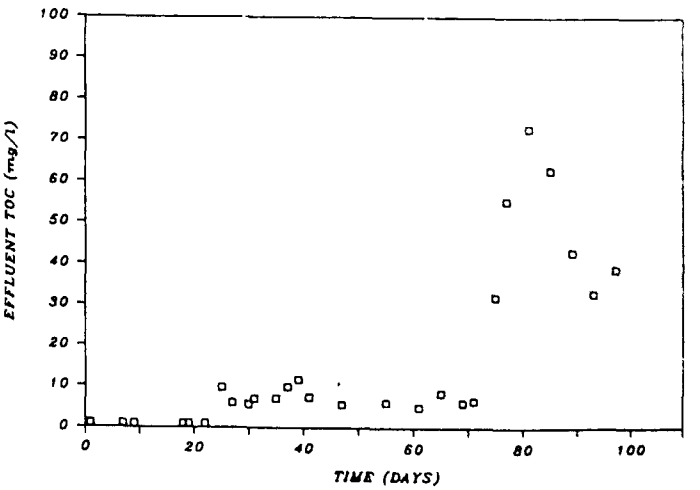

Figure 15
Treatment Bed - Well 3 (Effluent TOC)

attributed to development of the microbial population and modification of the target application rate to 0.5 in./day. Significant rainfall occurred during this period, also.

Effluent TOC for the Treatment Bed is presented in Figure 15. The peak observed between Days 70 and 90 is the response expected during development and acclimation of the microbial

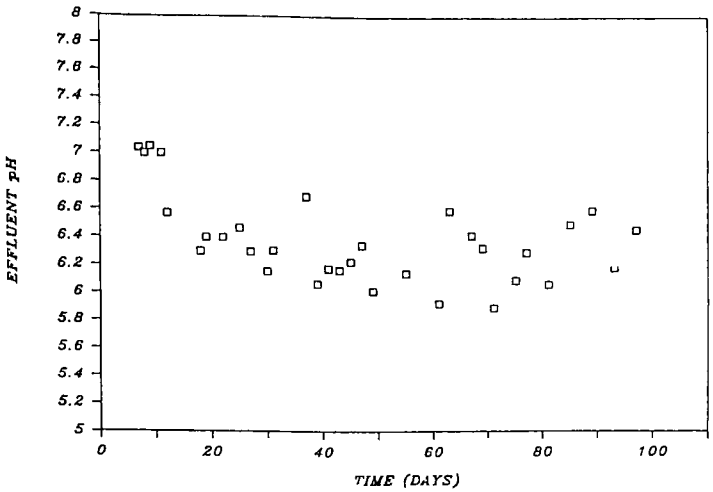

Figure 16
Treatment Bed Well 3 (Effluent pH)

population. This peak was accompanied by a decrease and subsequent increase in effluent pH (Fig. 16). This variation in pH also was an expected response of the system. Both phenomena were observed in previous laboratory column experiments.

Throughout operation, process effluent pH was between 6 and 8 and effluent TOC and TDS were less than 50 mg/l and 900 mg/l.

CONCLUSIONS

A pilot-plant to demonstrate a state-of-the-art process for cleanup of an industrial sludge lagoon has been designed, constructed and operated successfully for a period of over 100 days. The cleanup process consists of two coupled treatment steps. The first step is removal of contaminants from the sludges through in situ extraction with aqueous sodium hydroxide. Extractant is injected into the sludges through well-points or applied to the surface through a perforated pipe distribution network. Extract is recovered by means of two wells screened near the bottom of the sludge deposits. Operation of this system indicates that up to a 15-fold increase in removal efficiency, over natural processes, can be obtained through increased extract concentration. An additional 4-fold increase in the rate of renovation is obtained through increased hydraulic flux through the sludges.

Extract recovered from the sludges is treated for removal of TOC through a soil-based sequential aerobic/anaerobic microbial treatment system. Treatment occurs on-site, immediately adjacent to the extraction process. A diverse, mixed microbial population is developed in the soil system. Neutralized extract is applied to the surface of the Treatment Bed and allowed to percolate through the soil system. Aerobic and anaerobic microbial processes metabolize organic contaminants to carbon dioxide and methane. Treatment efficiencies in excess of 95% have been demonstrated.

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Cleanup of Contaminated Soils and Groundwater Using Biological Techniques

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ABSTRACT

On-site biological cleanup following spills of biodegradable hazardous organic compounds in lagoon, soil and groundwater environments is a cost-effective technique when proper engineering controls are applied. Biodegrdation of hazardous organic contaminants by microorganisms minimizes liability by converting toxic reactants into harmless end products.

The two case histories presented in this paper describe:

- Bench-scale evaluation of the potential for biological cleanup in the spill site matrix
- Field implementation of biological cleanup systems

O.H. Materials Co. has performed biological cleanups of spilled substances since 1978 when a railroad incident resulted in spillage of acrylonitrile. Subsequent biological environmental restoration projects have included additional acrylonitrile spills and cleanup of other materials such as methylene chloride, methylethylketone, crude oil, petroleum hydrocarbons, butylcellosolve, ethylacrylate, n-butylacrylate, toluene, styrene, acetone, isopropanol, tetrahydrofuran and various phenolics.

Cost-effectiveness, minimal disturbance to existing operations, on-site destruction of spilled contaminants and permanence of the solution are several of the advantages identified for implementing biodegradation as a technique for spill cleanup and environmental restoration.

TREATMENT OF METHYLENE CHLORIDE-CONTAMINATED GROUNDWATER

Many current and emerging technologies are available for the on-site removal of groundwater contaminants. For cost-effective cleanup following spills of hazardous organic materials, combinations of treatment alternatives often are employed.

The case history presented here describes the physical and biological treatment of methylene chloride-contaminated groundwater following rupture of an underground pipeline. After 2 months of field operation, air stripping techniques provided an estimated 97% reduction in the concentration of methylene chloride in the groundwater. In a downgradient monitoring well located within 20 ft of the pipeline break, the methylene chloride concentration was reduced from 9,300 mg/l to 300 mg/ by the end of the second month.

Since it became increasingly difficult to remove the residual methylene chloride from the groundwater by physical treatment methods, biological techniques were initiated. Biological treatment, using adapted microbial strains, was implemented by the end of the third month and achieved an estimated 97% reduction of the residual methylene chloride in groundwater. After 4 months of field operation, greater than a 99.9% reduction in the concentration of methylene chloride was attained.

On Aug. 16, 1983, it was discovered that a buried methylene chloride line, located in proximity to a water main, had ruptured and an undetermined amount of methylene chloride had leaked into the soil and groundwater. Following discovery of the methylene chloride leak, OHM was summoned to conduct an emergency response site investigation. Free product was collected first and staged in vessels for eventual on-site treatment. Monitoring wells that were installed established that the contamination was within a confining clay layer at the 20-ft level and did not reach the aquifer located at 100 ft. Monitoring wells were utilized to identify the contaminant plume, and pumping techniques were employed to contain the spilled methylene chloride.

Emergency response to the spill involved only containment. An investigative phase was initiated immediately to examine various alternatives for environmentally restoring the site once the spill was contained. Several alternatives were considered, including: excavation and disposal; physical containment; and biological techniques. After reviewing the alternatives, it was determined that a combination of the alternatives would be the most beneficial for site remediation.

Following removal of 160 yd^3 of highly contaminated soil to a Class A secure landfill, positive placement and suction lift techniques were implemented. Air stripping was used to remove methylene chloride from the recovered groundwater. When it became increasingly difficult to remove methylene chloride from the groundwater, biological techniques utilizing adapted microorganisms were employed.

Physical Treatment

Air stripping was selected as the preferred treatment technology for removing methylene chloride from the recovered groundwater. This decision was based on several important factors. The first factor was OHM's documentation of the strippability of this compound in past emergency and remedial cleanup operations. Second, the regulatory agencies did not require the implementation of vapor phase scrubbing units to cleanse the air emissions from aeration devices. Finally, unlike granular activated carbon, the use of air stripping is generally maintenance-free, and regeneration and/or disposal of contaminated media is not necessary.

Bench-Scale Evaluation

Characterization and bench-scale testing of recovered groundwater was performed prior to final selection of the packed column air stripping treatment alternative. Among the wastestream parameters characterized were:

- Influent concentration of volatile organic(s)
- Presence of phased product(s)
- Hardness and alkalinity

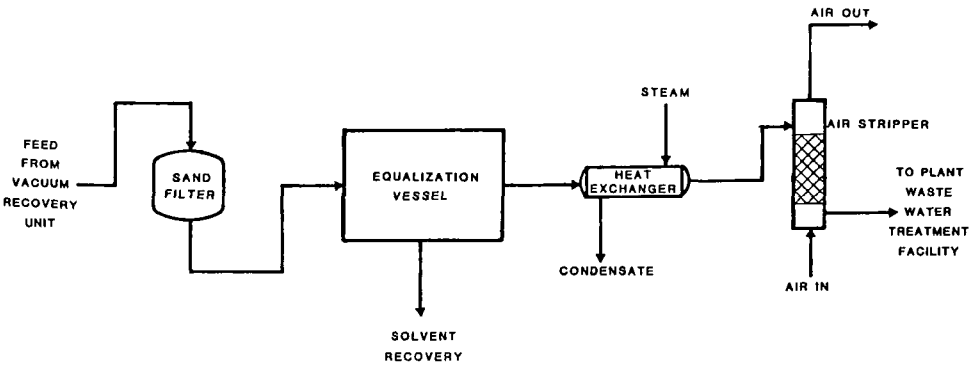

Figure 1
Physical Treatment System Schematic for Methylene Chloride-Contaminated Groundwater

- Suspended solids concentration
- Scale-forming tendency at influent pH

Characterizing these parameters determined if pretreatment was necessary prior to implementation of the primary treatment process. A particular primary treatment process may be cost-effective, but the pretreatment costs may render the process cost-prohibitive.

Methylene chloride was obtained when the groundwater was initially pumped from several monitoring wells. The recovered groundwater often had a murky brown color with visible particulate matter that slowly settled with the heavier-than-water methylene chloride.

Following the separation of methylene chloride (by phase separation) from recovered groundwater in quart jar samples, the supernatant was analyzed for methylene chloride concentration. The methylene chloride concentration approached the accepted limit of solubility at ambient temperature.

Dilling *et al.*[7] calculated the volatilization rate of methylene chloride for concentrations ranging from several hundred to several thousand mg/l from the liquid-air interface in open laboratory vessels. OHM assumed that similar volatilization rates of methylene chloride would occur in process settling chambers following gravity separation. OHM also assumed that the action of system pumps and surface winds blowing over water surfaces into open vessels would result in even greater rates of volatilization. Evaluations of the remedial alternatives were based upon those assumptions.

Field Implementation

Figure 1 is a schematic of the treatment system designed to treat groundwater at a rate of 10 to 15 gal/min. The recovered groundwater was pumped through a mixed-media filter bed to remove sand and other particulate matter. Three types of porous media were used in this filter: (1) anthracite, (2) silica sand and (3) pea gravel, with the sand placed above the gravel and the anthracite above the sand. This media configuration provided a large pore size near the filter surface to capture particulates with a relatively low head loss. Smaller sized particles were trapped in the lower sand layer.

Groundwater leaving the mixed-media filter bed was piped to an equalization vessel having a residence time of 14 hr. This vessel was basically a rectangular holding tank which allowed the denser methylene chloride to separate from the water by gravity. The vessel was equipped with sludge collection equipment to remove accumulated solids and float controls in the last chamber to maintain a constant flow to the next treatment step.

Liquid from the equalization vessel was then pumped through a skid-mounted shell and tube heat exchanger to raise the temperature of the water from 10 °C to more than 40 °C. The heated water was then pumped to the top of the air stripping column for removal of soluble methylene chloride.

Data collected during the project demonstrated that methylene chloride, as pure product, settled in the equalization vessel together with fines and other particulate matter that were not trapped by the mixed-media filter. While the total volume of the

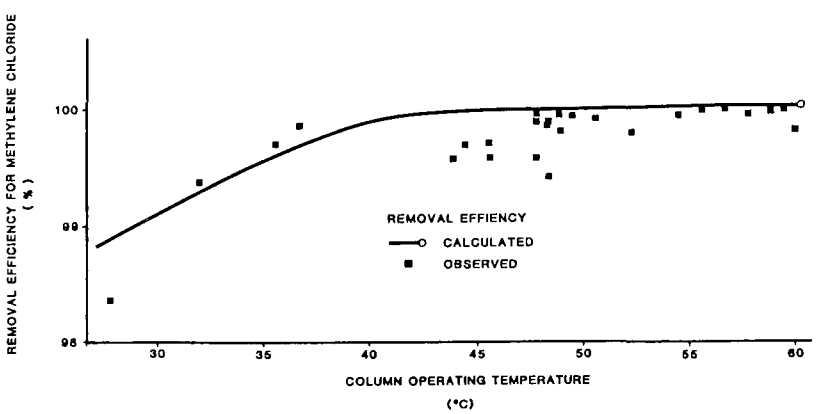

Figure 2
Removal Efficiencies of Methylene Chloride from Groundwater by Air Stripping at a Function of Column Operating Temperature

pure product collected in this manner did not exceed more than a few gallons, the vessel operated efficiently. Methylene chloride concentrations in the water entering the air stripping column rarely exceeded 150 mg/l. The mixed-media filter removed virtually all particulate matter in the water, and backwashing of the filter was infrequently required. The tower operating temperature was maintained between 27 and 60°C.

Figure 2 is a summary of actual removal efficiencies obtained during the 3 month operation of the air stripper. The same plot contains predicted data. The predicted removal efficiency was calculated from the mass transfer model of Onda *et al.*[2, 29] At operating temperatures less than 38°C, removal efficiencies agreed with those predicted.

However, significant deviations from expected values were observed at the higher operating temperatures. One explanation for those deviations is the non-adiabatic nature of the air stripping system. The column was constructed of mild steel and was not insulated since the system was meeting the discharge criteria of 20 mg/l methylene chloride. As ambient temperatures became progressively colder, column heat losses were greater. Those observations suggested that substantial deviations from the predicted removal efficiency would occur as the average operating temperature of the air stripper was increased.

The method used for predicting mass transfer rates of methylene chloride during the design phase of the project was adequate for estimating removal efficiencies at elevated temperatures. This same procedure has been implemented by OHM in numerous air stripping operations where mobilization of available equipment was used for emergency situations. Unlike other volatile organics, equilibrium and mass transfer data for methylene chloride have not been documented for aeration applications at elevated temperatures.

Results for the removal of methylene chloride from monitoring well B-5 are presented in Figure 3. This well was located 20 ft downgradient from the ruptured methylene chloride line. An exponential decay curve was used to quantify the removal rate (decline in concentration) of methylene chloride from the groundwater surrounding the well. Holding other variables constant, the rate of decrease was assumed to be a function of methylene chloride concentration, i.e.

$$\frac{dC}{dt} = -kC \qquad (1)$$

where,

C = the concentration of methylene chloride remaining (mg/l)
t = time (days)
k = the rate constant (day^{-1})

The curve generated was fitted to the following first-order equation:

$$C = C_o e^{-kt} \qquad (2)$$

where,

C_o = methylene chloride concentration at time zero (mg/l)

The first-order rate constant, k, was determined by linear regression using least squares, and the first order equation was converted to:

$$\ln C = \ln C_o - kt \qquad (3)$$

A 50% reduction in methylene chloride concentration was observed within the first 11 days of physical treatment. After 2 months of field operation, air stripping techniques provided an estimated 97% reduction in the concentration of methylene chloride in the groundwater being extracted. Since it became increasingly more difficult to remove the residual methylene chloride from the groundwater, biological techniques were considered for implementation.

Biological Treatment

Bench-Scale Evaluation

Prior to initiation of a methylene chloride biodegradation feasibility study, the following screening analyses were performed on 17 selected water samples collected from the site: methylene chloride, ammonia-nitrogen, nitrate-nitrogen, orthophosphate-phosphorus, pH and aerobic heterotrophic bacterial plate counts.

Results of the screening analyses indicated that the site matrix samples contained viable microbial populations; i.e., the site matrix did not appear toxic to microbial growth (geometric mean = 2.0×10^4 CFU/ml, n = 17). The analyses also indicated that inorganic nitrogen and phosphorus nutrient additions would be necessary for effective biological treatment of the contaminated groundwater. Ammonia-nitrogen, nitrate-nitrogen and orthophosphate were not detected in any of the groundwater samples analyzed. The average pH for all 17 wells was 7.7, an acceptable value for microbial growth.

The biodegradation study was performed using the electrolytic respirometer (Exidyne Instrumentation Technologies, Inc., Colorado Springs, CO). For this study, both the fate of methylene chloride and chloride release, resulting from the biodegradation of methylene chloride, were used as the test parameters. Chloride concentration was determined using an Orion model 96-17B combination chloride electrode.

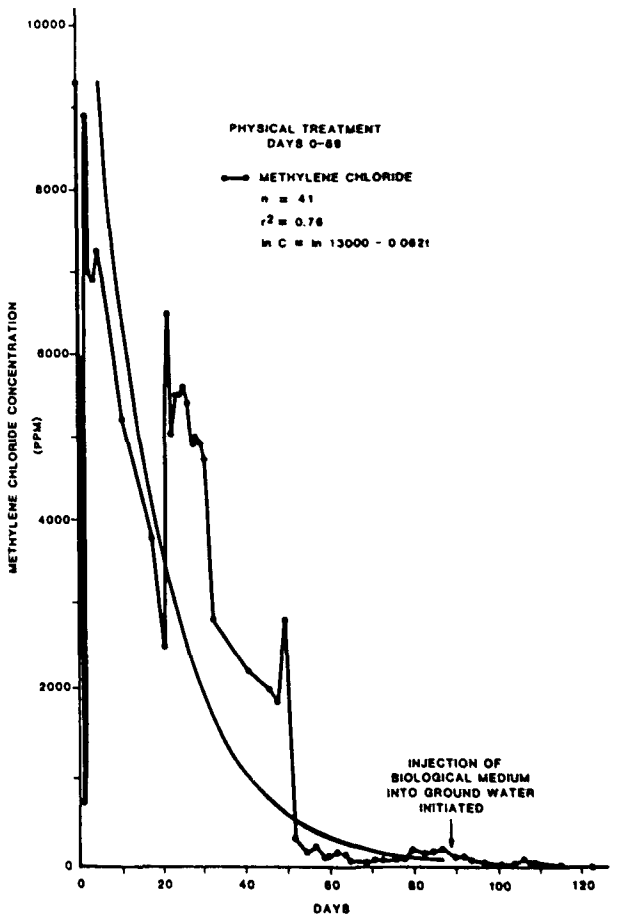

Figure 3
Physical Removal of Methylene Chloride from Monitoring Well B-5

An injection pool sample collected in November 1983, was used for the electrolytic respirometer study. Sludge collected from the plant's industrial wastewater treatment basin was used to inoculate the respirometer vessels. According to reports, the sludge in the wastewater treatment basin had been continuously exposed to low levels of methylene chloride for years and was, therefore, thought to contain populations of microorganisms acclimated to methylene chloride. The electrolytic respirometer vessels were prepared as follows:

	Treatment		
Vessel Number	Inoculum Source	Test Matrix	Poisons
1,2	S	IP	----
3,4	S	IP	X

Poisons added were KCN and NaN_3
S = wastewater treatment basin sludge
IP = injection pool

Methylene chloride was added to all respirometer vessels at a concentration of 100 mg/l. This concentration approximated average methylene chloride concentrations found in the groundwater at the site. Vessels 1 and 2 were replicates that demonstrated the feasibility of using the natural microbial flora. Any nonbiological loss of methylene chloride from the test environment would be quantified with the abiotic control (i.e., vessels 3 and 4). Respirometer vessels were prepared using procedures described by Young and Baumann[34] with diammonium phosphate and sodium dihydrogen phosphate added to each culture vessel. Nitrification was not suppressed.

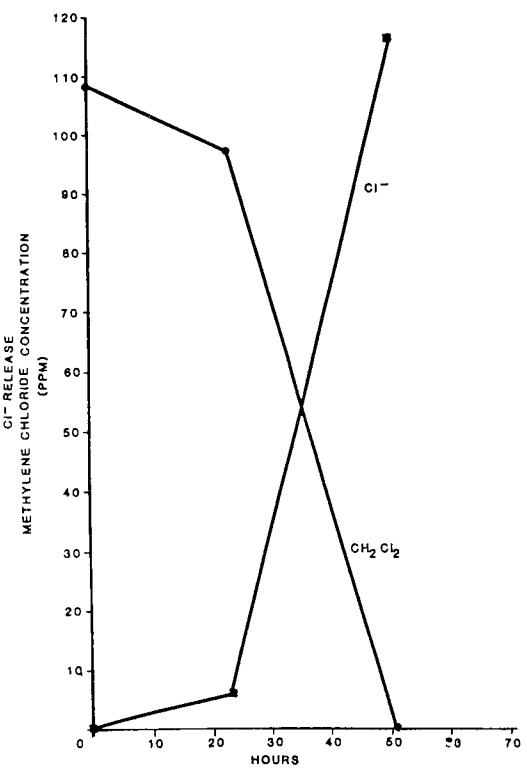

Figure 4
Biodegradation of Methylene Chloride with Chloride Release in a Microbial Reactor

On a periodic basis, 40 ml aliquots were removed from respirometer vessels and analyzed for methylene chloride and chloride concentrations. Throughout the study, aliquots were periodically removed from culture vessels and analyzed for pH and for ammonia-nitrogen, nitrate-nitrogen and orthophosphate concentrations. When necessary, pH and inorganic nitrogen and orthophosphate concentrations were adjusted to ensure that the chemical environment remained optimal for microbial growth.

Methylene chloride biodegradation and chloride release data for respirometer vessel 1 are presented in Figure 4. Results for vessel 2 were similar. Neither loss of methylene chloride nor chloride release was observed in the abiotic control vessels.

The theoretical chloride release for mineralization of methylene chloride was calculated from the following relationship:

$$CH_2Cl_2 + O_2 \longrightarrow CO_2 + 2\,HCl$$

The theoretical chloride release is 0.835 mg chloride per mg of methylene chloride following complete oxidation.

Methylene chloride was biodegraded stoichiometrically to chloride in respirometer vessels 1 and 2 (Fig. 4). Using the following relationship, it was determined that 130 and 120% of the theoretical chloride release for methylene chloride biodegradation was met in respirometer vessels 1 and 2.

The results indicated that methylene chloride was completely oxidized to carbon dioxide, water and the chloride ion. The lack of a significant lag period indicated the presence of adapted, naturally occurring microbes that could biodegrade methylene chloride.

Field Implementation

Use of the underground recovery and treatment system for aquifer restoration has been described previously.[11-15, 25, 27, 28] A schematic of the biological treatment system is shown in Figure 5.

A modified activated sludge system was the preferred method for aboveground treatment. In addition to providing efficient biological treatment, the activated sludge system provided a supply of adapted microorganisms for inoculation of the groundwater through the injection system. The injection system was used to inoculate the groundwater with naturally occurring microbes capable of biodegrading methylene chloride and to provide a suitable chemical environment necessary to support microbial growth.

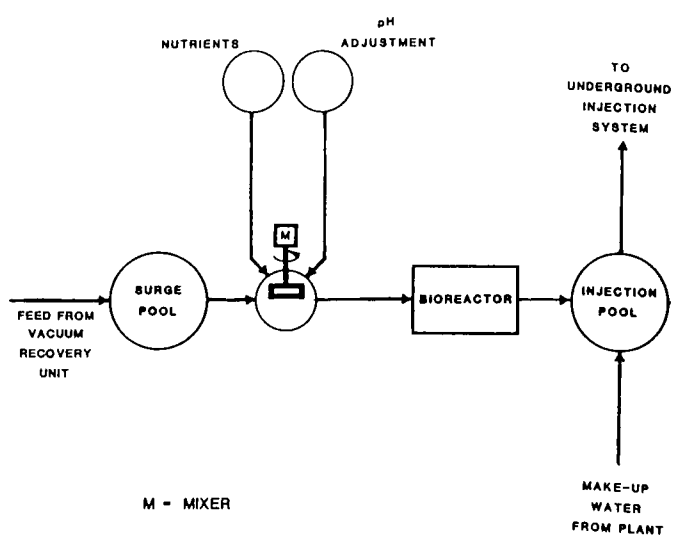

Figure 5
Biological Treatment System Schematic for Oxidation of Methylene Chloride in Groundwater

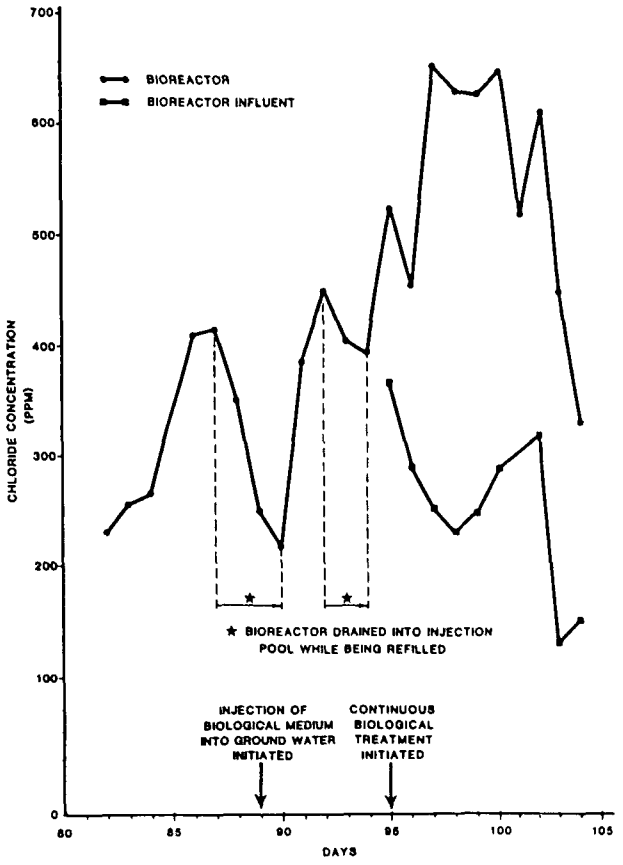

Figure 6
Chloride Release in the Bioreactor Resulting from the Biodegradation of Methylene Chloride in Groundwater

The recovery system was used to withdraw contaminated groundwater for aboveground treatment. The supernatant from the treatment system was reinjected into the subsurface environment, creating a closed-loop system. Biodegradation of methylene chloride took place in the ground as well as above the ground in the biological treatment system.

On day 82 of field operation, the bioreactor was prepared for batch treatment of methylene chloride-contaminated groundwater to provide a large quantity of adapted microorganisms for injection. To maintain a methylene chloride concentration in the bioreactor capable of supporting microbial growth, air containing methylene chloride vapor was bubbled into the bioreactor. Between days 82 and 87, an 80.4% increase in the chloride concentration was observed as a result of chloride release from the biodegradation of methylene chloride. Between days 87 and 90, the bioreactor was drained into the injection pool while being refilled. Injection of methylene chloride adapted microorganisms into the groundwater environment began on day 89 (Fig. 6).

Batch biological treatment of methylene chloride-contaminated groundwater again was performed in the bioreactor between days 90 and 92. A 110% increase in chloride concentration was observed as a result of methylene chloride biodegradation. The bioreactor again was drained into the injection pool while being refilled. On day 95, continuous biological treatment was initiated. Over the 10-day operational phase, bioreactor effluent chloride concentration averaged 131 ± 65% greater than influent concentration. Therefore, the bioreactor contained a population of microorganisms adapted to methylene chloride.

Removal of methylene chloride from the groundwater was rapid. A 50% reduction in methylene chloride concentration was observed in monitoring well B-5 (Fig. 7) within 8 days after the commencement of biological treatment. The rate of decrease was assumed to be first-order;[21] i.e., holding other variables constant, the rate of decrease was assumed to be a function of methylene chloride concentration.

With the onset of winter, biological treatment was temporarily suspended on day 123 (Jan. 2, 1984). At that time, a 97% reduction in methylene chloride concentration had been achieved since the injection of adapted microorganisms into the groundwater.

The theoretical chloride release for biodegradation of 186 mg/l methylene chloride (i.e., from 192 to 6 mg/l methylene chloride) is 155 mg/l. The observed chloride release was 156 mg/l; i.e., chloride concentration in monitoring well B-5 increased from 175 mg/l on day 80 to 331 mg/l on day 123. Therefore, we concluded that biological treatment was responsible for the removal of methylene chloride from the groundwater.

TREATMENT OF ETHYLENE GLYCOL-CONTAMINATED GROUNDWATER

At the Naval Air Engineering Center in Lakehurst, New Jersey, biodegradation techniques were used successfully to treat ethylene glycol-contaminated groundwater following the loss of an estimated 4,000 gal of cooling water from a lined surface storage lagoon. The cooling water was estimated to contain 25% (vol/vol) ethylene glycol.

The problem developed on Jan. 5, 1982, following a storage lagoon liner break. A subsequent investigative program confirmed soil contamination around the lagoon and identified a 180-ft long by 45-ft wide contaminant plume extending to the east. At the start of the project, the average ethylene glycol concentration in the groundwater was 1,440 mg/l. Approximately 85 to 93% of the ethylene glycol was removed from the groundwater within the first 26 days of biological treatment. By the completion of the project, ethylene glycol was reduced to below the limits of detection (<50 mg/l) in all production wells at the site.

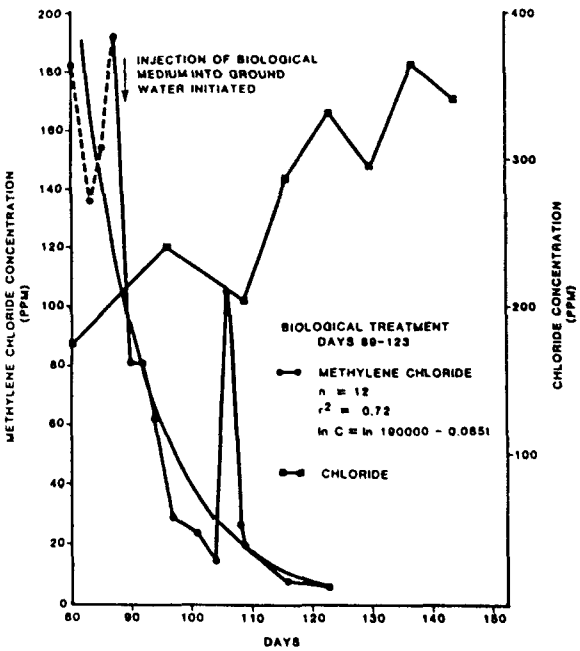

Figure 7
Biodegradation of Methylene Chloride with Chloride Release Based on Samples Taken from Monitoring Well B-5

Biofeasibility Evaluation

The biofeasibility study assessed the biodegradation potential of ethylene glycol in the ground as well as the presence of a toxic or inhibitory environment to microbial growth. In addition, techniques to increase the biodegradation rate in the ground also were evaluated. Such techniques commonly include the use of surfactants, cosubstrates, primary substrates, vitamins, trace elements and selected microbial strains. The results of the biofeasibility evaluation form the basis for subsequent field implementation, as discussed in this case history.

Ethylene glycol can be used as a carbon and energy source for aerobic migroorganisms.[6,10,17,31] The aerobic metabolism of ethylene glycol is relatively common, and the pathways of its metabolism are known.[4,5,18,19,26,31-33]

Anaerobic metabolism of ethylene glycol has been reported by Dwyer and Tiedje.[8] Using a sewage sludge inoculum under methanogenic conditions, ethylene glycol was converted to ethanol, acetate and methane. The ethanol produced was further oxidized to acetate with methane as the final end product. It has been shown that *clostridium glycolicum* fermentation of ethylene glycol yields equimolar amounts of acetate and ethanol.[16]

Prior to initiation of the feasibility study, screening analyses, as previously described for the first case history, were performed on representative soil and groundwater samples collected from the site. Ethylene glycol concentration was determined by direct aqueous injection into a gas chromatograph.

Screening analyses indicated that the groundwater contained a viable microbial population; i.e., the environment did not appear toxic to microbial growth. Aerobic heterotrophic bacterial population densities ranged from 10^2 to 10^6 colony forming units (CFU)/ml. Bacterial population densities of soil samples collected within the spill area varied from 10^2 to 10^6 CFU/g oven-dry soil. Screening also indicated that both pH adjustment and inorganic nitrogen and phosphorus nutrient additions would be necessary for biological treatment of ethylene glycol. The average pH of the 13 samples was 4.5.

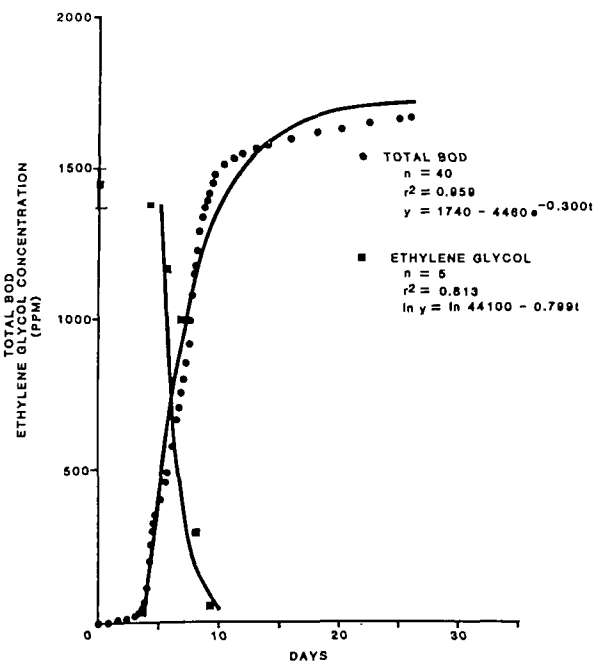

Figure 8
Biodegradation of Ethylene Glycol in Composite Groundwater Sample (Vessel 1)

The biodegradation study was performed using the electrolytic respirometer with the composite groundwater sample. All samples were prepared in a liquid nutrient medium containing basal salts and yeast extract.

Vessel Number	Test Matrix	Treatment: Glucose (1000 mg/l)	Treatment: Poisons*
1	GW**	----	----
2	GW	X	----
3	LGW†	X	----
4	GW	----	X

*Poisons added were $HgCl_2$, KCN, NaN_3
**GW = Composite groundwater sample
†LGW = Laboratory grade water

Results from vessel 1 would measure the rate of biodegradation of ethylene glycol by the natural microbial flora. Comparison of oxygen uptake rates in vessels 2 and 3 would demonstrate the presence of significant quantities of substances toxic or inhibitory to microbial growth in the composite groundwater sample. Any nonbiological loss of ethylene glycol would be quantified with the abiotic control (i.e., vessel 4).

Ethylene glycol biodegradation data for respirometer vessel 1 is presented in Figure 8. A loss of ethylene glycol was not observed in the abiotic control (vessel 4). The theoretical oxygen demand (ThOD) for aerobic mineralization of ethylene glycol was calculated from the following relationship:

$$2\,(CH_2OH)_2 + 5\,O_2 \longrightarrow 4\,CO_2 + 6\,H_2O$$

The ThOD is 1.29 mg O_2 per mg of ethylene glycol. With an initial concentration of 1440 mg/l ethylene glycol, 1860 mg O_2 would be required for complete oxidation. The ultimate BOD (BODu) was determined by fitting oxygen uptake data to a modified crescent curve:[30]

$$BOD = a + be^{-kt} \tag{4}$$

where,

BOD = the amount of BOD expressed or exerted at time t (mg/l)
a = BODu, the ultimate amount of oxygen uptake to be expressed (mg/l)
b = a lag period parameter (mg/l). (Note: b = a if the fitted crescent curve intersects the origin)
k = the rate constant (hr^{-1})
t = time (hr)

The ultimate BOD is defined as the total amount of oxygen required to biodegrade the immediately available organic matter present in a sample.[24]

Using the following relationship, it was determined that 94% of the theoretical oxygen demand for ethylene glycol biodegradation was met:

$$\frac{BODu}{ThOD} \times 100 \tag{5}$$

Thus, the results indicate that ethylene glycol was completely oxidized to carbon dioxide and water without the accumulation of incomplete oxidation products. With a BODu of 1700 mg/l, an estimated minimum of 170 mg/l NH_3-N and 17 mg/l PO_4-P would be required in the groundwater to prevent nitrogen and phosphorus from limiting microbial growth during biological treatment.[24]

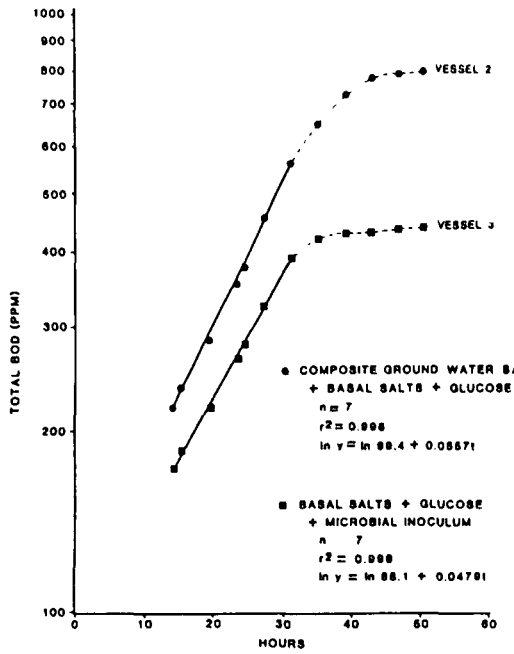

Figure 9
Oxygen Uptake Data for the Composite Groundwater Sample Containing Glucose and for a Glucose Control

The lack of a significant lag period in both oxygen uptake and ethylene glycol biodegradation by the natural microbial flora in vessel 1 indicated the presence of adapted microbes that could biodegrade ethylene glycol. That finding was significant because it indicated that in situ biodegradation of ethylene glycol already was occurring and that the management approach should be to increase the natural biodegradation rate.

The groundwater appeared to be slightly stimulatory to microbial growth, as evidenced by the slightly greater rate of oxygen uptake in the composite groundwater sample compared to the glucose-basal salts control (Fig. 9). At the termination of the study, initial oxygen uptake data in the toxicity/inhibition control (respirometer vessels 2 and 3) were compared on a semi-log plot. A comparison was made of the slopes of the lines-of-best-fit through the linear portion of the natural log transformed oxygen uptake data. In the linear portion of the semi-log plot, the rate of oxygen uptake in the glucose-containing composite groundwater sample was 1.2 times greater than in the glucose-basal salts control. Thus, evidence for an environment toxic or inhibitory to microbial growth was not found.

The feasibility study results indicated that biodegradation techniques were a viable option for reducing ethylene glycol concentrations in the groundwater.

Field Implementation

The biological treatment program at the site was divided into a 14-day operational phase, a 3-month monitoring phase and a 9-month maintenance program. The operational phase was designed primarily to provide maximum recovery, treatment and enhanced bacterial growth in the groundwater both within the spill area and within the contaminant plume (Fig. 10). The monitoring program was designed to assess the ethylene glycol degradation rate in the groundwater following nitrogen and phosphorous nutrient addition, pH adjustment and enhanced bacterial growth. The maintenance program was designed to provide an environment suitable for the continued biodegradation of any residual ethylene glycol remaining in the groundwater environment.

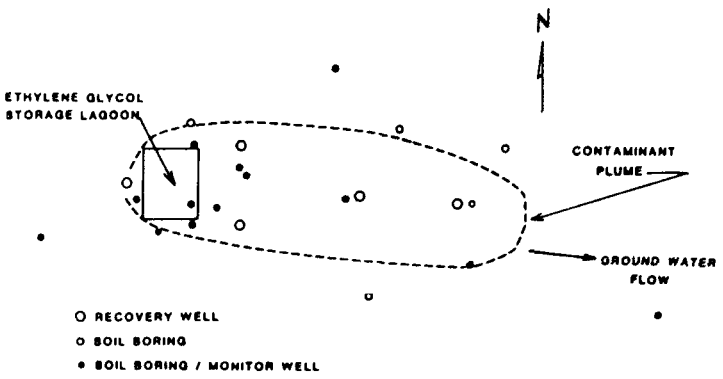

Figure 10
Schematic of Ethylene Glycol Storage Lagoon and Contaminant Groundwater Plume

Ethylene glycol contamination at the site was divided into two zones. The first zone was the unsaturated zone between the surface and the water table where ethylene glycol had been retained through capillary action. The highest contamination level detected in that zone was 4,900 mg/l ethylene glycol. Surface contamination also was indicated following analysis of shallow samples (0 to 2 ft) collected adjacent to the lagoon.

The second zone of contamination was the groundwater. Groundwater samples within the spill area had ethylene glycol concentrations as high as 2,100 mg/l. Monitoring wells were installed, and subsequent water analyses indicated significant groundwater contamination. A downgradient contaminant plume was estimated to be 180 ft long by 45 ft wide.

A two-phased approach was implemented to deal with both soil and groundwater contamination. Using injection and recovery wells, initial efforts addressed the highly contaminated soils underlying the storage lagoon. The second phase concentrated on groundwater cleanup. Its goals were (1) to prevent further migration of contaminated groundwater and (2) to treat any contamination released during treatment of the unsaturated zone.

The injection system was used to adjust groundwater pH as well as provide the inorganic nitrogen and phosphorus necessary to support microbial growth. The recovery system withdrew contaminated groundwater for above ground treatment in an activated sludge treatment system (Fig. 11). Supernatant from the treatment system then was reinjected into the subsurface environment, creating a closed-loop system.

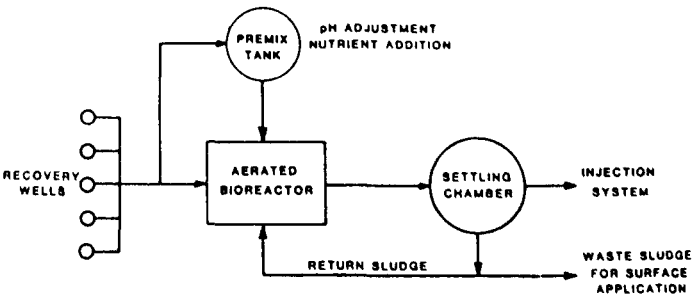

Figure 11
Flow Diagram for the Activated Sludge Treatment System of Ethylene Glycol-Contaminated Groundwater

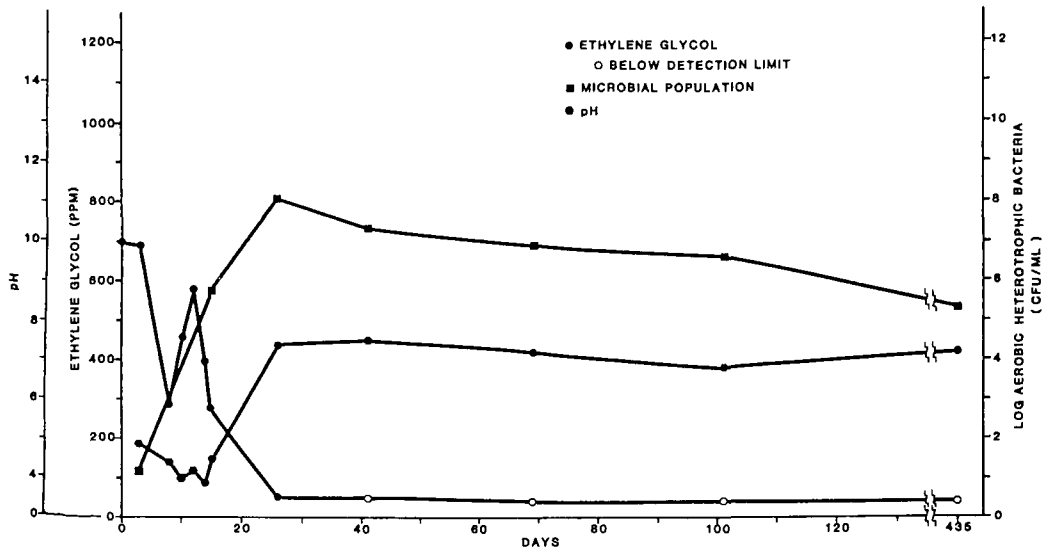

Figure 12
Ethylene Glycol Concentration, Bacterial Population Density, and pH as a Function of Time for a Contaminant Plume Production Well

Based on the information obtained during the site investigation, five recovery wells were installed to recover contaminated groundwater (Fig. 10). Three wells located near the lagoon provided zones of attraction for treated water injected in that area. The remaining two recovery wells were positioned east of the lagoon to recover contaminated water from the contaminant plume and aid in the distribution of treated water from the plume injection system.

Following pH adjustment and nutrient addition, supernatant from the biological treatment system was recharged through a three-phase injection system. The lagoon injection system was employed to flush contaminated soil and thereby transmit contaminated water to the three recovery wells located in the vicinity of the lagoon. The plume injection system was similar to the lagoon system in both construction and operation. The primary functions of the plume injection system were to enhance bacterial growth through pH adjustment and nutrient addition and to create a gradient from the fringe of the plume toward the two recovery wells located at the center of the contaminant plume. The third injection phase was implemented through surface application. Surface application was used primarily in the lagoon area to flush the unsaturated zone and enhance bacterial growth in the contaminated soil.

The activated sludge biological treatment system was designed to reduce ethylene glycol concentration through microbial bioxidation using the indigenous microbial flora. A second role of the bioxidation reactor was to provide adapted microorganisms for the three-phase injection system (Fig. 11). The biofeasibility study had demonstrated that the natural microbial flora were adapted to biodegrading ethylene glycol and that the management approach for the project should be to increase the natural biodegradation rate using microbes indigenous to the groundwater.

Throughout the operational phase, treatment system and recovery well samples were analyzed for aerobic heterotrophic bacteria, pH, dissolved oxygen, inorganic nitrogen, phosphorus and ethylene glycol. Based on the results of those analyses, environmental parameters were modified to maintain an effective

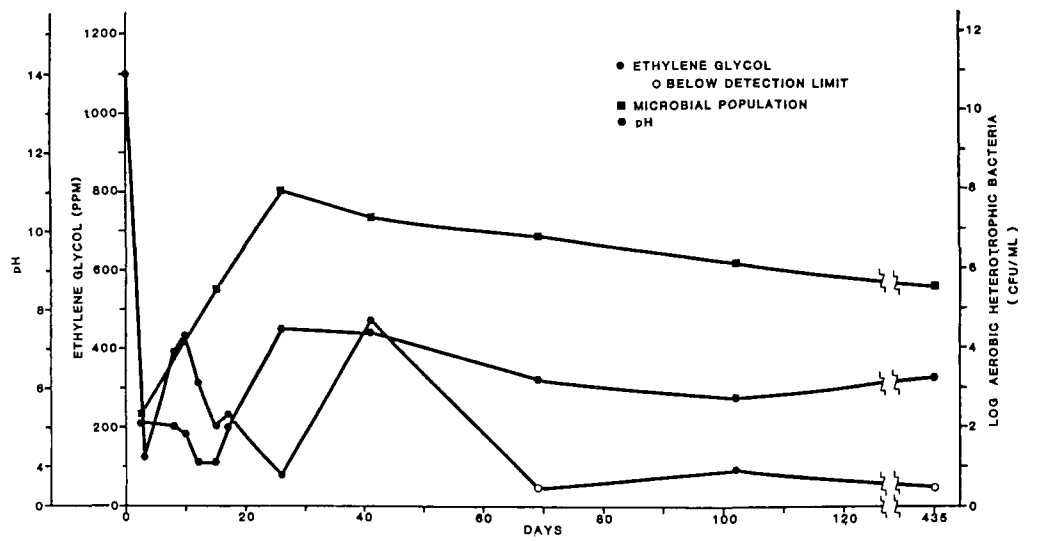

Figure 13
Ethylene Glycol Concentration, Bacterial Population Density, and pH as a Function of Time for a Downgradient Spill Area Production Well

rate of biological treatment. During the monitoring phase, those same parameters were quantified on a monthly basis from recovery well samples.

In the initial phases of treatment, ethylene glycol concentrations in two plume recovery wells were reduced from 690 and 420 mg/l to below limits of detection (LOD = 50 mg/l) within 26 days of treatment. With the exception of one monitoring phase data point (day 40), ethylene glycol concentration remained below detection limits. As shown in Figure 12, groundwater pH was maintained within an optimal range for bacterial growth (i.e., pH 6 to 7). Bacterial population density was returning to background levels (i.e., 10^5 CFU/ml) following a high of 10^8 CFU/ml.

In the two downgradient recovery wells adjacent to the storage lagoon, the groundwater concentration of ethylene glycol was reduced by more than 85% and 92%, respectively, within the first 26 days of treatment (Fig. 13). Initial concentrations were 3,400 and 1,100 mg/l, respectively. In the upgradient recovery well adjacent to the lagoon, the ethylene glycol concentration in the groundwater increased from 100 mg/l on day 0 to 880 mg/l by day 13. However, monitoring data showed a continued decrease in ethylene glycol concentration after day 13. The increase in ethylene glycol concentration prior to day 13 reflected the project's aggressive operational phase, whereby, the injection system flushed pockets of ethylene glycol from the unsaturated zone into the groundwater.

The maintenance program focused on the removal of those remaining pockets of contamination, particularly in the lagoon area. As part of that program, both lime and diammonium phosphate were applied to the soil surface in the lagoon and contaminant plume areas. Lime increased the pH of the soil and groundwater to a favorable range for microbial growth. Diammonium phosphate, a readily available source of nitrogen and phosphorus, supported the growth of an increased microbial population.

By the completion of the project, ethylene glycol was reduced to below the limits of detection in all production wells at the site.

CONCLUSIONS

The two case histories presented demonstrate the application of biological techniques for environmental restoration of areas contaminated with spilled organic materials.

The combination of physical and biological techniques effectively removed methylene chloride from the groundwater at a relatively rapid rate. If it had been necessary to remove the contaminated soil from the site, transportation and disposal (T&D) costs for 14,000 yd^3 of contaminated soil would have been at least $1,050,000. The estimate for traditional treatment was based on a transportation cost of $3/mile in 20-$yd^3$ sized trucks to a hazardous waste disposal facility 100 miles from the treatment site. The disposal cost for the contaminated soil was $60/$yd^3$.

By successfully decontaminating the soil and allowing it to remain on-site, a two-fold cost savings was achieved and all future liability was reduced substantially. This cost estimate for T&D was conservative since removal of soil from an area increases void volume for transportation and disposal often by a factor of 1.2 to 1.3. Moreover, hazardous materials cannot be shipped off-site in bulk, but most be packaged into drums. Additional chemical analyses generally are required to characterize the waste prior to off-site transportation and disposal. Inclusion of these additional factors that must be considered for off-site disposal resulted in an even greater cost benefit for in situ cleanup.

Biological techniques, as described in the second case history, were also effectively used to remove ethylene glycol from the groundwater at a relatively rapid rate. The flexibility of the injection/recovery system in maintaining an environment conducive to biodegradation while flushing ethylene glycol from the groundwater was a key factor in the removal of scattered pockets of contamination. If it had been necessary to remove the soil from both the spill area and the contaminant plume to a hazardous waste disposal facility 500 miles from the treatment site, the T&D cost would have been more than 16 times the cost for on-site treatment.

Biodegradation as a method for spill cleanup and environmental restoration is considered to be a promising technology. Land treatment techniques have been engineered and are accepted as an economical and environmentally sound means of destruction for many types of industrial wastes. With regard to the cleanup of contaminated soil and groundwater, excavation has been a common method for remediation. However, combinations of physical and biological techniques now are gaining increasing acceptance as a practical, cost-effective alternative for environmental restoration.

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Physical/Chemical Removal of Organic Micropollutants from RO Concentrated Contaminated Groundwater

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ABSTRACT

The reverse osmosis (RO) concentrate of contaminated groundwater from the Gloucester Landfill site near Ottawa, Ontario, was treated by air stripping (AS), ozonation (O_3) and ultraviolet (UV) irradiation for the removal of organic micropollutants.

Fourteen compounds, predominantly volatiles, were monitored during this 6-week study. The concentration ranges of some of the compounds in the reverse osmosis concentrate were: trichloroethylene 2-280 μg/l; benzene 28-1,350 μg/l; chloroform 800-40,100 μg/l; diethyl ether 136-2,300 μg/l and acetone 750-36,000 μg/l.

Based on the results of this study, the air stripping process alone is considered to be adequate for treating the RO-concentrated contaminated groundwater at the Gloucester Landfill site. Residual concentrations of four of the six compounds with proposed groundwater quality objectives met or exceeded those levels.

The removal efficiency achieved by all three unit processes combined, however, was better than that obtained by AS alone. For the degree of additional improvement that might be achieved, it is doubtful that the addition of O_3/UV to the AS process would be economically justified.

INTRODUCTION

From 1969 to 1980, federal government laboratories in Ottawa, Ontario, disposed of their hazardous wastes (mainly organic solvents) in a Special Waste Compound (SWC) at the nearby Gloucester Municipal Landfill.[1] In 1981 contaminants including diethyl ether, acetone and some chlorinated solvents were detected in the groundwater migrating from the landfill site. This contamination was a potential danger to the drinking water source of nearby residents. Subsequently, Environment Canada and Transport Canada undertook a number of studies to define the extent of the problem and identify possible remedial measures.[2]

In 1984 Environment Canada's Wastewater Technology Centre (WTC), in cooperation with the Environmental Emergencies Technology Division, carried out a pilot scale study on the removal of toxic organics from the contaminated groundwater within the SWC. To define one remedial action, the objectives of this study were: (1) to evaluate the effectiveness of selected reverse osmosis (RO) membranes for removing toxic organics from the contaminated groundwater and (2) to evaluate the effectiveness of air stripping, ozonation and ultraviolet (UV) irradiation for treating the concentrate from the RO system.

The results related to the RO tests have been presented elsewhere.[3] This paper presents the results for the removal of organics from the RO concentrate by air stripping, ozonation and ultraviolet irradiation. For each treatment process, the results are discussed with reference to specific toxic organic compounds which were present in the groundwater at concentrations higher than the proposed groundwater quality objectives.[4]

METHODS AND MATERIALS

A trailer facility outfitted for this project was set up at the Gloucester site beside test well 36 W. This well, located within the SWC, was found to have the highest concentrations of organic micropollutants.[4] A schematic of the pilot plant used during this study is shown in Figure 1.

The air stripping unit in the pilot plant consisted of two 1.22 m by 10 cm (I.D.) plexiglass columns connected in series. The columns were packed with 1.3 cm Intalox* saddles. A Whispair 1707J† blower was used to force air through the stripping columns.

The ozonation experiments were conducted using a bubble column 91 cm by 10 cm (I.D.). Ozone was generated from oxygen using a Welsbach T-816‡ ozonator. The O_3 concentrations in the inlet gas and the off-gas were measured using a standard iodometric method.[5] Ozone in the liquid was measured using the indigo method.[6]

The UV irradiation chamber used was a Trojan System 2000.** It consisted of four 9 W low pressure mercury lamps. The total UV output of all the lamps in the reactor was determined by ferrioxalate actinometry[7] and was found to be 4.1×10^{-4} einsteins/min. The flow of liquid through the reactor was maintained during the tests to give a theoretical retention time (RT) of 22 min.

Air Stripping

During air stripping experiments, the following three variables were studied: air flow rate, the packing height and the water flow rate. A full 2^3 factorial experimental design was used to allow for the determination of the relative significance of the effect of these variables (Table 1). The air and water flow rate levels were chosen to bracket a wide range below the conditions at which the columns would become flooded. From the calculated stripping factor for the volatile compounds present in the concentrate, the values for the packing height were chosen to give a sufficient number of transfer units for >99% removal of these compounds.

* Norton Chemical Company, Akron, OH
† Roots Blower Operation, Dresser Industries, Inc., Cornerville, IN
‡ Polymetrics Inc., Sunnyvale, CA
**Trojan Technologies Inc., London, Ont.

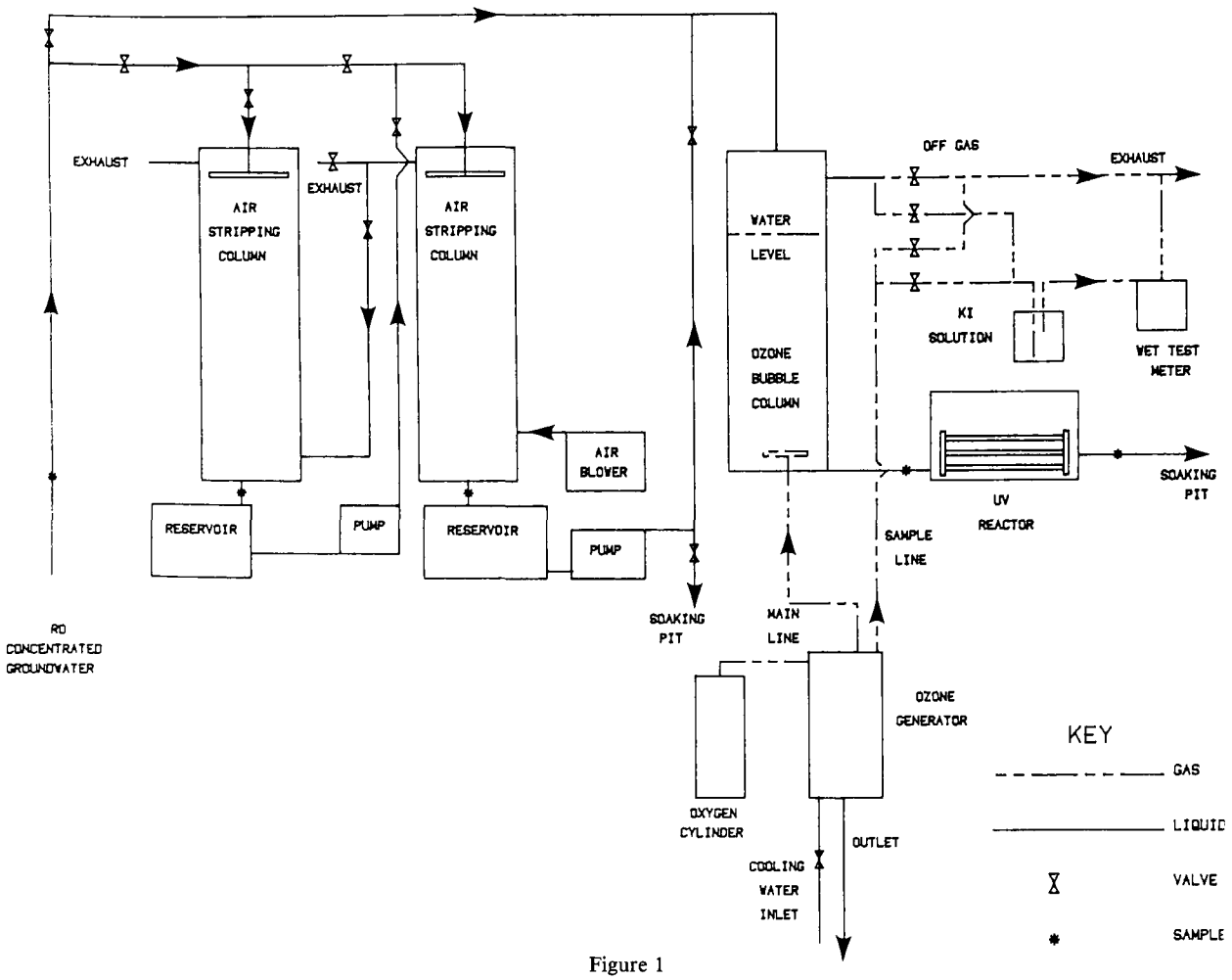

Figure 1
Process Schematic for Groundwater Treatment System

Table 1
Air Stripping Process Variable

Variables	Levels −	Levels +
Air flow rate (l/min)	15	300
Packing height (m)	1.22	2.44
Water flow rate (l/min)	0.5	2.0

Ozonation/Ultraviolet Irradiation

The effects of ozonation, UV irradiation, air stripping and water flow rates on the removal of organic micropollutants were observed using a full 2^4 factorial experimental design (Table 2).

Table 2
AS/O_3/UV Experiment Variables

Variables	Levels −	Levels +
Air stripping	OFF	ON*
O_3 dose (mgO_3/l of gas)	0	65
UV irradiation (einsteins/min)	0	$4.1 \times 10-4$
Water flow rate (l/min)	0.5	2.0

*Air flow rate = 300 l/min; packing height 1.22 m

Sampling and Methods of Analysis

The locations where samples of pilot plant influent and treated effluent were collected during the tests are shown in Figure 1. For each experiment, two sets of samples were collected: one set was collected at the beginning of the test and another set after 2 hr of continuous operation of the unit process(es) being tested. After collection, the samples were stored at 4 °C in glass vials with teflon-lined septums. Sample analyses were completed within 10 days of collection of a given set of samples.

The organic compounds, predominantly volatiles, were analyzed by the purge and trap method using a Hewlett Packard model 5830A Gas Chromatograph coupled to a Flame Ionization Detector (FID). The following pairs of compounds coeluted during the analysis and could not be quantified individually: (1) 1,1-dichloroethane (RT = 13.6) and tetrahydrofuran (THF) (RT = 13.7; (2) 1,1,1-trichloroethane (RT = 17.4) and 1,4-dioxane (RT = 17.4).

Water Characteristics

During this 6-week study the concentrations of various compounds in the RO concentrate varied widely. These data are presented in Table 3, together with the proposed groundwater quality objectives for these compounds.

STUDY RESULTS

Forty-seven tests were conducted during this study. Of these tests, 27 used AS, 7 used O_3 and 3 used UV alone to remove the organic micropollutants from the concentrate. In 11 tests, O_3 was

Table 3
The Influent Concentration for Some of the Organic Micropollutants

Organic Contaminant	RO Concentrate (μg/l)	Groundwater Quality Objectives (μg/l)
Dichloromethane	9- 1,670	150
Acetone	750-36,000	NA
1,1-Dichloroethylene	2- 1,531	0.3
Chloroform	800-40,100	30
Diethyl Ether	136- 2,300	NA
1,2-Dichloroethane	32- 653	10
Trichloroethylene	2- 280	30
Benzene	28- 1,350	10

NA — Not Available

followed by UV irradiation. Air stripping was followed by UV in 2 tests, by O_3 without UV in 5 tests and by O_3 in the presence of UV in 8 tests. Not all of the samples collected during these tests could be analyzed for all the parameters, so some of the data points required to complete the factorial analysis of the data are missing. A stepwise regression using backwards elimination routine was, therefore, applied for the analysis of the data.

Although the concentration of organic compounds in the RO concentrate varied greatly (see Table 3), the removal efficiency of the various processes tested was not affected by this variability in the concentration. Variations in the removal efficiencies were due to the experimental conditions applied.

Air Stripping

Table 4 summarizes the results for air stripping experiments.

Table 4
Percentage Removal and Residual Concentration Ranges Achieved During AS Treatment of Groundwater

Contaminant	Range of Removal Efficiency (%)	Residual Concentration (μg/l)
Dichloromethane	57- > 99	2.3- 38.2
Acetone	32- 99	67.4-9,340.4
1,1-Dichloroethylene	43- > 99	0.5- 130.2
1,1-Dichloroethane/THF	25- 99	6.4- 667.9
Chloroform	31- >99	33.6-2,775.7
Diethyl Ether	25- > 99	0.7-1,294.0
1,2-Dichloromethane	24- 99	1.6- 228.6
1,1,1-Trichloroethane/ 1,4-Dioxane	2- > 99	12.5- 813.7
Trichloroethylene	41- > 99	0.5- 63.4
Benzene	25- > 99	1.2- 78.2

In addition to the chemicals listed in Table 4, the removal efficiencies of four other compounds, listed in Table 5, were estimated. The estimates were based on the percent reduction in the peak areas for the compounds observed during the gas chromatographic analysis of the RO concentrate and the air stripping samples.

Analysis of the data from the AS experiments showed that water flow rate had the greatest effect on the removal of most compounds. The best removals were obtained in the experiments where the water flow rate was low (0.5 l/min). Packing height and air flow rate did not have a substantial effect on the efficiency of removal within the range of values used in these experiments.

Under the best conditions (water flow rate of 0.5 l/min), four of the compounds were removed to below their groundwater quality objective concentrations (see Table 6).

Table 5
Percent Reduction Range Estimated from the Peak Areas

Chemical	Estimated Removal ∅
Dichloropropane	21- > 99
Bromoform	15- > 99
Toluene	7- 98
Chlorobenzene	5- > 99

Table 6
Effluent Concentrations Achieved with Air Stripping

Compounds	Groundwater Quality Objectives (μg/l)	Residual Concentration (μg/l)
Dichloromethane	150	2.3 - 7.5
1,2-Dichloroethane	10	< 10
Trichloroethylene	30	0.5 - 2.7
Benzene	10	1.2 - 7.7

For two compounds, chloroform and 1,1-dichloroethylene, the residual concentrations after AS, even under the best conditions, were still above the proposed groundwater quality objective concentrations. However, the residual concentration of 1,1-dichloroethylene in six tests was very close to the detection limit for this compound.

Acetone and diethyl ether removals under the best conditions were 99 and > 99%, having residual concentrations of 67.4 μg/l and 0.7 μg/l, respectively. Since there are no proposed groundwater quality objectives for these compounds, it is not clear whether the residuals obtained through AS alone would be considered acceptable. If they were not acceptable, then AS would have to be augmented by some other process(es).

Ozonation

Results from direct ozonation of the RO concentrate are shown in Table 7.

The removal efficiencies for ozonation alone were generally either similar to or lower than those achieved by AS alone. The reason for lower removal during ozonation was probably due to the lower gas flow rate through the column. In AS, the gas flow rate was in the ranges of 15 to 300 l/min; for ozonation, the maximum gas flow rate was 2 l/min.

In one of the tests using O_3 alone, the ozonation column was operated at a gas flow rate of 2 l/min but the ozone generator was turned off. From the results of this test, it appears that approximately 30% of the removal observed was due to the stripping effect of the gas and 70% was due to the chemical oxidation of the organics.

With ozonation of air-stripped RO concentrate (Table 7), the removal of the organic micropollutants generally improved, particularly for acetone and diethyl ether. It is not clear whether this additional removal could be sufficient to justify the use of ozonation in conjunction with air stripping.

Ultraviolet Irradiation

Ultraviolet irradiation was used alone, as well as in combination with O_3 or AS. For most compounds, the removal was not as

good as that achieved by AS alone. For this reason, the data from these tests are not reported. The reader is referred to an earlier data report.[8] However, since the best removal efficiency for most of the organic compounds was achieved when all three unit processes were applied, the removals and residuals from these tests are presented in Table 8.

Table 7
Average Removals of Organic Chemicals from Groundwater after Ozonation and Air Stripping/Ozonation

Contaminant	Removal After AS (%)	Removal After O_3 (%)	Removal After AS/O_3 (%)
Dichloromethane	93	37	84
Acetone	57	28	64
1,1-Dichloroethylene	73	56	76
1,1-Dichloroethane/THF	61	67	83
Chloroform	90	33	70
Diethyl Ether	84	74	95
1,2-Dichloroethane	86	39	76
1,1,1-Trichloroethane/ 1,4-Dioxane	69	53	81
Dichloropropane (1,2- or 1,3-)	57	99	100
Trichloroethylene	92	93	99
Benzene	91	73	99
Bromoform	83	82	95
Toluene	77	53	78
Chlorobenzene	60	64	83

Table 8
Percentage Removal and Residual Concentration Ranges Achieved During AS/O_3/UV Treatment of Groundwater

Contaminant	Range of Removal Efficiency (%)	Range of Residual Concentrations (µg/l)
Dichloromethane	89- 99	7.1-45.5
Acetone	38- 95	36.5-1,933.8
1,1-Dichloroethylene	29- > 99	0.5-45.4
Chloroform	87- > 99	6.2-2,020.0
Diethyl Ether	84- > 99	0.7-95.0
1,2-Dichloroethane	63- > 99	1.6-56.5
Trichloroethylene	99- > 99	0.5-3.5
Benzene	85- > 99	0.3-13.5

Generally, the range of removal efficiencies obtained by the combination, AS/O_3/UV, was higher than AS alone (Table 4). The residuals were either similar or lower than the ones obtained by AS alone.

Based on these results, AS alone appears to be adequate to remove volatile organic compounds from the RO concentrate. However, all three unit processes combined provided marginally better removal efficiencies. It is doubtful, though, that the degree of improvement would justify the increase in cost that would occur by including O_3 and AS units in the treatment train.

CONCLUSIONS

The conclusions drawn from this study follow below.

Two pairs of compounds (1,1-dichloroethane/tetrahydrofuran and 1,1,1-trichloroethane/1,4-dioxane) coeluted during the gas chromatography analysis and could not be quantified individually.

The results of data analysis by stepwise regression showed that during air stripping experiments the water flow rate had the greatest effect on the removal of most organic compounds. The best removals were obtained at a water flow rate of 0.5 l/min.

During air stripping experiments, four compounds (dichloromethane, 1,2-dichloroethane, trichloroethylene and benzene) were removed to below the proposed groundwater quality objectives.

In the absence of groundwater quality objectives for acetone and diethyl ether, it is not clear whether the effluent concentrations obtained by air stripping (67.4 and 0.7 µg/l) would be considered as acceptable residual values. If they were not acceptable, O_3/UV in conjunction with air stripping could be considered.

Removal efficiencies observed after O_3 or UV irradiation alone were generally either similar to or lower than the results obtained by AS alone. Combinations of AS/O_3, AS/UV and O_3/UV unit processes compared to AS alone did not offer significant improvements in the removal efficiencies in most of the tests.

The removal efficiency achieved by all three unit processes combined was better than that obtained by AS alone. For the degree of improvement that can be achieved, it is not clear that the addition of O_3/UV to the AS process would be economically justified.

The data obtained in this study can be used to predict process performance for those situations where the contaminated groundwater has large variations in the micropollutants concentration range.

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State-of-the-Art Technologies of Removal, Isolation and Alteration of Organic Contaminants Underground

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ABSTRACT

The rising cost and increasing long-term liability of off-site treatment and disposal have caused a demand for on-site in situ treatment of organic contaminants located underground. There are generally three types of in situ treatment: removal, isolation and alteration.

The purpose of this paper is to provide the reader with a description of available state-of-the-art, in situ treatment alternatives for the treatment of various organic contaminants in both the vadose and saturated zones in the subsurface. Guided format tables are developed for the reader to search for the application that may work in an individual situation while considering regulatory, economic, risk and liability consequences.

INTRODUCTION

The treatment and disposal of hazardous waste and material off-site has become increasingly difficult due to closure of an already limited number of qualified waste handling and disposal facilities, tightening of regulatory standards, escalating transportation and disposal costs and risks of long-term liability. While the technology of in situ treatment is advancing at a rapid pace, there is a need to evaluate periodically the applicability of various technologies to specific on-site contamination problems and underground conditions.

The purpose of this paper is to provide the reader with a description of available in situ treatment alternatives for application on various organic contaminants in both the vadose and saturated zones in the subsurface. However, the best technology will work only if it is in agreement with regulatory remediation standards and permits, economic feasibility and long-term risks and liability as shown in Figure 1.

The following sections discuss the three possible types of in situ treatment alternatives: removal, isolation and alteration. These alternatives will encompass a broad combined spectrum of science and engineering areas:

- Chemistry
- Physics
- Geology
- Geohydrology
- Biology
- Environmental Engineering

IN SITU REMOVAL

An initial requirement for on-site remediation always is the removal of the source and control of the contaminated plume, whether it is in the soil (vadose zone) or in the groundwater (saturated zone) or both. The in situ removal process may involve primary, secondary and tertiary methods.

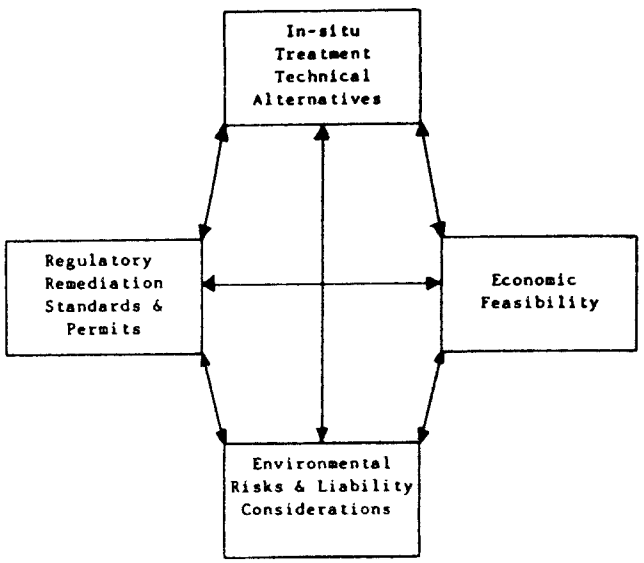

Figure 1

The primary methods include the following:

- Vadose zone—air vacuum venting
- Saturated zone—pumping of recovery well

The air vacuum venting works well with volatile organic compounds located underground, in particular, permeable strata in the vadose zone where the soil can serve as a migration pathway. In general, the venting process will require an air emission permit which may be prohibitive in some areas. If organic emissions to the atmosphere are not allowed, an oil stripper (OS) or an activated carbon adsorption unit is required. If the vent stream is steady and loaded with high concentration volatile organics, it may be advisable to recover the product by either an oil strip/desorption or a regenerative activated carbon process (Fig. 2).

The secondary method of removal involves both injection and recovery wells. Usually, injection wells for the vadose zone should be discouraged because the injected air/water stream may "push" the volatile organics toward undesirable off-site locations.

The tertiary method of removal involves temperature enhancement and addition of surfactants to increase the release rate and mobility of the organic compound movement through the porous media toward ultimate recovery. The addition of surfactants may create new problems in recovery and surface treatment if not properly applied. Temperature enhancement is generally a desir-

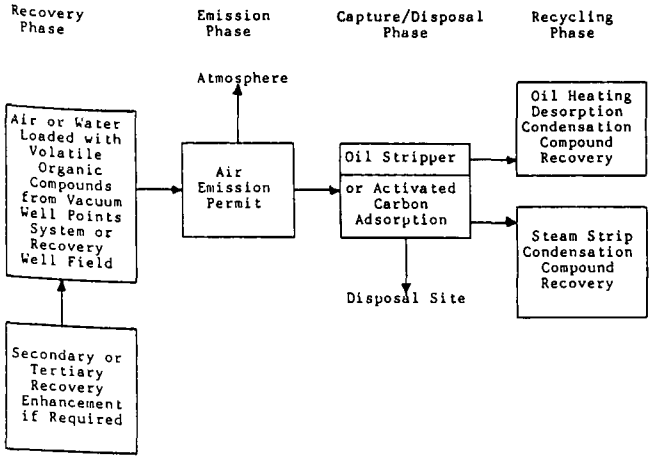

Figure 2
Generic Flow Diagram of In Situ Removal Process

able process (if duration of treatment can be prolonged) by a passive solar heating system. The system works as underground space heating under steady circulation. The system cost and maintenance are usually very attractive.

For the saturated zone, the application is similar to the vadose zone with the exception of depth of the contaminated zone and liquid handling.

The following design criteria are important for recovery well field applications:

- The recovery rate must exceed the recharge/safe yield of the geohydrologic system
- Drilling and well installation design must now allow vertical migration of contamination from shallow depth
- Pumping of recovery wells must begin with shallow wells and move to deeper wells to avoid pressure induced vertical migration of contamination
- It is not advisable to establish pumping wells in low permeability material (generally less than 1×10^{-4}cm/sec)
- Well screen design must be designed specifically for "sinkers" or "floaters" organic compounds

Unfortunately there will never be 100% removal of the contaminants. Some portion of the contamination will remain affixed to the fine grain matrix in the subsurface material.

IN SITU ISOLATION

There are specific geohydrologic conditions which will not allow in situ removal treatment. Also, less volatile organic compounds may not be easily removed by even secondary or tertiary treatment processes. The utilization of hydraulic isolation may be the solution in these situations. Hydraulic isolation can be used as a follow-up to in situ treatment after removal of a major portion of the contamination.

There are three different in situ hydraulic isolation methods: surface cover, subsurface barriers and sorption processes.

The surface cover method generally involves placement of a clay or concrete cover over a defined contaminated area to prevent percolation of surface water into the contaminated zone to contact the contaminants below the surface.

Subsurface barriers include a number of isolation techniques:

- Slurry trench walls
- French drain
- Sheet pile
- Interceptor ditch
- Curtain grouting

The first four types of hydraulic barriers are best for hydraulic isolation of low permeability media and shallow depths (20 to 40 ft maximum). Curtain grouting involves injection of impervious material into permeable strata to block off potential migration pathways in the subsurface environment.

Sorption in situ treatment is a relatively new technology involving replacement of the permeable strata in a known contaminated area with a specially formulated fluid with both absorption and adsorption properties. In the absorption process, the material will expand up to 30 times its original volume while absorbing the contaminant and blocking off or filling in the pore spaces. Due to the microscopic size of the material, the large surface area of contact with contaminants will make an effective sealant to the permeable pathways when contaminants are released. The formulated fluid will work for both polar and non-polar organic compounds. Since this treatment process is still in the experimental stage, it may not be very cost-effective at the present time.

A shallow interceptor ditch may work in relatively low permeable saturated material. The ditch may act and perform like a line of hundreds of wells. Sometimes a combination of the in situ hydraulic isolation techniques may work for sites with multiple organic compounds of different physical and chemical properties when other treatment processes do not provide a total solution.

IN SITU ALTERATION

In situ alteration treatment involves the breakdown of hazardous organic compounds into harmless compounds. It has been demonstrated that biodegradation of non-halogenated organic compounds to harmless compounds can be effected in surface aerobic treatment of sludge and waste water. The same result can be attained in subsurface conditions which control the growth of aerobic bacteria. The parameters controlling bacterial growth and metabolism are:

- Pressure
- Temperature
- pH
- Salinity
- Dissolved oxygen
- Nutrients
- Biotoxins
- Radiation
- Mixing

The transport mechanism in the vadose and saturated zones is the major problem that hinders subsurface treatment. If the contaminated fluid can be pumped to the surface, it is better to perform surface treatment. The application of the in situ alteration process should not be a primary means of treatment.

The in situ alteration treatment of halogenated hydrocarbons is still in the experimental stage. The recent advances are well documented in the references found at the end of this paper. The process of breakdown of halogenated hydrocarbons depends on the successful control of methanogenic conditions (addition of methane mixed with air to the contaminated soil and water). When aerobic bacteria are exposed to methanogenic conditions, selective species will degrade the halogenated organic compounds into carbon dioxide and chlorides which are harmless compounds. While the researchers are developing a better understanding of the mechanism of degradation, forseeable problems of field application are as follows:

- Aerobic bacteria only occur in shallow depths
- A specially formulated carrier fluid must be coupled with methane and other nutrient when introduced underground
- Introduction of methane gas underground may create hazardous conditions (i.e., explosion) if not properly contained

Table 1
Practical Application of In Situ Treatment of Volatile Organics

In-situ Treatment Techniques	Vadose Zone		Saturated Zone	
	Less Pervious	Permeable	Less Pervious	Permeable
Removal				
• Pumping/evacuation to create sink	Yes, but difficult	Yes need (b) or (c)	Yes, but difficult	Yes, need (a) (b) or (c)
• Flushing	NA	Yes, need (a) (b) or (c)	NA	Yes, need (a) (b) or (c)
• Elevated temperature enhancement	Yes, but not effective	Yes, need (b) or (c)	Yes, but not effective	Yes, need (a) (b) or (c)
Isolation				
• Surface cover	Yes	Yes	Yes	Yes
• Subsurface barriers	Yes	Yes	Yes, depth considerations	Generally NA
• Sorption	NA	Yes, need (d)	NA	Yes, need (d)
Alteration				
• Aerobic Process	Demonstrated for non-halogenated organic compounds. Experimental for halogenated organic compounds. Need to couple with removal techniques.			
• Anaerobic Process	Experimental, need pilot program. Need to couple with removal techniques.			

NA Not applicable
(a) Air stripper
(b) Oil stripper
(c) Activated carbon adsorption
(d) Detail geohydrologic definition

Table 2
Practical Application of In Situ Treatment of Acid/Base Neutral Extractables, Pesticides and Herbicides

In-situ Treatment Techniques	Vadose Zone		Saturated Zone	
	Less Pervious	Permeable	Less Pervious	Permeable
Removal				
• Pumping/evacuation to create sink	NA	NA	NA	Need (a) or (b)
• Flushing	NA	Need (c)	NA	Need (a) or (b) and (c)
• Elevated temperature enhancement	NA	Long duration	NA	Long duration
Isolation				
• Surface cover	Yes	Yes	Yes	Yes
• Subsurface barriers	Yes	Yes	Yes, depth considerations	Generally NA
• Sorption	NA	Yes, need (c)	NA	Yes, can be expensive
Alteration				
• Aerobic Process	Demonstrated for non-halogenated organic compounds. Experimental for halogenated organic compounds. Need to couple with removal techniques.			
• Anaerobic Process	Experimental, need pilot program. Need to couple with removal techniques.			

NA Not applicable
(a) Oil stripper
(b) Activated carbon adsorption
(c) Detail geohydrologic definition

The understanding of the anaerobic degradation of halogenated organic compounds is in its infancy, but it has great potential. Because of the low cost of bacteriological processes, it is worthwhile to have engineers perform opportunistic trial and error experiments on both laboratory bench and field pilot tests using this technique. Once demonstrated, the cost saving over other in situ treatment alternatives may be substantial.

At the present state of knowledge of biodegradation, there is immense room for improvement and development of original research and application. Hopefully, the economic advantage of innovative in situ technology will push the alteration techniques to a major breakthrough in the near future.

PRACTICAL APPLICATIONS

The above mentioned in situ treatment techniques may work individually or in combination for specific contamination cases. However, there is no general formula to produce an optimal remediation solution for a case-specific problem.

An attempt is made to provide a general guidance for practical application of the specific in situ treatment techniques on organic compounds in the vadose and saturated zones in Tables 1 and 2. These tables will not provide a total solution for a specific site. However, they will provide an individual with an opportunity to evaluate the "cans," "cannots" and effectiveness of the full spectrum of the available alternatives.

These in situ treatment techniques are only one aspect of the total remediation plan. The engineer will still have to consider regulatory standards and permits, economic feasibility and long-term risks and liability for a total remediation program.

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Assessment of Volatile Organic Emissions from a Petroleum Refinery Land Treatment Site

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ABSTRACT

A field assessment was performed to measure the emissions of volatile organics from a petroleum refinery land treatment site. As part of this study, the emissions of total volatile organics from surface-applied and subsurface-injected oily sludge were measured over a 5-week period. The effect of soil tilling on the emissions also was monitored.

Volatile organics emission rates were measured using the emission isolation flex chamber method. Soil samples were collected during the test periods to determine soil properties, oil levels and microbe count. Soil surface and ambient temperatures, both inside and outside the flux chambers, were measured throughout the test periods.

INTRODUCTION

The U.S. EPA currently is developing background information on air pollutants at hazardous waste treatment, storage and disposal facilities (TSDFs) to provide supporting data for setting standards as necessary under Section 3004 of RCRA as amended in 1984. This regulatory development is the responsibility of the Office of Air Quality Planning and Standards (OAQPS). The U.S. EPA Hazardous Waste Environmental Research Laboratory-Cincinnati (HWERL) has the responsibility of providing technical support to OAQPS in the area of atmospheric emissions determination from hazardous waste management.

In order to assess emissions from hazardous waste TSDFs, a field study was performed at a land treatment facility located at a large West Coast petroleum refinery. This study was intended to: (1) measure the total volatile organics emission rates from surface- and subsurface-applied oily refinery sludge and (2) to determine how emissions of volatile organics varied with time. Based on these measurements the total emissions over a 5-week period were estimated.

Little work has been performed to characterize volatile organic emissions from large full-scale land treatment sites. The study approach and selected results are summarized in this paper. A more detailed description of the work and its limitations in included in a previous U.S. EPA report.[1] The emissions of individual measured compounds are provided in that U.S. EPA report.

DESCRIPTION OF THE TEST SITE

The test site was located at a large West Coast refinery. The land treatment area covers approximately 42,000 m^2 (10 acres). Three test plots, each approximately 420 m^2 (0.1 acre) in area, were located side-by-side at one corner of the facility. The area containing the test plot has been in land treatment service for several years.

During normal operation, sludge from refinery operations is collected and stored in a fixed-roof tank at the land treatment area. The sludge is injected subsurface using an 8,000 l (50-barrel) capacity injector vehicle equipped with four separate injector tines. The injector vehicle consists of a tractor and an 8,000 l (50-barrel) capacity tank trailer. The tines are attached to the tank trailer. The waste is injected 15 to 28 cm below the surface and immediately disked by a disk unit pulled behind the injector vehicle. The area is cultivated with a disk and/or rototiller several times per week until the next sludge application.

According to the operators of this facility, the annual application rate at this site is about 5.4 - 9.1 $\times$ 10^6 kg/year, and the individual application rates are typically about 16 l/m^2 (400 barrels/acre). The sludge typically consists of 50 to 75% DAF/API separator float, 20 to 30% API separator sludge and about 5% miscellaneous oily waste. The soil is irrigated periodically to maintain proper soil moisture content.

EXPERIMENTAL APPROACH

The experimental design, sampling techniques, analytical methods and test procedures are summarized below.

Experimental Design

The experimental design of this program was developed to obtain data of sufficient accuracy to fulfill the major objectives of the study. The primary emphasis of the program was on obtaining volatile organics emission rate measurements. The test design was a synthesis of two sampling strategies for obtaining emission measurements: totally randomized sampling over the test plots and semi-continuous sampling at a single location in each plot.

To provide an overall estimate of the volatile organics emission rate for a total test plot area, a number of measurements at randomly selected points must be performed. One method of ac-

complishing this is to divide the area into discrete segments and then randomly select segments to be tested. On the other hand, the best strategy for examining the change in emission rate with time is the repeated sampling of a limited number of points over a period of time.

Three test plots were used in this study. Sludge was surface-applied to one plot (Plot A) and subsurface-injected at another plot (Plot C). In between these two plots was a third plot (Plot B) with no sludge applied. Plot B served as a baseline or control plot. Each plot was approximately 420 m² (0.1 acre) in size, and each was divided into 21 segments, as shown in Figure 1, to provide for randomized sampling.

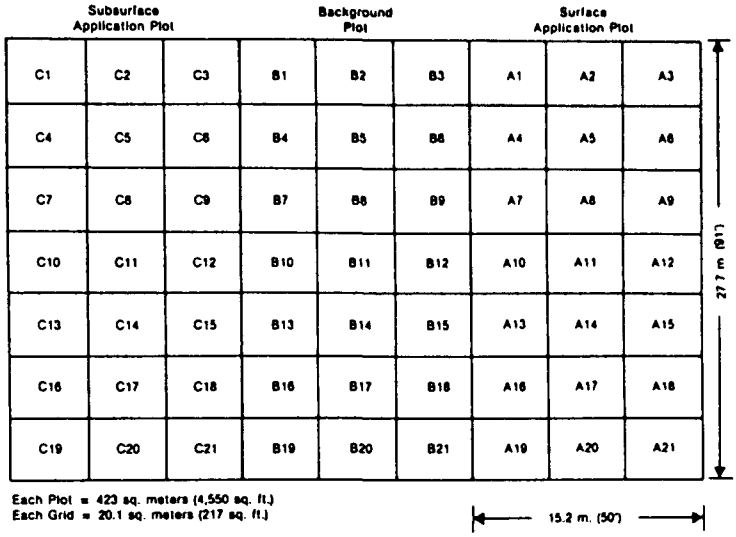

Figure 1
Test Plot Grid Assignment for Assessment of Emissions from Land Treatment of Petroleum Wastes

Sampling schedules for each plot were developed for each separate day of sampling. Each sampling day was divided into two parts. During each half day, one sampling crew made measurements at the surface-applied plot, and the other crew performed similar measurements at the subsurface injected plot. Each crew performed emission measurements at two separate control points, at two randomly selected points in their assigned plot and at one randomly selected point in the control plot. Random number tables were used to select the order of sampling, the crew used on each plot and the equipment set used by each crew. The sampling order for composite soil samples, soil cores, gas samples and their associated duplicates within a given plot were also randomly selected. A typical daily sampling schedule is shown in Table 1.

Table 1
Typical Daily Sampling Schedule

Approximate Time	Grid Point[a]	Flux Chamber Sampling Crew ID	Flux Chamber Sampling F/C ID[b]	Samples Collected Canister	Soil	Syringe	Comments
	TEXT PLOT A	DATE:	11/09/84	APPLICATION METHOD:		SURFACE	
0800	—	002	003	-	-	X	QC
0845	A07[c]	002	003	-	X	X	
0930	B03	002	003		X	XX	
1015	A05	002	003	-	-	X	
1100	A19[c]	002	003	X	X	X	
1145	A01	002	003	-	-	X	
1230	—	002	003	-	-	-	TIII
1400	A07[c]	002	003	X	-	X	
1445	A19[c]	002	003	X	-	X	
1530	B14	002	003	X	-	X	
	TEST PLOT A	DATE:	11/09/84	APPLICATION METHOD:		SUBSURFACE	
0800	—	001	002	-	-	X	QC
0845	C11[c]	001	002	X	X	X	
0930	C13	001	002	-	-	X	
1015	C14	001	002	-	-	X	
1100	C15[c]	001	002	-	-	XX	
1145	B15	001	002	-	-	X	
1230	—	001	002	-	-	-	TIII
1315	C15[c]	001	002	X	-	X	
1400	C11[c]	001	002	-	-	X	
1445	C04	001	002	-	X	X	
1530	C06	001	002	X	X	X	
1615	B03	001	002	-	-	X	

a. Prefix A, B, C refers to plot A (surface applied), plot B (background or control plot), and plot C (subsurface applied).
b. F/C = flux chamber
c. Control points

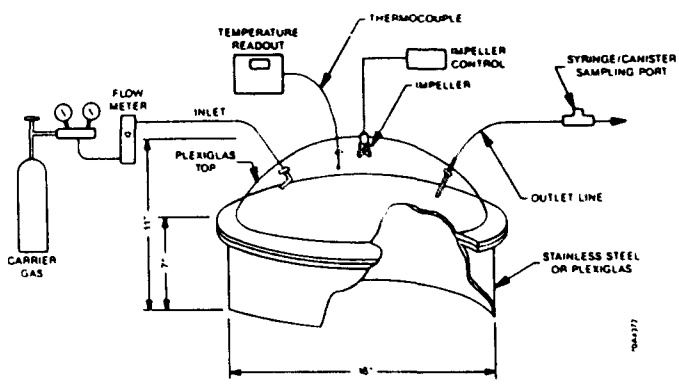

Figure 2
Cutaway Side View of Emission Isolation Flux Chamber and Sampling Apparatus

Sampling Procedures

The main sampling technique employed at this site involved the direct measurement of emissions using the emission isolation flux chamber. The enclosure emission measurement approach has been used by others to measure emission fluxes of sulfur and volatile organic species.[2,3,4]

A diagram of the flux chamber is shown in Figure 2. The flux chamber was placed on the emitting surface. Clean, dry air was passed through the chamber at a controlled and measured rate. The concentration of the specie(s) of interest was measured at the outlet of the chamber. The emission rate of the measured specie(s) from the enclosed surface was then calculated from the flow rate and concentration in the gas.

The flux chamber encloses a surface area of 0.13 m² and has a volume of 0.031 m³. The sweep air flow rate was 0.003 - 0.005 m³/min. Air samples were collected from the outlet gas line using both gas-tight syringes (for on-site analyses) and evacuated stainless steel canisters (for off-site analyses).

Liquid grab samples of the sludge and of the service water used to irrigate the soil were collected. Sludge from two tank trucks was transferred to the application vehicle (tractor) and applied to the soil. Each tank truck held two application tractor loads. After the first load was transferred from the tank truck to the application tractor, 4-6 sample containers were filled with sludge from the tractor. The samples were collected consecutively, while the tractor tank was full, from a gravity-fed line. While two tractor

loads were required to empty each tank truck, samples were collected after only one of the two transfers from each tank truck load. One service water sample was collected from the plant service water line to determine the concentration of organics in this water which the facility applies as part of its site management technique.

Two types of solid samples were collected: soil composites and undisturbed soil cores. Both types of samples were collected immediately adjacent to points where flux chamber measurements were made. Soil composites were used in the determination of oil and moisture contents. These samples were collected using a hand auger and boring to a depth of 30 to 40 cm. The undisturbed soil samples were used for determining the physical properties of the soils. They were obtained by driving a brass sleeve approximately 20 cm into the ground, removing the sleeve and capping both ends.

Type K thermocouples were used to monitor the air and soil temperatures both inside and outside each flux chamber. Two separate thermocouples were used to measure soil surface temperatures inside and outside the flux chamber. Each was placed in the ground to a depth of 1.3 to 1.9 cm.

Analytical Procedures

The on-site analyses were limited to gas-phase analyses of the air samples collected in gas-tight syringes from the outlet of the flux chambers. A Byron Instruments Model 401 Total Hydrocarbon (THC) Analyzer was used to determine the concentrations of total hydrocarbons (THC), CO_2 and methane in the effluent air samples from the flux chamber.

The off-site analyses included the chemical speciation of the flux chamber air samples collected in stainless steel canisters and of the liquid sludge and water samples collected at the land treatment site. The oil, moisture and microbe levels in the soil also were determined, as were the physical properties of the soil samples.

Chemical speciation of the air and liquid samples for C_2 and C_{10} hydrocarbons was performed with a Varian 3700 Gas Chromatograph. The chemical species were cryogenically concentrated to increase the sensitivity of the analyses. Liquid samples were analyzed using a purge-and-trap technique modified to utilize the cryogenic trap. For both air and liquid samples, total volatile organics concentrations were obtained as the sum of the species concentrations.

The oil, water and solids contents of the sludge samples were determined by solubilizing the oil and water in the waste with tetrahydrofuran (THF). This liquid phase was then separated from the insoluble solids. Residual solids were weighed, and the amount of water in the THF was determined by Karl Fischer titration. The oil content was calculated by difference. The oil and grease content of the soil samples was determined using U.S. EPA Method 413.1. Standard methods were used to determine the bulk density, particle density, total porosity, moisture content and particle size distribution.

Sludge Application

The sludge was applied as evenly as possible to the surface-applied Plot A (SA plot) and to the subsurface-injected Plot C (SSA plot). The application tractor started injecting sludge at grid point (GP) C19 (Fig. 1) and moved across Plot C from GP C19 through GP C21. The injector then was lifted above the soil, and the tractor proceeded across Plot B (control plot) from GP B19 across GP B21. No sludge was applied to Plot B. Sludge then was allowed to flow from the raised injector tines onto the surface of Plot A as the tractor passed across it from GP A19 through GP A21. The tractor then made a U-turn and returned across Plots A, B and C while applying sludge. Several application passes were made to complete the application to the entire area of Plots A and C. Three complete tractor loads and part of another were required. The average waste loading was 1.4×10^4 kg/plot. All three plots were tilled with a disk tiller pulled behind the tractor during the sludge application.

Emission sampling with the flux chambers was started immediately after application and continued for 4 days. Emission sampling was performed during two other 4-day periods in the 3rd and 5th weeks following application. Each plot was tilled 2-3 times per week during the 5-week test period. The plots also were irrigated with water once between the first and second sampling periods and three times between the second and third sampling periods. The complete tilling and irrigation schedule for the test period is summarized in Table 2.

Table 2
Tilling Schedule for Land Treatment Facility During Test Study

Date	Tilling Time	Hours from Start[a]	Activity
10-10-84	0950-1030	0	Apply waste and till
10-12-84	1224-1258	50.5	Till
10-15-84	0930-1100	120.5	Till and irrigate
10-16-84	1300-1400	147.5	Till
10-18-84	0800-0930	191	Till
10-19-84	1300-1430	220	Till
10-24-84	1222-1235	338.5	Till
10-26-84	1218-1233	386.5	Till
10-29-84	0815-0930	455	Till
10-30-84	0900-1100	480	Till and irrigate
10-31-84	1000-1100	504.5	Till
11-01-84	0900-1100	528	Till and irrigate
11-02-84	0900-1030	552	Till
11-05-84	1300-1430	628	Till and irrigate
11-09-84	1225-1245	722.5	Till
11-12-84	1047-1110	793	Till

a. Rounded off to nearest 1/2 hour.

SAMPLING AND ANALYSES RESULTS

The results of the sample analyses for the gas, liquid and soil samples are summarized below.

Gas Samples

The results of the on-site Byron THC analyses agreed quite well with the off-site Varian 3700 analyses. The results were correlated with a correlation coefficient of 0.977. The Varian GC generally gave slightly higher concentrations, with an average difference of 13.8% between the Byron and Varian instruments.

No methane was detected in any of the on-site samples analyzed with the Bryon 401, which is capable of detecting methane at levels of 1 ppm.

The CO_2 concentrations in the on-site gas samples were found to range from about 50 ppm to almost 500 ppm. Most values fell between 100 and 300 ppm. Background CO_2 levels, as determined by sealing the bottom of the flux chambers and passing air through them, were in the range of 10 to 200 ppm.

Liquid Samples

The sludge samples were analyzed several times to define the sludge nonhomogeneity and obtain an average value for the level of volatile organics. The analyses were performed over a period of several months (during which the samples were kept under refrigeration). The measured volatile organics content of the sludge, as determined with the purge-and-trap technique, ranged from 4,250 to 16,600 μg/g. Most volatile organics concentrations were between 4,000 and 6,000 μg/g, with the mean value being 7,800 μg/g. The variability was believed to be at least partially attributable to the difficulty of obtaining a representative sample in small quantities for analysis. The sludge volatile organic component was made up principally of paraffins (average concentration = 3,600 μg/g), olefins (1,200 μg/g) and aromatics (2,900 μg/g). The remainder of the volatiles were halogenated and oxygenated hydrocarbons and unidentified organics. From the characterization tests, the sludge was found to consist of 3.9 to 4.5% solids, 57.5 to 59.1% water and 37.0 to 38.0% oil.

The sample of service water used to irrigate the soil was also analyzed for volatile organics to determine whether this water could be a significant source of volatile organics (this sample was kept under refrigeration and analyzed approximately 3 months after collection). The volatile organics content was found to be 0.089 mg/l. The total amount of volatile organics applied with the water over the duration of the test was estimated to be about 0.03 kg/plot. This amount is equivalent to less than 0.5% of the volatile organics applied in the sludge.

Soil Samples

The mean values for the physical properties determined for the soil samples are summarized in Table 3. Also included are the mean moisture content and oil/grease levels for the collected samples. The results are summarized for two of the three sampling periods.

Table 3
Mean Soil Properties

Test Week	Particle Density (g/cm^3)	Moisture Content (wt %)	Bulk Density (g/cm^3)	Porosity, (%)	Oil and Grease (mg/g)
1	2.50	7.40	1.21	52	64
3	2.54	7.89	1.42	44	56

STATISTICAL ANALYSES OF THE DATA

A statistical analysis was performed primarily to investigate the effects of time, temperature inside the chamber (soil and air), plot samples, location within each plot and chamber shading on emission rates. The frequency distribution of the emission rate data was highly skewed and a log normal distribution was used to model the frequency distribution of emission rates. To determine whether measurable differences existed among the emission rates from the test plots, an analysis of covariance was performed. The analysis of covariance technique eliminates the variation in emission rates due to other variables such as time, temperature (inside the chamber) and chamber surface shading. In this way, the average emission rates for the test plots can be directly compared. A discussion of the analysis of covariance can be found in Brownlee.[5]

The statistical analysis indicated that the emission rates were significantly affected by test plot and elapsed time. The results of the statistical analysis are summarized in Table 4. Soil or air temperatures within the chamber were marginally significant. None of the other variables were found to have a significant affect on the emission rates.

Table 4
Components of Variability

Source of Variability	Variance Component[a]	Percent of Total Variance[b]	Percent of Total Minus Temporal Variance
Temporal (day-to-day)	58.3	63.0	—
Air Temperature in Chamber	3.3	3.6	9.6
Plot	28.1	30.4	82.2
Sampling Location (within the plot)	1.4	1.5	4.1
Surface Chamber Shading	0.42	0.4	1.2
Sampling/Analytical	1.0	1.1	2.9
Total	92.5	100	100

a Variance components are equal to standard deviations squared and thus have units which are the squares of that used for the log-emission rates $(\mu g\ m^{-2}\text{-}sec)^2$

b Relative contribution of parameters to the total variance

The oil and moisture contents of the soil samples were examined to determine whether there was any significant change with time in these parameters. There appeared to be little change in the oil content of the soil over the duration of the test. The moisture content of the soil appeared to decrease by about 14 to 40% over the test period. Both changes were so small that no correlation with emission rates could be determined.

MEASURED VOLATILE ORGANICS EMISSION RATES

The volatile organics emission rates were examined with respect to elapsed time since application, ambient conditions at the time of sampling and tilling activities.

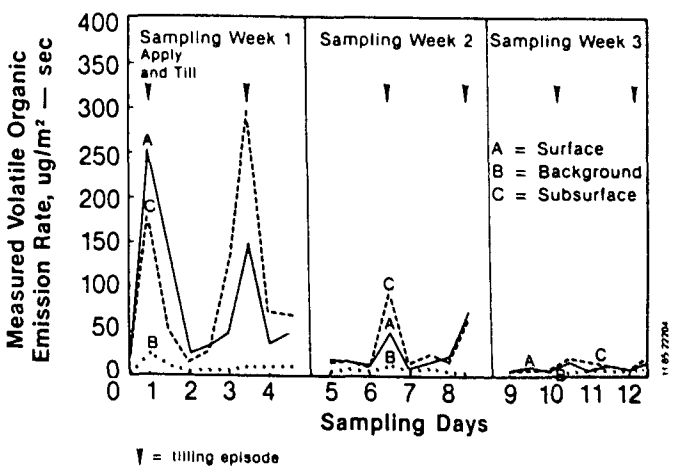

Figure 3
Measured Emission Rates as a Function of Time Elapsed Since Sludge Application

Table 5
Average Measured Emission Rates by Plot by Half-Day

Sampling Day	Date	Emission Rate ($\mu g/m^2$-s) A Plot (Surface)	B Plot (Background)	C Plot (Subsurface)	Comments
0	10-09-84	1.88	1.48	1.95	
1	10-10-84	249	24.7	176	
	10-10-84	142	10.0	52.8	
2	10-11-84	22.5	4.09	13.8	early start
	10-11-84	32.6	5.11	26.5	
3	10-12-84	48.2	4.09	120	
	10-12-84	146	9.93	295	tIII
4	10-13-84	33.4	8.18	71.2	
	10-13-84	46.3	8.86	67.4	
5	10-23-84	16.6	2.71	12.4	
	10-23-84	15.0	6.13	15.1	
6	10-24-84	8.04	2.73	10.1	
	10-24-84	49.1	10.0	91.3	tIII
7	10-25-84	6.41	2.04	12.1	early start
	10-25-84	13.5	5.80	22.0	
8	10-26-84	21.8	1.32	13.0	
	10-26-84	71.1		59.3	tIII
9	11-08-84	2.56	2.59	2.93	
	11-08-84	7.25		5.76	
10	11-09-84	1.24		3.94	
	11-09-84	12.34	1.22	16.2	tIII
11	11-10-84	2.49	1.39	11.5	
	11-10-84	6.4	1.43	7.13	
12	11-12-84	2.97	1.19	4.06	
	11-12-84	10.5	4.42	16.2	tIII

Each Plot Area = 423 m^2

Effect of Elapsed Time from Application on Emission Rates

The measured emission rates for the three plots are shown as functions of elapsed time in Figure 3. The average measured emission rates are summarized for each half-day of sampling. These rates are tabulated in Table 5. The first point (Day 0) was measured before sludge application. The tabulated values and the figure show the approximately exponential decline in emission rates with time elapsed from application (and, to some extent, elapsed time from tilling episodes). The emission rates from the control Plot B remained substantially below those of the test plots throughout the duration of the testing.

The cumulative measured volatile organics emissions are summarized in Table 6 and shown graphically in Figure 4. An approximately exponential decline in the emission rates is evident.

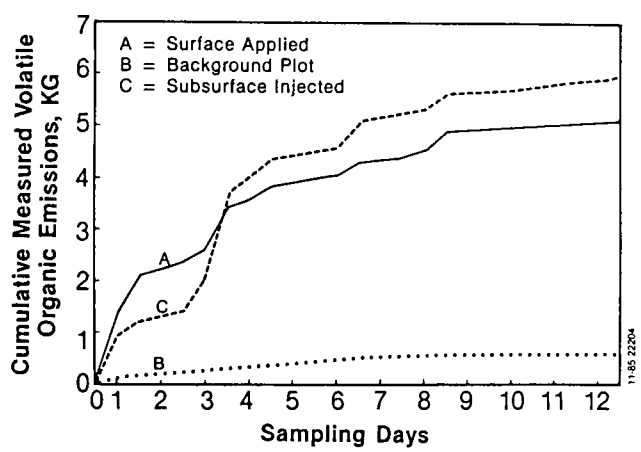

Figure 4
Cumulative Measured Emissions as a Function of Sampling Day (includes only measured rates for days on which sampling was performed)

Table 6
Cumulative Measured Emissions

Sampling Day	Emission Rate (kg) A Plot (Surface)	B Plot (Background)	C Plot (Subsurface)	Comments
1	1.327	0.1317	0.938	
	2.084	0.1850	1.219	
2	2.204	0.2068	1.293	early start
	2.378	0.2340	1.434	
3	2.634	0.2558	2.074	
	3.413	0.3088	3.646	tIII
4	3.591	0.3524	4.026	
	3.837	0.3996	4.385	
5	3.926	0.4140	4.451	
	4.006	0.4467	4.531	
6	4.049	0.4613	4.585	
	4.310	0.5146	5.072	tIII
7	4.345	0.5254	5.136	early start
	4.417	0.5563	5.254	
8	4.533	0.5634	5.323	
	4.912		5.639	tIII
9	4.925	0.5772	5.655	
	4.964		5.685	
10	4.971		5.706	
	5.036	0.5837	5.793	tIII
11	5.050	0.5911	5.854	
	5.084	0.5987	5.892	
12	5.100	0.6051	5.914	
	5.156	0.6286	6.000	tIII

Each Plot Area = 423 m^2

Effect of Tilling on Emission Rates

Tilling of the soil had a significant effect on the emission rate. The effect can be seen clearly in Figure 3 as spikes in the emission rates immediately after tilling. The percentage increase in average emission rates by half-day immediately following tilling episodes is shown for each plot in Table 7. The five tilling episodes for which emission measurements were made were distributed among the three sampling periods.

Table 7
Increase in Emission Rate Due to Tilling

Observed Tilling Episode	Percent Increase in Emission Rate A Plot (Surface)	B Plot (Background)	C Plot (Subsurface)
1	303	243	246
2	611	366	904
3	326	0[a]	456
4	995	0[a]	411
5	354	371	399

a. Incomplete data set

ESTIMATED EMISSION RATE FOR THE 5-WEEK TEST PERIOD

The emission rates and cumulative emissions for the entire 5-week test period were estimated from the measured rates. The following assumptions were made to estimate the total emissions:

- Tilling had no effect on emission rates beyond 6 hours after tilling occurred
- Each day had 12 hours of cooler temperatures (night)

The emission rates were estimated for three distinct times during each sampling period. These were: (1) nighttime, (2) non-tilling daytime and (3) tilling daytime. The nighttime emissions for each sampling period were estimated from the emission rate data obtained during the early morning hours of that period. The tilling and non-tilling day emissions for each sampling period were derived from the appropriate emission rate measurements. Emissions for the interval between sampling periods were obtained by interpolation among the three emission rates for the three sampling periods. Summing all the night-time, non-tilling daytime and tilling daytime emissions, the total emissions for each of the plots for the 5-week period were estimated to be:

Plot A (surface applied):	33.3 kg
Plot B (control):	5.2 kg
Plot C (subsurface inj.):	39.0 kg

The estimated total emissions per plot per week are shown in Figure 5.

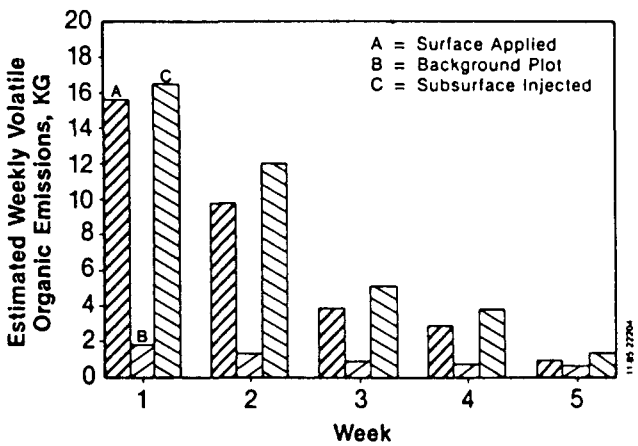

Figure 5
Total Estimated Weekly Emissions from Each Plot

CONCLUSIONS

The results of the detailed sampling and analysis of total volatile organic emissions from this land treatment facility indicate that emissions from both surface-applied and subsurface-injected waste varied in a similar, approximately exponentially decaying manner over the 5-week period of this test. This result is in agreement with the predictions of the Thibodeaux-Hwang emissions model for surface-applied plots.[6]

Also, the effect of tilling is similar for both application methods. Tilling resulted in a 2- to 10-fold increase in the emission rates. A large portion of the 5-week cumulative emissions from both plots is due to emissions which occurred within 4 hours after tilling was performed. The magnitude of emissions which occurred immediately after tilling decreases from tilling event to tilling event approximately in proportion to the decrease in emissions during non-tilling periods.

Based on a statistical analysis of the emissions, it was found that the emission rates were significantly affected by the elapsed time. Soil and air temperatures within the chamber were marginally significant. None of the other variables that were monitored were found to have a significant effect on the emission rates.

NOTICE

The information in this document has been funded wholly or in part by the U.S. EPA under contract to Radian Corporation. It has been subject to the Agency's peer and administrative review, and it has been approved for publication. Mention of tradenames or commercial products does not constitute an endorsement or recommendation for use.

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Technology for Remediation of Groundwater Contamination

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ABSTRACT

The AquaDetox* technology is a high-efficiency stripping technology for the removal of organics from water. The technology was developed by the Dow Chemical Company for internal use through considerable process research, and only recently has the technology become available for general use outside of Dow via a licensing program.

Two types of AquaDetox* units are available, air or steam AquaDetox*. Air AquaDetox* is capable of efficient removal of chlorinated solvents and other pollutants considered easily strippable from water. Steam AquaDetox* is used for the removal of low-volatility organic materials from water including many compounds not considered strippable by any prior process technology.

The technology has a wide range of applications including removal of 92 of the 111 organic priority pollutants as well as other organic materials. It is applicable to the removal of trace quantities of organics in water intended for drinking water purposes with the capability of producing waters with organic concentrations from $\mu g/l$ down to non-detectable levels.

This paper describes the AquaDetox* technology, describes its potential applications and presents economic and operating data from several operating commercial units.

INTRODUCTION

Extensive groundwater contamination from both active and inactive sites has been identified across the United States. It has been stated that more than 700 synthetic organic chemicals have been discovered in groundwater resulting from over 30 different types of sources of contamination. The House Public Works Subcommittee of Investigations and Oversight has estimated from an inquiry last year that 4,000 city drinking wells were affected by hazardous waste seepage into groundwater. Hence, the subcommittee has assessed groundwater contamination as potentially one of the most expensive problems confronting Congress and the country.

ERT has been involved extensively in the assessment of groundwater contamination at a variety of active and inactive sites. These efforts have focused largely on determining the nature and extent of contamination, modeling the migration of contaminants beyond the site boundaries, assessing risks associated with this off-site migration and preparing conceptual approaches to remediating the contamination as a means to reduce risk to acceptable levels. To address the implementation of cost-effective remediation strategies, ERT has licensed a high efficiency air/steam stripper known as the AquaDetox™ technology from Dow Chemical.

This paper discusses the current regulatory climate governing groundwater remediation, describes the AquaDetox technology (including selected performance/economic case studies) and provides an overview of ERT's approach to offering it to the industry.

Regulatory Overview

In response to the growing concern for groundwater quality, the U.S. EPA has developed a national groundwater protection plan which is derived from eight different laws passed by Congress. This plan divides groundwater into three classifications based on its use or potential use. There are specific groundwaters that are irreplaceable drinking water sources and are particularly vulnerable to contamination; groundwaters that are currently used or available for drinking water; and groundwaters that are not potential sources of drinking water because they already are contaminated.

Under the various statutes, drinking water aquifers will be protected using RCRA (and its 1984 amendments) to discourage pollution from landfills, the Superfund law to select areas for urgent cleanup and TSCA to develop additional restrictions on the use and storage of potentially threatening chemicals over these areas. Other laws to be used by the U.S. EPA and state agencies to control groundwater pollution are: the Clean Water Act under its construction grants provisions; the Uranium Mining and Mill Tailings Reclamation and Control Act (radioactive contamination); and the Federal Insecticide, Fungicide and Rodenticide Act (pesticide contamination). Last, the National Environmental Policy Act's sole source aquifer program and the Safe Drinking Water Act's provisions for controlling underground injection will also be used.

With regard to the Safe Drinking Water Act, current versions of the Senate and House both refer to Phase I and Phase II lists of contaminants which the U.S. EPA published in 1982 and 1983. The Senate version of the Act requires the U.S. EPA to set standards for 85 contaminants with nine regulations due within a year, another 40 within 2 years and the remainder within 3 years.

In January 1988, the U.S. EPA will be directed to publish a new list of 25 priority pollutants with a year to propose recommended and maximum contaminant levels and an additional year to promulgate final standards. This process is to repeat on a 3-year cycle. The House version of the Act addresses 64 contaminants and dictates either the promulgation of regulations or a

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determination that no rational basis exists to believe the contaminant may have adverse health effects. This action must be completed on 14 volatile organic compounds within a year, and decisions on the remaining contaminants are due within 3 years. Beginning in 1988, the bill demands annual priority lists for possible regulation, calling for standards within 3 years of publication.

Under either version of the Act, the U.S. EPA must propose filtration and disinfection as treatment for drinking water. The target maximum contaminant levels will be set as close to health-based recommended maximum levels as possible, considering cost and available technology. In both cases, granular activated carbon (GAC) is suggested, though not mandated, as the "feasible" technology. Generally speaking, however, GAC is a very expensive treatment technology, and trade organizations such as the Synthetic Organic Chemical Manufacturer's Association, as part of a Safe Drinking Water Coalition, have stated that GAC is too expensive and impractical. It is this same thinking which led to the development of the AquaDetox stripping technology by the Dow Chemical Company and ERT's participation as a Licensee of that technology.

The AquaDetox™ Technology

The technology was developed by the Dow Chemical Company for internal use through considerable process research and only recently has it become available for general use outside of Dow via a licensing program. AquaDetox achieves high stripping efficiency at lower operating and capital costs when compared to other technologies or unit operations. In many cases, removal of organic contaminants, including many which have boiling points in excess of 200 °C and are typically considered "not strippable," can be achieved by a single, continuous stripping operation.

The process has a wide range of applications including removal of 92 of the 111 organic priority pollutants as well as other organic materials. It is applicable to the removal of trace quantities of organics in water intended for drinking purposes with the capability of producing waters with organic concentrations from μg/l down to non-detectable levels. The ability to achieve these low levels of organics can eliminate the need for a polishing step using GAC.

Two types of AquaDetox units are available as shown in Figures 1 and 2. The air unit is capable of extremely efficient removal of chlorinated solvents such as perchloroethylene, trichloroethylene, 1,1,1-trichloroethane, methylene chloride and other pollutants considered easily strippable from water. The steam AquaDetox is used for the removal of low volatility organic mateials from water including many compounds not considered strippable by any prior process technology. For example, it has effectively removed chlorinated phenols (i.e., pentachlorophenol) and chlorinated benzenes. The steam unit also removes easily strippable pollutants from water when vent gas emissions from the air process are unacceptable.

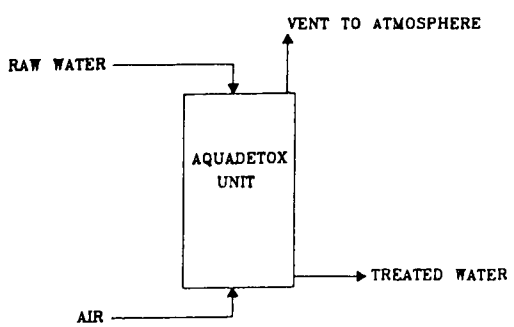

Figure 1
Air AquaDetox Unit

Primary Advantages

The benefits afforded by the application of AquaDetox units are many. First and foremost, it is a fully developed, proven technology. The Dow Chemical Company has 12 units operating at its Michigan Division treating a range of process wastewaters at flow rates of 10 to 3,000 gal/min. In addition, four field applications of AquaDetox for outside firms have been installed and are operating on contaminated groundwater.

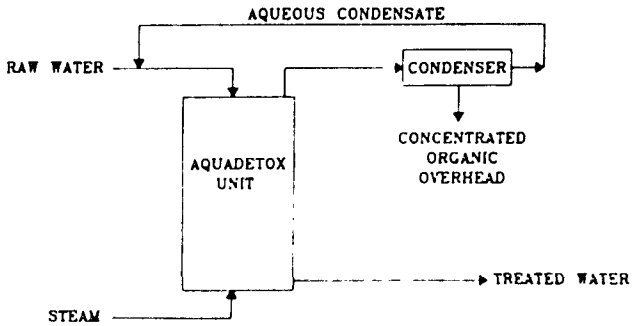

Figure 2
Steam AquaDetox Unit

The continuous nature of the technology offers simplicity of operation as compared to batch processes and has low maintenance requirements and low operating costs (as will be demonstrated in the following section). The technology provides maximum flexibility for the sizing and location of units for both permanent and mobile installations. Finally, its ability to achieve high-efficiency removal (99 to 9.99%) of organics to achieve at least μg/l levels makes it a viable alternative to GAC, which is expensive, introduces solids handling equipment and poses disposal and/or regeneration problems.

PERFORMANCE/ECONOMIC CASE STUDIES

Current applications of the AquaDetox technology have demonstrated its ability to cost-effectively remove organics from water. Three case studies emphasizing groundwater remediation are briefly presented to demonstrate this point.

Case Study No. 1

An air AquaDetox was applied to groundwater contaminated with 1,1,1-trichloroethane, methylene chloride, trichloroethylene and perchloroethylene. The system was designed to treat a 10 gal/min stream and achieved extremely high removal efficiencies for all pollutants as shown in Table 1.

The estimated capital cost for this installation was $80,000 with an operating cost (including utilities, labor, maintenance, taxes and depreciation) of $2.82/1000 gal (or $0.0028/gal). This compared to an estimated GAC operating cost of $20.42/1000 gal for the same level of pollutant removal.

Table 1
Performance Data: Air AquaDetox
Case Study No. 1

	Pollutant levels, ppm	
Pollutant	Contaminated Groundwater	Treated Effluent
1,1,1-Trichloroethane	220	0.08
Methylene Chloride	180	non-detectable
Trichloroethylene	60	non-detectable
Perchloroethylene	24	non-detectable

Case Study No. 2

A steam AquaDetox system was installed to treat groundwater contaminated with 6,000 mg/l of a wide variety of organics shown in Table 2. Typical pollutant removals from this 10 gal/min stream exceeded 99% with several in excess of 99.99%.

Estimated capital cost for the unit was $225,000 with an operating cost of $10.00/1000 gal (or $0.010/gal). Estimated GAC operating costs to achieve these levels of pollutant removal were $113 to $135/1000 gal of water.

Table 2
Performance Data: Steam AquaDetox
Case Study No. 2

Pollutant	Pollutant levels, ppm: Contaminated Groundwater	Treated Effluent	Percent Removal
Methylene choride	18	0.0007	99.996
1,1,1-trichloroethane	434	0.0019	99.999
Isopropanol	5674	0.191	99.996
Acetone	772	2.7	99.6
MEK	252	0.01	99.996
2-butanol	399	0.014	99.996
MIBK	130	0.002	99.998
2-hexanol	21	0.059	99.7

Case Study No. 3

An air AquaDetox system was utilized to treat groundwater contaminated with trace quantities of toluene (22,000 μg/l) and benzene (150 μg/l). The technology achieved an effluent quality with respect to both pollutants of less than 2 μg/l, the analytical detection limits.

This removal was achieved at an estimated operating cost of $1.35/1000 gal versus an estimated cost for carbon adsorption of $16.00/1000 gal.

OTHER CONSIDERATIONS

One of the primary considerations when evaluating the use of stripper technologies for groundwater contamination is the acceptability of the vent gas discharge. In general, this is evaluated on a case-by-case basis at the state level, but it is estimated that less than half-a-dozen states have any specific legislation at this time. The crux of the matter centers on a cost-benefit analysis where the trade-offs are between the additional cost to control vent gas emissions (or avoid them entirely) using GAC and the health risk to these uncontrolled emissions.

Since a number of industries already emit volatile organic carbon at legal levels much higher than those under consideration for the groundwater cleanup situation, the key question becomes whether a reduction of the already low health risk, especially with the rapid dispersion of pollutants, is worth the price of controlling air emissions from groundwater cleanup. To put this issue into perspective, it has been determined in many instances that the concentrations of pollutants in the vent gas prior to their dispersion in the atmosphere do not exceed OSHA workplace standards for the individual pollutants. Clearly, each application will have to be reviewed individually with consideration given to the relative health risk associated with the lack of control of such emissions.

In instances where vent gas control is dictated, the use of GAC to remove the pollutants from the gas may be considered. Such a combination of stripping and GAC has been applied on a Superfund site in Michigan and has proven cost-competitive with direct adsorption of the organics from the water. This competitiveness has been enhanced by the incorporation of humidity control prior to the carbon beds since the adsorptive capacity of GAC is reduced dramatically when it gets wet.

CONCLUSION

As a process wastewater treatment technology, AquaDetox can be used alone or in combination with GAC or biological treatment systems to produce a more cost-effective or reliable operating system.

Anaerobic Biological Treatment of Sanitary Landfill Leachate

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ABSTRACT

The anaerobic treatment of sanitary landfill leachate was investigated in bench-scale studies at ambient room temperature. The test runs were conducted in continuous operation for more than 6 months using the leachate collected directly from the leachate collection sump installed at a lined landfill site. No pre-adjustments of pH or other chemical or physical features were made. The leachate used in the study showed highly variable characteristics with a COD of 2,000 to 35,000 mg/l, BOD_5 of 1,800 to 24,000 mg/l and ammonia nitrogen of 50 to 500 mg/l.

An anaerobic fixed-flim reactor, with a volume of 22.24 l and with a controlled rate of sludge recycling, was operated with upflow feeding at organic loading between 0.23 and 2.48 kg COD/m^3/day and hydraulic detention times of 6.9 to 10.3 days.

The test resulted in filtered COD removals from 92 to 94%, unfiltered BOD_5 removals of 90-94% and ammonia removal from 40 to 50%. Despite the wide range of loading conditions, the system showed a high level of stability in terms of COD removal efficiency which hovered about 93%. With influent COD of 1,700 to 17,000 mg/l, the effluent leaving the system was in the range of 100 to 1,300 mg/l, depending on the organic loading rate. The effluent can be further purified by an aerobic biotreatment unit to reduce the COD and BOD_5 levels below 250 and 35 mg/l, respectively.

INTRODUCTION

The landfill is located off Route 17M east of the Wallkill River in the Town of Goshen, Orange County, New York (Fig. 1). The site was designed to protect surface and groundwater from leachate contamination by utilizing the following technologies:

- Low permeability on-site glacial till material used as soil liner to minimize the impact of leachate on adjacent surface and groundwater
- A sloped landfill bottom to direct leachate toward a collection system
- A leachate collection piping system to intercept and collect the leachate
- A collection well with level-controlled pumps that transfer the leachate collected in the landfill to a geomembrane-lined pond, thus maintaining the hydraulic head in the landfill at a low level

The leachate management issues currently facing the landfill are the establishment of a feasible and economically sound disposal scheme that will meet the needs of the current operation and future closure of the landfill, and the acquisition of permits from state and/or local agencies for disposal of the leachate generated.

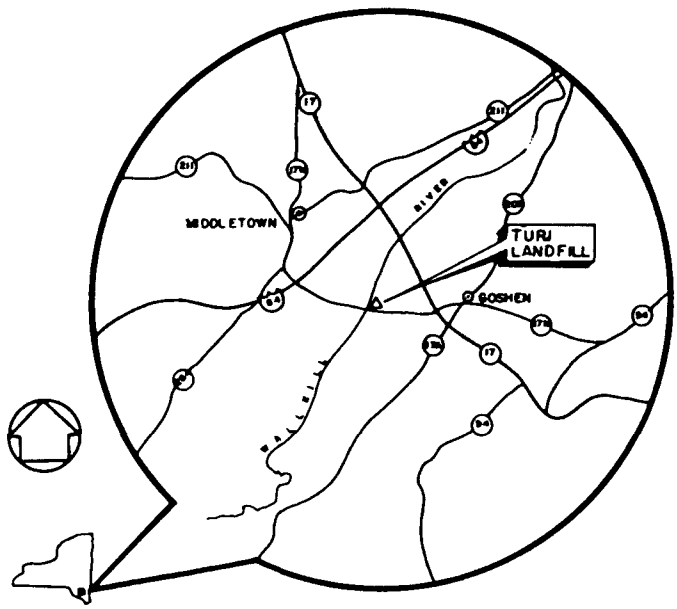

Figure 1
Location Map — Turi Landfill

Wehran Engineering has been retained to conduct a study that will provide a viable system for leachate treatment and to furnish the necessary framework for implementation.

This paper includes a detailed investigation of all relevant features and data pertaining to leachate treatment. Specifically, the scope included the following:

- Analysis of leachate characteristics to determine the quality and quantity of leachate generated by the site
- Performance of bench-scale treatability tests to confirm the technical feasibility of on-site treatment options
- Development of engineering design criteria

Quantity and Characteristics of Leachate

An extensive monitoring, sampling and analysis program was conducted for a period of 1 year at Turi Landfill to determine the quantity and quality of leachate generated from the operational cell of the landfill. Weekly and monthly samples were collected during this period and analyzed in the laboratory.

The weekly samples were analyzed for the conventional pollutant parameters of chemical oxygen demand (COD), 5-day bio-

chemical oxygen demand (BOD_5), total solids (TS), ash, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), hardness, conductivity and pH.

The monthly samples were analyzed for iron (Fe), zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), manganese (Mn) and total phosphate ($T\text{-}PO_4$).

Leachate Flow

The flow of leachate generated in the active landfill operation is shown in Table 1. The actual monthly average daily leachate flow, measured in the operating landfill area for the period between April 1984 and March 1985, ranged from 100 to 18,000 gal/day, with an annual average of 6,300 gal/day. The variation in flow probably is due to the absorptive characteristics of the solid waste.

Characteristics of Leachate

Starting in November 1984, sampling and analysis of the conventional pollutant parameters described above were performed as part of the study program. In conjunction with this sampling and analysis, leachate flows were recorded weekly.

With the exception of pH, the pattern of changes in the concentrations of these pollutant parameters appears to be in general correlation with the changes in leachate flows. The concentration changes are inversely proportional to the leachate flow rates which may be attributed to the percolation of rainfall. The external water percolation in the landfill will thus act as a dilutant in carrying leachables out of the landfill bed.

Table 1
Leachate Generation Rates

	Measured Values				Estimated Values (5)			
Month	Ppt (1) (inch)	Perc (2) (inch)	Ratio (3)	Flow (4) (gpd)	Ppt (inch)	Perc (inch)	Ratio (3)	Flow (gpd)
April 84	4.65	1.080	0.23	12,840	3.86	2.12	0.55	25,135
May	10.03	--	--	--	4.22	1.48	0.35	17,548
June	3.95	0.270	0.07	3,212	3.86	1.35	0.35	16,006
July	6.27	0.430	0.07	4,920	4.01	1.41	0.35	16,717
Aug.	2.61	0.290	0.11	3,367	3.39	1.19	0.35	14,109
Sept.	1.18	--	--	--	3.01	1.06	0.35	12,567
Oct.	2.88	--	--	--	3.03	1.67	0.55	19,800
Nov.	2.58	0.008	0.03	92	2.88	1.59	0.55	18,852
Dec.	2.99	0.540	0.18	6,139	2.46	2.09	0.85	24,780
Jan. 85	1.06	0.127	0.12	1,463	2.46	1.23	0.50	14,584
Feb.	1.99	1.430	0.72	18,192	2.68	1.34	0.50	15,888
March	2.21	0.516	0.23	5,916	3.88	3.30	0.85	39,127
Annual	42.4	4.7+	--	--	39.74	19.83	--	--
Average Monthly			.19	6,239			.50	19,584

Notes:
(1) Precipitation (ppt) from climatological data, Middletown Station, NY, NOAA.
(2) Calculated percolation (perc) through cover soil and underlying solid wastes based on actually measured leachate flow within 13.1 acres of operating landfill.
(3) Ratio of perc to ppt.
(4) Actual leachate flow measured.
(5) Calculated leachate flow, based on the estimated values of percolation for 13.1-acre area.

The range and average concentrations for the conventional pollutant parameters during the study's test period are given in Table 2. The ranges are comparable with reported ranges for sanitary landfills published in technical literature.[4,7]

Table 2
Leachate Characteristics - Turi Landfill

Parameter	Range	Arithmetic Average
BOD_5	180 - 36,900 mg/l	12,042 mg/l
COD	200 - 45,800 mg/l	19,527 mg/l
Ammonia Nitrogen	5 - 640 mg/l	340 mg/l
Organic Nitrogen	1 - 140 mg/l	46 mg/l
Total Solids	1,005 - 25,330 mg/l	14,367 mg/l
Ash	805 - 13,580 mg/l	7,037 mg/l
Hardness	345 - 9,460 mg/l	5,647 mg/l
Conductivity	900 - 15,500 umhos/cm	9,360 umhos/cm
pH	5.30 - 6.00	5.55

The monthly results for the metals and total phosphate analyses are summarized in Table 3. These concentrations are comparable to reported ranges for sanitary landfills.[4] All concentrations observed in this study are below reported threshold limits for biological assimilation in a wastewater treatment facility.[1,4,8]

Table 3
Monthly Analysis of the Concentration of Metallic Elements and Phosphates

Metallic Elements	10/25/84	12/20/84	1/24/85	2/27/85	4/4/85
Fe	770.00	420.00	1,100.00	1,140.00	840.00
Cu	0.05	0.08	0.05	0.05	.35
Pb	0.05	0.05	0.16	0.05	.14
Mn	190.00	41.00	310.00	200.00	200.00
Zn	11.00	14.00	33.00	6.30	11.00
Cd	0.01	0.01	0.01	0.01	.01
$T\text{-}PO_4$	8.40	1.90	3.40	2.50	6.50

Note: All units are in mg/l

The concentrations of priority pollutants which were present in the leachate at levels above analytical detection limits are given in Table 4. All organic chemicals on the list are reported to be effectively removed by conventional biological treatment processes at both POTWs and industrial wastewater treatment facilities.[1]

Leachate Treatability Evaluation

A review of the literature reveals that leachate may be treated by aerobic[1,2,3,4,6,9] or anaerobic biological processes[7,8], physical methods and chemical means.[4,9] Existing reports discuss mainly laboratory-scale studies.

Bench-Scale Treatability Tests

In the selection of systems for a treatability study, consideration was given to the processes available at local POTWs, industrial wastewater treatment facilities and for the purchase of packaged treatment systems for possible on-site use. The following process techniques were chosen for the bench-scale treatability studies:

- Aerobic bio-oxidation system utilizing local POTW activated sludge for the evaluation of maximum ratio of leachate to sewage flow
- Anaerobic biological system for treating raw leachate
- Aerobic treatment for polishing the effluent of the anaerobic system
- Physical/chemical treatment for removing solids or COD as a pre-treatment or post-treatment process

Table 4
Concentrations of Detectable Priority Pollutants in Turi Landfill Leachate

Parameter	Reported Concentration (mg/l)
Benzene	0.025
Chloroethane	0.062
Dichlorodifluoromethane	0.089
1,1-Dichloroethane	0.301
1,2-Dichloroethane	0.081
1,2-Dichloropropane	0.015
Ethylbenzene	0.051
Methylene Chloride	2.600
Tetrachloroethylene	0.079
Toluene	1.000
1,2-Trans-Dichloroethylene	0.228
1,1,1-Trichloroethane	0.111
Trichloroethylene	0.130
Vinyl Chloride	0.010
Diethyl Phthalate	0.076
Isophorone	0.067
Naphthalene	0.010
Arsenic	0.018
Cadmium	0.015
Chromium	0.240
Copper	0.027
Lead	0.090
Nickel	0.390
Selenium	0.007
Zinc	12.000
Total Cyanide	0.100
Total Phenolics	4.000

The bench-scale treatability tests were performed using the following equipment:

- For anaerobic biological system: A fixed film upflow reactor, 6 in. diameter × 5 ft high with hydraulic detention time of 7 days, was used in a plug flow mode with recycle (Fig. 2).
- For aerobic bio-oxidation system: A 4-l reactor with air diffusers was used in a completely mixed mode. Sludge was wasted directly from the unit or recycled from a settling unit to maintain the desired MLVSS under aeration (Fig. 3).
- For physical/chemical test: A multiple stirrer, Phipps-Bird stirring apparatus was used to test the effect of coagulation/precipitation with lime, caustic and/or alum.

POTW ACTIVATED SLUDGE TOLERANCE STUDY

In this test, activated sludge seed from the Harriman Wastewater Treatment Facility was aerated in a bio-oxidation unit. The system was run to a steady state MLVSS with a sewage and nutrient feed prior to the addition of raw leachate. Once the bench-scale activated sludge system achieved this steady state, raw leachate was added in ratios of raw leachate to sewage of 1 to 5%.

The results of this study are given in Table 5. At dosage ratios of raw leachate to raw sewage greater than 2%, the aerobic treatment system is adversely impacted. The system failed to maintain a steady state MLVSS at a 5% dosage, and higher order organisms were observed. At the high dosage levels, increased phosphate addition on the order of 1,000 mg/l was necessary for adequate cell development.

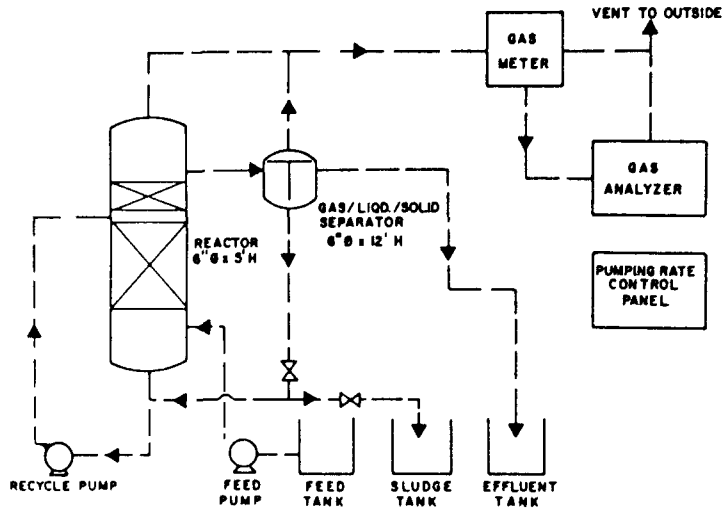

Figure 2
Bench-Scale Anaerobic Fixed Film Biological Treatment System

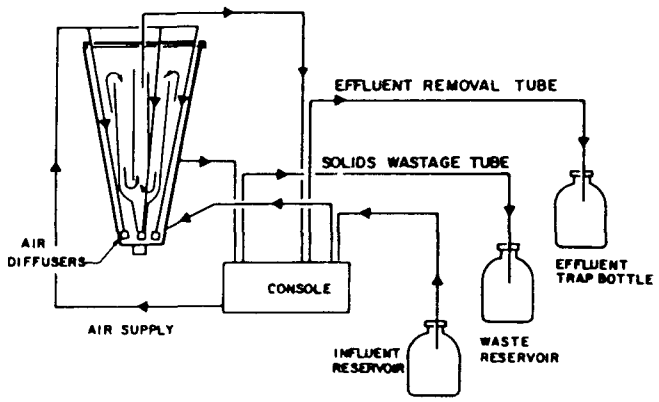

Figure 3
Aerobic Bio-Oxidation Treatment Unit

Table 5
POTW Tolerance Study of Aerobic Bio-Oxidation System Treatment of Leachate

Raw Leachate/ Raw Sewage (%)	Average COD Removal (%)
1	81
2	70
3	54
4	37
5*	12

*At 5% the system could not attain a steady state MLVSS

ANAEROBIC TREATMENT

The parameters monitored in studying the efficiency of the anaerobic biological treatment system were COD, BOD_5 and TVA. The total volatile acid removal (TVA) is an important step in methane fermentation and is therefore included. The results for the removal of these parameters are summarized in Table 6.

In evaluating the anaerobic treatment of landfill leachate, the removal of COD and BOD are the most important parameters to study. As can be seen from the data in Table 6, the efficiency of

Table 6
Anaerobic Test Results of Leachate Treatment

Run	BOD_5 (mg/l)			COD (mg/l)			TVA (mg acetate/l)		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal
1	--	--	--	1,670	100	94.0	1,730	405	76.6
2	4,500	390	91.3	6,480	355	94.5	6,520	660	89.9
3	8,775	855	90.3	13,430	935	93.0	12,300	1,545	87.4
4	11,250	960	91.5	16,990	950	94.4	14,485	925	93.6
5	11,625	1,200	89.7	16,990	1,275	92.5	14,160	1,710	87.9
6	8,700	540	93.8	9,875	545	94.5	8,060	205	97.5

*TVA is total volatile acids.

the removal of these two parameters is quite constant. For Run No. 1, which had an organic loading rate of 0.23 kg COD/m^3 • day, the COD removal was 94%, while with an organic loading rate of more than 10 times that in Run No. 1, the COD removal rate (Run No. 5) was 92.5%. The system showed an ability to operate efficiently under a wide range of COD loading conditions, which is an important characteristic in the treatment of landfill leachate. In conjunction with the COD removal, the study of two other system paramters is important: methane and sludge production.

Methane Production

One of the major advantages of the anaerobic process is that organic material in the wastewater is converted to methane gas. The methane gas evolution rates and composition for the anaerobic treatability study are summarized in Table 7.

Table 7
Gas Production Data for Anaerobic Treatment of Leachate

Run	Gas Evolution Rate (ml/hr)	Methane (%)	Methane Rate (l/day) (at STP)
1	125	67	1.84
2	500	71	7.81
3	745	64	10.48
4	965	70	14.85
5	1,350	67	19.89
6	745	---	10.97

To determine the efficiency of the methane fermentation, the experimental gas production rate can be compared to the theoretical value which is 0.35 l CH_4/g of organics removed. The methane production rates are shown as a function of the removal of BOD, COD and TVA in Table 8.

Table 8
Methane Production Rates for Anaerobic Treatment of Landfill Leachate
Gas Rate as a Function of Organic Removal

Run	Liters CH_4/ g COD removed	Liters CH_4/ g BOD removed	Liters CH_4/ g TVA removed
1	0.39	---	0.46
2	0.42	0.53	0.44
3	0.39	0.61	0.45
4	0.43	0.67	0.51
5	0.39	0.59	0.49
6	0.36	0.41	0.43

As can be seen, methane production rates determined from experimental removal of organics are higher than theoretical rates. This may be a result of average daily influent conditions actually being higher than those detected in the samples analyzed; this would mean that the organics removal rate is higher than the rate used in the calculations. An important finding of this portion of the study is that the methane production rate was directly proportional to the organics loading rate.

Solids Production

Another advantage of the anaerobic system is the low solids production rate. Sludge production from anaerobic biological treatment systems typically ranges from 0.04 to 0.10 g VSS/g COD removed. The sludge production rates as a function of organics removal are summarized in Table 9. The amounts of solids produced were estimated from the increase in volatile solids concentrations in the circulation stream.

Table 9
Anaerobic Sludge Production in Treatment of Landfill Leachate

Run	(g/day)	COD Removed (g/day)	TVS/ COD (g solid/g COD removed)
2	2.82	18.52	.15
3	2.81	26.99	.10
4	1.67	34.64	.05
5	6.67	50.92	.13
Average			.11

The sludge production of the anaerobic digestion of the leachate was slightly higher than normal anaerobic sludge production, yet the amount of sludge was still significantly lower than the amount of sludge produced by a conventional activated sludge process.

AEROBIC TREATMENT OF ANAEROBIC EFFLUENT

The aerobic treatment of the effluent from the anaerobic system was conducted in a fill and draw manner. Anaerobic effluent was added to activated sludge from the Harriman Sewage Treatment Plant, and the system was aerated. Samples were drawn from the system at 12, 24 and 48 hrs for analysis. The characteristics of these samples were compared to the anaerobic effluent that was added initially. The test was conducted with COD and BOD values of 1,300 and 200 mg/l. The MLSS, MLVS and SVI values were 8,100, 3,950 and 135, respectively.

Table 10
Results of Aerobic Treatment of Anaerobic System Effluent

Hour	COD	COD % Removed	BOD	BOD % Removed	NH_3-N	NH_3-N% Removed	COD/BOD_5
0	1,300	--	1,200	--	135	--	1.1
12	400	69.2	100	91.7	110	18.5	4.0
24	260	80.0	70	94.2	45	66.7	3.7
48	235	81.9	35	97.1	5	96.3	6.7

The removal of the conventional pollutants (COD, BOD and NH_3-N) was monitored to determine the efficiency of the process. The results of these tests are summarized in Table 10.

Removal of BOD and COD

In discussing the removal of organics by the aerobic system, an important parameter to consider is the ratio COD/BOD_5.

The general trend is an increase of the COD/BOD ratio with increased aeration. This increase is due to a rise in the non-biodegradable portion of the leachate over time. The test for chemical oxygen demand will detect some organics which are non-biodegradable and thus will not be measured by the BOD test. As the aeration time increases, the biodegradable organics will be removed by the system microorganisms, and the non-biodegradable organics will represent an increasing proportion of the remaining organics.

Based on the results of this test, we concluded that a removal rate of 80% of the COD and 95% of the BOD is attainable by the conventional aerobic treatment systems.

Removal of Ammonia

The aerobic system removes ammonia by the process of nitrification; the ammonia is oxidized to nitrate. The bacteria responsible for nitrification have a growth rate slower than that of the bacteria responsible for the removal of organics. Thus, it is expected that a longer aeration time will be required for the removal of NH_3-N than that for BOD. As can be seen from the test results, the removal of BOD was as high as 90% in only 12 hr, while an aeration time of 48 hr was needed to remove 96% of the ammonia.

Solids Production

The production of sludge is an important parameter in the design of the aerobic process. Table 11 contains a summary of the solids production as a function of the amount of organics removed.

The reported range of sludge production for activated sludge is 0.25 to 04 g of VSS formed per gram of COD removed. The results of the bench-scale aerobic polishing unit indicate an average sludge production rate of 0.68 g VSS per g COD removed. This increased sludge production is attributed to the extended aeration time and the lack of sludge wasting in the test to maintain a steady state MLVSS. The results do indicate that under typical conditions for aerobic biological treatment, the sludge production from treatment of the leachate would be within the expected range for such systems.

Table 11
Aerobic Sludge Production for Treatment of Anaerobic System Effluent

Time (hrs)	COD (mg/l)	MLVSS (mg/l)	COD Removed (mg/l)	MLVSS Increase (mg/l)	MLVSS/COD
0	1,300	1,610	--	--	--
12	400	1,860	900	250	.28
24	260	2,030	1,040	420	.40
48	235	3,060	1,065	1,450	1.36
Average					.68

CHEMICAL COAGULATION/PRECIPITATION

The effect of chemical coagulation and precipitation on COD and suspended solids removal also was evaluated in this study. The test conditions for the study are summarized in Table 12. In this test, the samples were dosed with the coagulating chemicals, rapidly mixed using a Phipps-Bird stirring apparatus at 50 revs/min for 30 sec, flocculated at 15 revs/min for 20 min and then allowed to settle for 30 min. The supernatants then were sampled and analyzed for COD and TSS.

Table 12
Chemical Coagulation/Precipitation Treatment Operating Conditions

Waste Stream	Chemical Coagulant Dosages $Ca(OH)_2$ (mg/l)	NaOH (mg/l)	Alum (mg/l)
Raw Leachate	1. 800-4200	--	--
	2. 2800	--	0-333
	3. --	1200	0-333
Anaerobic Effluent	1. 1800	--	0-333
	2. --	--	0-333
	3. --	--	0-333
	4. --	--	0-2000
Aerobic Effluent	1. --	--	0-1455
	2. --	--	0-1500
	3. --	--	0-2000

The results for the chemical coagulation/precipitation treatability studies on the raw leachate, anaerobic filter effluent and aerobic polishing unit effluent are presented in Tables 13, 14 and 15, respectively.

Table 13
Results of Chemical Coagulation/Precipitation Treatment of Raw Leachate

Run	Chemical Coagulant Dosages (mg/l) $Ca(OH)_2$	NaOH	Alum	Parameters COD (mg/l)	COD Percent Removed	TSS (mg/l)	TSS Percent Removed
1	0	--	--	31,740	--	3,700	--
	830	--	--	32,105	--	1,400	62.2
	1,670	--	--	32,230	--	900	75.7
	2,500	--	--	32,350	--	--	--
	3,330	--	--	31,130	1.9	5	99.9
	4,170	--	--	31,660	0.3	600	83.8
2	0	--	0	31,335	--	3,780	--
	2,800	--	0	30,805	1.7	2,045	45.9
	2,800	--	33	31,700	--	2,585	31.6
	2,800	--	83	30,600	2.4	3,050	19.3
	2,800	--	167	31,660	--	1,540	59.3
	2,800	--	333	30,805	1.7	1,495	60.5
3	--	0	0	26,110	--	4,915	--
	--	1,200	0	22,010	15.7	3,340	32.0
	--	1,200	33	22,560	13.6	4,535	7.7
	--	1,200	83	22,440	14.1	3,560	27.6
	--	1,200	167	23,665	9.4	1,765	64.1
	--	1,200	333	--	--	955	80.6

Table 14
Results of Chemical Coagulation/Precipitation Treatment of Anaerobic Filter Effluent

Run	Chemical Coagulant Dosages (mg/l) $Ca(OH)_2$	Alum	Parameters COD (mg/l)	Percent Removed	TSS (mg/l)	Percent Removed
1	0	0	485	--	--	--
	1,800	0	600	--	45	--
	1,800	33	600	--	5	--
	1,800	83	620	--	35	--
	1,800	167	550	--	0	--
	1,800	333	625	--	35	--
2	--	0	610	--	120	--
	--	33	620	--	80	33.3
	--	83	575	5.7	40	66.7
	--	167	560	8.2	70	41.7
	--	250	555	9.0	45	62.5
	--	333	530	13.1	50	58.3
3	--	0	980	--	39	--
	--	83	955	2.6	12	69.2
	--	167	955	2.6	19	51.3
	--	333	880	10.2	37	5.1
4	--	0	685	--	45	--
	--	1,000	635	7.3	--	--
	--	1,500	565	17.5	--	--
	--	2,000	585	14.6	8	82.2

Table 15
Results of Chemical Coagulation/Precipitation Treatment of Aerobic Polishing Unit Effluent

Run	Chemical Coagulant (mg/l) Alum	Parameters COD	Percent Removed	TSS	Percent Removed
1	0	235	--	--	--
	545	220	6.4	--	--
	910	205	12.8	--	--
	1,455	180	23.4	--	--
2	0	320	--	70	--
	500	310	3.1	50	28.6
	1,000	270	15.6	20	71.4
	1,500	245	23.4	20	71.4
3	0	485	--	240	--
	1,500	360	25.8	2	99.2
	2,000	330	32.0	--	--

Removal of COD

Raw Leachate

Of the three tests run, only the addition of caustic and alum showed any significant reduction in COD, and this was less than 20%. The addition of lime only, and lime and alum showed no appreciable decrease in COD from pH elevation or coagulation. The results of the third run indicate that the best COD removal was obtained with caustic alone, and that alum was ineffective as a coagulating agent for COD removal.

The results obtained in this study indicate that chemical coagulation and precipitation processes do not appear to be adequate as a pretreatment process for disposal of the leachate either off-site at a POTW or through an on-site treatment system.

Anaerobic Filter Effluent

The results of the chemical coagulation and precipitation of the anaerobic filter effluent indicate that large dosages of alum are required to obtain moderate removal efficiencies. The results of the second and third runs indicate that a dosage of 333 mg/l of alum results in a 10-13% removal of COD. By increasing the dosage to 1,500 mg/l in Run No. 4, a removal of only 17.5% is attained. These results indicate that an increase in the alum dosage of 500% results in only a 5% increase in COD removal. This process is, therefore, not considered effective for reducing residual COD from the anaerobic filter effluent.

Table 16
Operating Conditions and Performance of Bench-Scale Anaerobic Filter

	Operating Conditions: Hydraulic Det. Time (days)	kg COD/ m^3 day Org. Loads	Removals: Percent COD rem.	Products: g VS/ g COD rem. Solids Prod.	LCH_4/gCOD rem.	LCH_4/g VFA rem.
Run 1	7.7	0.216	94.0	--	0.478	0.760
Run 2	7.3	0.419	94.6	0.150	0.458	0.672
Run 3	10.3	1.302	93.7	0.100	0.418	0.504
Run 4	10.3	2.100	94.0	0.040	0.497	0.596
Run 5	6.8	2.380	92.0	0.112	0.434	0.656

* liters of methane produced/g COD removed

Table 17
Summary of Performance of the Four Treatment Systems

Process	Performance in Removal of COD (%)	NH_3-N (%)
Anaerobic system	94	49
Aerobic system	80	95
Alum coagulation	25	--
Integrated efficiency	99.1	97.5

Aerobic Polishing Unit Effluent

The results presented in Table 15 indicate that very high levels of alum (1,500-2,000 mg/l) will remove only 25-30% of the COD in the aerobic polishing unit's effluent. This process, therefore, is not considered effective for removing any residual COD in the aerobic polishing unit, should such removal be essential to meet discharge standards.

Removal of Suspended Solids

Raw Leachate

The test results presented in Table 13 indicate that effective suspended solids removal in the raw leachate is achieved only with very high dosages of lime (3,330-4,170 mg/l). Such high dosages generate proportionally high sludge volumes which would require further processing for proper disposal.

Based on these results, we concluded that this process is not effective as a pretreatment process for disposal of the leachate either off-site at a POTW or through an on-site treatment system.

Anaerobic Filter Effluent

The results presented in Table 14 indicate that effective removal of suspended solids in the anaerobic filter effluent is achieved only with high levels of alum (2,000 mg/l). At lower dosages (33-83 mg/l), moderate removals were attained, indicating that this process may be viable for solids removal in conjunction with a clarification system, should subsequent biological or physical/chemical treatment for residual organics and ammonia-nitrogen require pretreatment for solids removal.

Aerobic Polishing Unit Effluent

The results presented in Table 15 indicate that relatively high levels of alum (1,000 mg/l) effectively reduce the suspended solids level in the aerobic polishing unit's effluent to acceptable discharge standards (20 mg/l). Full-scale clarification units, with tube or plate settlers, may reduce the chemical dosage required to achieve this effluent quality. This process is considered viable for consideration as a polishing treatment for suspended solids removal.

CONCLUSIONS

The laboratory bench scale study using an anaerobic fixed-film reactor for the treatment of sanitary landfill leachate demonstrated the amenability of the process and its application for the stabilization of leachate.

The landfill raw leachate was rapidly adopted by the sludge used in the anaerobic fermentation system. Hydraulic detention times as short as 7 days and organic loads up to 2.2 kg COD/m^3 day resulted in a 94% removal of COD. The gas produced in the system was composed of 60-70% combustible material. Based on the rate of gas production, we estimated that more than 99% of the COD removed was converted to CH_4 gas.

The process performance with respect to COD removal and gas production at various loading conditions is shown in Table 16. The removal of COD and the rate of solids production were very steady. The response of process performance to changes in organic or hydraulic loads was reflected in the rates of methane production; however, the efficiency of COD removal remained unaffected for the conditions tested.

The performance of the activated sludge system for treating the effluent from the anaerobic filter was much better than anaerobic treatment alone. With a loading of 0.90 g COD/g MLVSS, the system attained removals of 80 and 95% for COD and NH_3 – N, respectively, within 48 hr of aeration. The estimated rate of sludge formation in the aerobic system was 0.41 g/VS/g COD removed.

The series of tests conducted in the bench-scale treatability study have confirmed that the landfill leachate can be treated with the use of conventional biological and physical/chemical processes. The effluent qualities achievable are comparable to the effluent of wastewater treatment plants with secondary treatment facilities. Since the processes tested are all conventional technology, the equipment required for use is commercially available.

Based on the results of each test included in this treatability study, a combination of anaerobic and aerobic treatment in series alum coagulation could achieve more than 99% removal of COD from raw leachate.

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On-Site Versus Off-Site Treatment of Contaminated Groundwater — An Evaluation of Technical Feasibility and Costs

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ABSTRACT

The Pollution Abatement Services, Inc. (PAS) site is an abandoned hazardous waste incinerator site located in the City of Oswego, New York. Groundwater contamination has resulted due to leakage from a surface impoundment, buried tanks and drums—both above and below ground. The principal groundwater contaminants include volatile organic compounds, organic acids and other low molecular weight organics, and nickel, which also appears to be organically bound.

Groundwater recovery and leachate collection were included in the site remediation plan. Alternatives considered for treatment of the groundwater/leachate were: (1) hauling to an off-site commercial treatment facility, (2) conveyance to the local POTW and (3) on-site treatment. The relative merits of these alternatives were evaluated on the basis of the degree of treatment technically achievable and the relative cost.

Critical to the evaluation was the identification and demonstration of technology capability for treatment of the groundwater/leachate. Initial laboratory treatability studies demonstrated that biological treatment followed by carbon adsorption was required for cost-effective treatment, while carbon adsorption alone was not effective. Further studies demonstrated the feasibility of the treatment system on an intermittent basis—a necessary requirement based on the expected low rate of groundwater/leachate recovery.

In this analysis, the costs and ultimate selection of a groundwater/leachate treatment alternative were sensitive to several factors including: (1) the wastewater character, (2) the wastewater volume and rate of recovery and (3) the degree of treatment required. On-site treatment was offered a higher degree of treatment than would be achievable at the local POTW and a lower cost than would be expended for hauling to an off-site commercial facility.

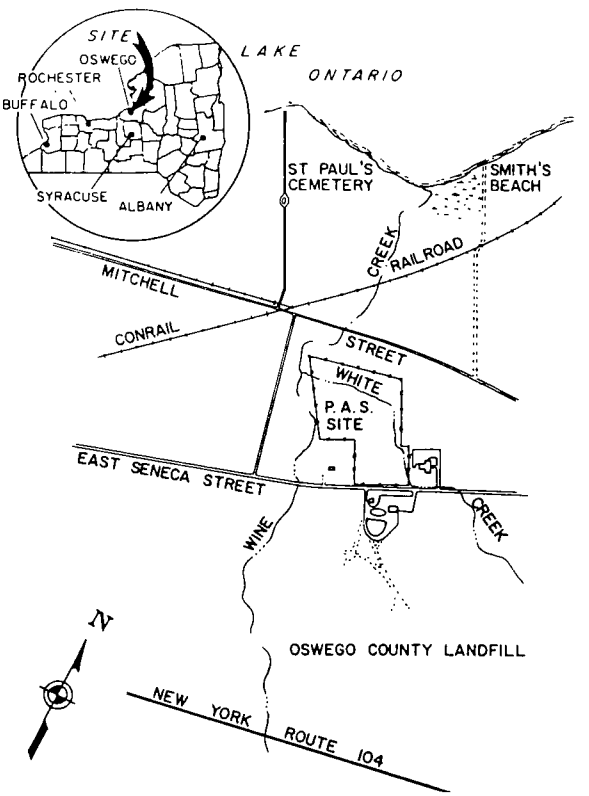

Figure 1
Location of the Pollution Abatement Site

INTRODUCTION

The Pollution Abatement Services, Inc. (PAS) site, located near the eastern limit of the City of Oswego, New York (Fig. 1), is an abandoned hazardous waste facility which is listed among the top 10 priority sites on the U.S. EPA's National Priorities List. During the period from 1982-84, URS Company, Inc. was contracted by the New York State Department of Environmental Conservation (NYSDEC to perform a Remedial Investigation/Feasibility Study (RI/FS) of the site. One result of the field investigation was the determination that the groundwater underlying the site and leachate taken from two on-site drainage ditches was highly contaminated by organic priority pollutants.

Hydrogeological data collected during the RI/FS supported the conclusion that all subsurface contaminant migration was being intercepted by two creeks which bounded the site on three sides. Based on these findings, the RI/FS report recommended specific remedial measures for subsurface cleanup and closure of the PAS site. These measures included construction of a leachate collection system, installation of a groundwater recovery system and treatment of the groundwater/leachate.[1]

As part of the subsequent Remedial Design Study, laboratory treatability studies were conducted to identify process requirements to determine the level of treatment attainable and to develop design and cost data. Results of the treatability studies are reviewed in this paper. Estimates of the cost of on-site treatment also are presented. Finally, the on-site and off-site treatment methods are compared to identify the most cost-effective treatment alternative.

SITE HISTORY

The facility known as Pollution Abatement Services, Inc. (PAS) was constructed and put into operation in 1969-70. A high temperature, liquid chemical waste incinerator was the principal unit installed by the owners. Throughout its active life, PAS experienced continuous operating problems, numerous air and water quality violations and mounting public opposition.

During its operating period (from 1970 through 1977), large numbers of drums containing various chemical wastes were collected and stored on-site. Liquid wastes also were stored in lagoons.

Beginning in 1973, a series of incidents including liquid waste spills and overflowing of lagoon wastes into the adjacent White Creek led to the involvement of the U.S. Coast Guard, the U.S. EPA and the New York State Department of Environmental Conservation (NYSDEC). This involvement included a number of limited and temporary remedial actions during the period from 1973-1976. In 1977, PAS was abandoned.

During the several years immediately following abandonment, a number of emergency remedial actions and preliminary investigations were undertaken at the PAS site including draining and filling the waste lagoons and removing approximately 3,000 leaking barrels and several waste storage tanks from the site. Late in 1981, contract documents for the surficial cleanup of PAS were prepared, including the demolition and disposal of on-site facilities, the removal of the remaining (approximately 8,000) drums from the site and the drainage and disposal of approximately 80,000 gal of liquid chemical waste from 10 bulk storage tanks. This surficial cleanup was completed in October 1982.

In November 1982, URS Company, Inc. (URS) entered into a contract with NYSDEC to evaluate alternative remedial measures for final cleanup of buried wastes, contaminated soil and groundwater and site closure.

TREATMENT ALTERNATIVES

Alternatives considered for treatment of the contaminated groundwater/leachate were: (1) hauling to an off-site commercial treatment facility, (2) treatment at a local POTW and (3) on-site treatment. Two commercial hazardous waste disposal facilities are located approximately 180 miles from the PAS site. The Oswego East Sewage Treatment Plant, which provides primary and secondary treatment, is located just 1 mile from the site.

A preliminary estimate indicated that on-site treatment would be less costly than off-site disposal at a commercial facility. For this reason, laboratory treatability studies were conducted: (1) to determine treatment process requirements, (2) to measure the degree of treatment achievable and (3) to develop design and cost data.

TREATABILITY STUDIES

Available hydrogeological data indicated that the strata underlying the PAS site would be low yielding and, on this basis, it was estimated that groundwater pumping would yield only approximately 24,000 gal per each 1-3 week period. Since a 24,000 gal basin remains on the site and could be used for pumped groundwater storage, it was anticipated that the treatment system would be operated on an intermittent basis with treatment being performed whenever the storage basin was full. A chemical analysis of this contaminated groundwater is given in Table 1.

As part of the PAS remedial design project, laboratory wastewater treatability studies were conducted to determine specific treatment process requirements and capabilities. These studies have been described previously.[4] The key findings are summarized below:

- Only a minor fraction ($<1\%$) of the wastewater total organic carbon (TOC) was removed by air stripping. This result indicated that very little of the TOC consisted of volatile organic contaminants. Therefore, air stripping was determined to be unnecessary.
- Nickel was not removed by hydroxide precipitation but was removed by activated carbon adsorption. From these data, it was concluded that nickel was organically bound or complexed.
- Adsorption of the organic contaminants by activated carbon was enhanced at acidic pH values.
- Wastewater COD was reduced from a concentration of 4,000 mg/l to approximately 450 mg/l (89% removal) by carbon adsorption at pH 3.
- Carbon requirements per 24,000 gal batch of wastewater were computed to be 6,030 lb based on an effluent quality of 800 mg/l COD (i.e., 20% breakthrough of the influent COD concentration). This usage is equivalent to a carbon loading of 0.106 lb COD/lb activated carbon.
- With a period of 1 week acclimation, biotreatment achieved a COD removal of 85%. Rate studies showed that this level of treatment could be achieved in less than 8 hr retention time. A final effluent quality of less than 50 mg/lCOD was achieved by treating the bioreactor effluent with activated carbon.

On the basis of the batch bioreactor studies, we concluded that a treatment process consisting of biological treatment followed by activated carbon polishing was feasible, would be more cost-effective and would produce a much higher quality effluent than carbon adsorption alone. For these reasons, further laboratory studies were subsequently performed to develop the necessary design and cost data for a batch biological process to be operated intermittently. The results of these studies, which have been reported previously,[3] are summarized below.

Table 1
Wastewater Analysis[1]

Pollutant Parameter	Concentration[3]
Positively Identified (ug/l)[2]	
Methylene Chloride	11,000
Acetone	42,000
trans-1,2-Dichloroethane	3,500
2-Butanone	14,000
Benzene	1,500
4-Methyl-2-Pentanone	12,000
Toluene	4,300
Total Xylenes	1,600
Phenol	5,700
Aniline	5,600
2-Methylphenol	2,300
4-Methylphenol	15,000
2,4-Dimethylphenol	3,400
Tentatively Identified (ug/l)[2]	
Ethyl Benzene	620
2-3-Diethyl Oxirane	28,000
4-Methyl-2-Pentanol	6,400
Methyl Benzene	8,500
N,N-Diethyl Formamide	5,400
Butanoic Acid	14,000
1-Methoxy Ethanol	2,900
Ethylbenzene	940
1,4-Dimethyl Benzene	2,400
Pentanoic Acid	6,300
2-Ethyl Butanoic Acid	2,300
1-Methyl-2-Pyrrolidinone	7,900
N,N-Dimethyl Benzenamine	4,700
2-Ethyl Hexanoic Acid	4,200
2,3-Dimethyl Phenol	20,000
Benzene Acetic Acid	1,700
3-Methyl Benzoic Acid	5,200
Conventional Parameters (mg/l)	
Sulfate	32
Phosphate	5.5
N-NH3	80.7
TKN	80.7
Alkalinity	1,500
Hardness (Ca^{2+})	2,350
Iron	96
Nickel	2.6
COD	1900
TOC	1020
BOD_5	1100
TDS	6400

[1] Samples analyzed were 50:50 mixtures of leachate.

[2] A complete analysis of the U.S. EPA Contract Lab Protocol Hazardous Substances was performed. Only the hazardous substances found at concentrations above analytical detection limits are reported in this table. In addition, the ten nonhazardous substance list compounds present in each fraction (volatile, acid and base/neutral) at greatest concentration were tentatively identified and quantified. These compounds are also reported in this table.

[3] All concentrations in µg/ unless otherwise indicated.

Pretreatment Requirements

- The PAS waste has no toxic or inhibitory effect on biological treatment. Consequently, pretreatment of the wastewater to remove substances (such as iron) potentially inhibitory to the biological treatment process is unnecessary.
- Approximately 8 hr of aeration were required to achieve optimum COD removal at 25 °C.
- No difference in bioreactor performance was observed when wastewater feed volumes in the range of 10-70% of the total reactor volume were used.

Nutrient Requirements

- The addition of nutrients (i.e., nitrogen and phosphorous) to the wastewater is not required to achieve optimum biological removal of COD.
- The addition of nitrogen and phosphorous actually resulted in a higher total suspended solids concentration.

Effect of Extended Lags Between Bioreactor Operation

- Little difference was observed in the COD removal efficiency of the batch bioreactors when operated with idle periods of 1-3 weeks.
- The rate of COD removal is inversely proportional to the length of the idle period.
- The cycle time required to achieve optimum COD removal increased from 8-11 hr when the bioreactor was operated at 1 week idle periods, to 25 hr when the idle period was 3 weeks.

Effects of Temperature on Bioreactor Performance

- During the initial weeks of bioreactor operation, the effluent COD was inversely proportional to the bioreactor temperature.
- After several weeks of intermittent operation (1 week idle period), the effluent COD level achieved at the different temperatures (i.e., 25 °C, 15 °C and 5 °C) began to converge.
- Bioreactor performance as measured in terms of COD removal rate and efficiency is adversely impacted by cooler temperatures. The exact temperature at which performance begins to degrade is not known, but lies somewhere between 5 °C and 15 °C.

Effects of Powdered Activated Carbon Addition to the Bioreactors

- Powdered activated carbon (PAC) addition substantially enhances COD removal rates under conditions of extended bioreactor idle periods and low temperature.
- COD removal efficiency increases as the PAC dosage is increased.
- The time of PAC addition during the reactor cycle does not affect the effluent quality achieved.
- When PAC is added to the bioreactor, the COD removal mechanism involves simultaneous adsorption and biodegradation.

Oxygen Supply Requirements

- Oxygen uptake rates are greatest in the initial phases of the reactor cycle and decrease rapidly with time.
- As the length of the idle period between bioreactor react periods is increased, the rate of oxygen uptake during the initial phase of the react cycle decreases.

Sludge Production

- The net biological sludge production in sequenced batch bioreactors operated at 25-50% fill ratios was minimal or negative.
- Total bioreactor sludge production was found primarily to be a result of inorganic precipitates. This production averaged 800 mg/l solids of wastewater treated in bioreactors operated at 50% fill, nonpretreated and 1 week idle periods.
- The use of PAC in the bioreactor increased the amount of sludge produced in direct proportion to the PAS dosage.

Activated Carbon Column Studies

- Results of batch adsorption isotherm studies indicated very little difference in adsorption characteristics at pH 3 and 7.5. Based on this result, no pH adjustment of bioreactor effluent is necessary to achieve optimum COD removal by carbon column polishing.
- The carbon inventory requirement for a granular activated carbon column is a function of the allowable breakthrough level. Effluent from a reactor operated at a 50% fill and 1 week idle period was polished to determine carbon requirements. For breakthrough levels of 20, 30 and 40% of the carbon column influent, carbon requirements of 2,670, 1,460 and 700 lb/24,000 gal of wastewater treated were calculated.
- Approximately 95% COD removal was achieved using a sequenced batch bioreactor followed by carbon column polishing.
- Essentially complete removal of priority pollutants was achieved by biological treatment followed by granular activated carbon adsorption.

DEGREE OF TREATMENT ATTAINABLE

The effluent quality obtainable is a function of the raw wastewater concentration, the operating conditions (length of idle time, temperature, etc.) and the specific treatment process employed. A summary of the effluent quality achieved, in terms of commonly used measures, is presented in Table 2.

Table 2
Summary of Achievable Effluent Quality

Sample Identification	Temp. (°C)	COD (mg/l)	TOC (mg/l)	BOD_5 (mg/l)	TSS (mg/l)
Raw Wastewater	--	1900-2700	1020	1050-1130	--
Bioreactor Effluent (1)					
• 1 React cycle/wk	25	360-410 (2)	140	12-22	82
• 1 React cycle/2 wks	25	385-410 (2)	128	17	--
• 1 React cycle/3 wks	25	370-440 (2)	128	--	--
• 15°C 1 react cycle/wk	15	450-550	--	--	99
• 5°C 1 react cycle/wk	5	600-750	--	--	262
• 1000 mg/l PAC 1 react cycle/wk	25	150-200	58	1-5	69
• 2000 mg/l PAC 1 react cycle/wk	25	110-140	37	2-4	65
• 5000 mg/l PAC 1 react cycle/wk	25	80-90	24	1-2	57
• 1 React cycle/wk GAC column polishing 20% breakthrough (3)	25	100	--	--	--

Notes:

(1) For bioreactors operated at 50% fill.
(2) Equilibrium COD.
(3) Bioreactor effluent contained 465-580 mg/l COD.

COST OF ON-SITE TREATMENT ALTERNATIVES

Based on the treatability study results, seven treatment alternatives were identified for cost analysis. The central process in each of these schemes is biological treatment in a batch reactor.

These seven alternatives vary primarily with respect to the size of the activated carbon column units incorporated and the quantity of PAC used. These alternatives are identified below. For our purpose, carbon breakthrough was defined as the time at which the COD concentration in the carbon column effluent reached 100 mg/l.

Treatment Processes

- A batch biological reactor followed by a granulated activated carbon (GAC) system sized for 30 min retention time at a flow rate of 100 gal/min (System I-A). (Carbon breakthrough approximately every 4th batch treated.)

- A batch biological reactor followed by a GAC system sized for 30 min retention at a flow rate of 27 gal/min (System I-B). (Carbon breakthrough approximately every batch treated.)
- A batch biological reactor followed by a GAC system sized for 60 min retention at a flow rate of 100 gal/min (System I-C). (Carbon breakthrough approximately every 8th batch treated.)
- A batch biological reactor with 1,000 mg/l powdered activated carbon (PAC) addition and a GAC system sized for 30 min retention at a flow rate of 100 gal/min (System II-A). (Carbon breakthrough approximately every 9th batch treated.)
- A batch biological reactor with 1,000 mg/l PAC addition and a GAC system sized for 30 min retention at a flow rate of 11 gal/min (System II-B). (Carbon breakthrough approximately every batch treated.)
- A batch biological reactor with 1,000 mg/l PAC addition and a GAC system sized for 60 min retention at a flow rate of 100 gal/min (System II-C). (Carbon breakthrough approximately every 18th batch treated.)
- A batch biological reactor with 5,000 mg/l PAC addition and no GAC system (System III).

Cost Estimates

Cost estimates were based on the following assumed operating conditions:

- Bioreactor volume (approximately 50,000 gal) is twice the feed volume to accommodate a 50:50 ratio of mixed liquor to wastewater feed.
- One batch (24,000 gal) of wastewater is processed each week.
- Groundwater/leachate is pumped directly to the bioreactor so that the bioreactor is filled and ready for the reactor cycle to begin when the operator arrives.
- Twelve hours aeration per batch.
- Two hours settling time per batch.
- Discharge time varies according to GAC system.
- A treatment system operator is available locally on an on-call basis.
- Minimum effluent quality required is 100 mg/l COD.
- GAC column breakthrough is 20% of COD influent (500 mg/l COD reduced to 100 mg/l COD) for systems not using PAC (Systems I-A, I-B and I-C).
- GAC column breakthrough is 40% of COD influent (250 mg/l COD reduced to 100 mg/l COD) for systems using 1,000 mg/l PAC addition (Systems II-A, II-B and II-C).
- The treatment system is housed in a temperature-controlled building.

Information regarding reactor size, sludge production, carbon requirements and oxygen requirements that affected capital and operating costs was determined on the basis of the treatability study results. Capital costs were derived on the basis of vendor quotes and annually published cost manuals.[4,5]

COST OF OFF-SITE ALTERNATIVES

The cost of contract hauling and disposal at a commercial facility is a function of the particular firm that is contracted. Costs for this alternative were based on quotes from three commercial waste management firms located within 180 miles of the PAS site.

No basis could be established for deriving the cost of treatment of PAS groundwater/leachate at the local POTW. The city does not have a surcharge system for treatment of high-strength wastewater. Furthermore, this POTW has a history of operating problems. To alleviate this problem, the city has established a policy that no "scavenger wastes" will be accepted at the plant. Due to this circumstance, no further consideration was given to treatment at the local POTW as an off-site alternative.

COMPARISON OF ALTERNATIVES

A summary of the capital and annual operation/maintenance (O&M) costs for each on-site and off-site treatment alternative considered is presented in Table 3. These costs were developed on the assumption that PAS groundwater/leachate would be recovered and treated at a rate of one 24,000 gal batch per week. The actual rate at which the groundwater/leachate will be recovered is not known.

Table 3
Cost Summary of Treatment Alternatives

Treatment Alternative	Description	Capital Cost ($ 1986)[1]	Annual Operating Cost ($ 1986)[2]	Operating Cost Per Gallons ($ 1986)[3]
	Biological Treatment & GAC Column Polishing:			
A	I-A	564,700	155,800	0.125
B	I-B	500,000	179,000	0.143
C	I-C	707,700	163,800	0.131
	Biological Treatment with 1,000 mg/l PAC Addition & GAC Column Polishing:			
D	II-A	589,100	115,500	0.093
E	II-B	506,200	120,900	0.097
F	II-C	723,900	127,200	0.102
G	Biological Treatment with 5,000 mg/l PAC Addition	515,100	109,100	0.087
H	Contract Hauling/Off-site Disposal	0	499,200 - 1,123,000 (549,000)	0.40 - 0.90 (0.44)

Notes:
(1) Cost for facilities to treat wastewater in 24,000 gal batches.
(2) Cost to treat 24,000 gal/week.
(3) Cost/gal based on 1.248 million gal/yr (i.e., 52 wks × 24,000 gal/wk).

Consideration of the quantity of groundwater/leachate to be treated with time is essential to a comparison of the costs of the various treatment alternatives, since these costs are a function of both the quantity of wastewater to be treated and the length of time over which treatment is to be performed. The total quantity of groundwater/leachate requiring treatment has been estimated to be 3 million gallons based on hydrogeological data collected during the RI/FS and the Remedial Design Study. To address the various rates at which this wastewater may be recovered, four scenarios have been developed (Table 4).

Table 4
Hypothetical Rates of Groundwater/Leachate Recovery and Treatment

	1st Year				Remaining Years			
Scenario	Year	Annual Quantity	No.[1] Cycles	Cycle Period	Years	Annual Quantity	No. Cycles[1] Per Year	Cycle Period
1	1	1 MG	41.7	8.8 days	2-3	1 MG/YR	41.7	8.8 days
2	1	1 MG	41.7	8.8 days	2-5	0.5 MG/YR	20.8	17.5 days
3	1	1 MG	41.7	8.8 days	2-7	0.33 MG/YR	13.9	26.3 days
4	1	1 MG	41.7	8.8 days	2-10	0.22 MG/YR	9.2	39.4 days

(1) Assumes 24,000 gal per cycle.

A present worth analysis of each treatment alternative as a function of the four recovery rate scenarios is given in Table 5. The following observations are based on a review of this analysis:

- All on-site treatment alternatives (A through G) are more cost-effective than the off-site alternative (H).
- On-site alternatives which incorporate the smaller sized GAC columns (B,E) are more cost-effective than alternatives incorporating larger columns (A,C,D,F).

Table 5
Present Worth Analysis of Treatment Alternatives

(1) Scenario	(2) Treatment Alt.	(3) Years of Treatment	(4) Capital Cost ($x10³)	(5) 1st Yr. Operating Cost ($x10³)	(6) Remaining Yrs Operating Annual Cost A_x ($x10³)	(7) Total Present Worth ($x10³)
1	A	3	564.7	125.0	125.0	875.8
	B	3	500.0	143.0	143.0	855.9
	C	3	707.7	131.0	131.0	1033.8
	D	3	589.1	92.5	92.5	819.3
	E	3	506.2	96.9	96.9	747.4
	F	3	723.9	102.0	102.0	977.8
	G	3	515.1	87.4	87.4	732.7
	H	3	0	400.0	440.0	1095.9
2	A	5	564.7	125.0	62.5	858.3
	B	5	500.0	143.0	71.5	835.9
	C	5	707.7	131.0	65.5	1015.4
	D	5	589.1	92.5	46.2	806.3
	E	5	506.2	96.9	48.4	733.7
	F	5	723.9	102.2	51.0	963.5
	G	5	515.1	87.4	43.7	720.4
	H	5	0	440.0	220.0	1033.9
3	A	7	564.7	125.0	41.2	841.5
	B	7	500.0	143.0	47.2	816.9
	C	7	707.7	131.0	43.2	997.9
	D	7	589.1	92.5	30.5	794.0
	E	7	506.2	96.9	32.0	721.0
	F	7	723.9	102.0	33.7	950.0
	G	7	515.1	87.4	28.8	708.6
	H	7	0	440.0	145.2	975.5
4	A	10	564.7	125.0	27.5	822.1
	B	10	500.0	143.0	31.5	794.8
	C	10	707.7	131.0	28.8	977.4
	D	10	589.1	92.5	20.4	779.9
	E	10	506.2	96.9	21.3	705.7
	F	10	723.9	102.0	22.4	933.8
	G	10	515.1	87.4	19.2	695.0
	H	10	0	440.0	96.8	906.8

Notes:
Column 1: Scenario (Refer to Table 7-2)
Column 2: Treatment Alternative (Refer to Table 7-1)
Column 3: Total number of years that a treatment system is operated on-site
Column 7: Calculated on basis of:

Present worth of capital and annual O&M at year n

$$= (P/A, i, n) \times (O\&M) + \text{Capital}$$

$$= \frac{(1 + i)^n - 1}{i(i + i)^n} \times O\&M + \text{Capital}$$

where i = interest rate per year
n = number of years

- Biological treatment enhanced by a 5,000 mg/l dose of PAC (Alternative G) is more cost-effective than any of the alternatives (A through F) which include GAC columns for effluent polishing.

CONCLUSIONS

Based on laboratory treatability studies, biological treatment with activated carbon polishing was determined to be the most effective treatment method. These studies also demonstrated the feasibility of using a batch bioreactor operated intermittently. The disadvantage of lower COD removal rates when the bioreactor was operated at low temperature and increased idle periods was overcome by the addition of powdered activated carbon. Results of a present worth analysis showed that on-site treatment will be much more cost-effective than off-site treatment/disposal at a commercial facility.

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Optimization of Free Liquid Removal Alternatives in the Closure of Hazardous Waste Surface Impoundments

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ABSTRACT

A flowchart is presented to serve as a guide in determining the optimal alternative for removal of free liquids during the closure of hazardous waste surface impoundments. The flowchart addresses each part or element within a closure alternative as a discrete decision process. This flowchart allows separate evaluation of each phase of removal such as preclosure engineering, removal and treatment and ultimate disposal. Criteria used to select the best option within an element include technological feasibility, environmental soundness, regulatory acceptance and unit cost. Once the best elements for each phase of free liquid removal are determined, they are recombined to form the optimal removal alternative.

Important factors such as in situ reduction and provisions for mixed wastes are discussed. Removal equipment and treatment processes are presented as a function of the waste type. Ultimate disposal options such as discharge to surface water vs. discharge to sewer, on-site vs. off-site treatment and disposal and process reuse and recovery are included. To illustrate the use of the flowchart, three case studies of actual surface impoundment closures are presented. Optimal free liquid removal alternatives are developed for impoundments containing heavy metals, heavy metals and degreasers, and oily wastes.

INTRODUCTION

There are tens of thousands of hazardous waste lagoons, pits or ponds in the United States.[1] These types of storage facilities or surface impoundments are used for continuous or intermittent storage of process water, stormwater and spent products from the chemical and manufacturing industries. RCRA or CERCLA can require closure of an impoundment when soil and groundwater contamination is discovered or if the impoundment poses an environmental risk. Stricter liner requirements for impoundments under RCRA are also forcing an increased number of closures. Given the trend toward greater environmental protection, increased enforcement and stricter regulations, it is certain that impoundment closures and their associated remedial actions will continue at a rapid pace.

Regardless of the RCRA or CERCLA regulations governing closure, removal of free liquids is required as one of the first steps in an impoundment closure. The removal process can present a number of technological and regulatory problems as a large volume of liquid hazardous waste must be removed from the site which frequently has no suitable direct outlet. The free liquids often have a high solids content, exhibit extremes of pH and viscosity, have concentration gradients and are stratified mixtures of both inorganic and organic chemicals. These technological problems combined with the regulatory pressures for tight closure schedules and strict air and water discharge limits require careful engineering of the free liquid removal processes. Recognizing the inherent problems in dealing with liquid hazardous wastes in surface impoundments, the flowchart directs the user in the selection of the optimum free liquid removal alternative.

FLOWCHART DESCRIPTION

In assembling the flowchart elements into a system of logical steps, the universe of processes used for free liquid removal were identified. Once the available processes were identified, they were categorized into three elements: preclosure engineering; removal and treatment; and ultimate disposal. Figure 1 shows the basic outline of the flowchart. To determine the optimal removal alternative, each process within an element is subjected to a set of decision criteria developed from recent CERCLA guidance[2] and actual closure experience. Through evaluation of each process according to the developed decision criteria, the best option for that process can be identified. By combining the best options within each element, the optimal removal alternative is determined.

Flowchart Elements

The flowchart contains three major elements: preclosure engineering; removal and treatment; and ultimate disposal (Fig. 1). Pre-closure engineering addresses the processes for flow diversion, waste characterization and the removal alternative's impact

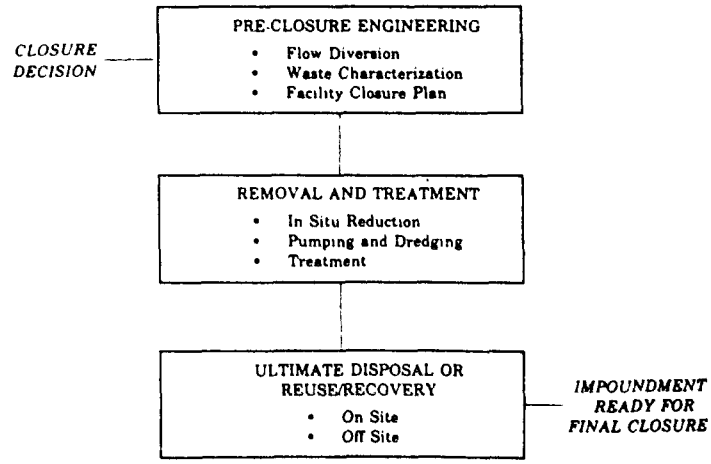

Figure 1
Overview of Flowchart for Determining Optimal Liquid Removal Alternatives

on the overall facility closure plan. The removal and treatment element is composed of three processes: in situ reduction, liquid removal and treatment prior to ultimate disposal. In situ reduction considers whether the hazard or volume of the free liquid should or can be reduced while in the impoundment before actual removal. The removal section addresses the equipment used in removing the waste, such as pump type and construction material. Treatment alternatives include physical and chemical treatment of the free liquids for reduction or elimination of the hazard from the waste before ultimate disposal. The treatment process and the ultimate disposal option often are synergistic, requiring concurrent evaluation. The ultimate disposal element reviews the options for final deposition of the liquids such as surface water, publicly owned treatment works or an RCRA facility.

Careful consideration always should be given to those processes which allow reuse or recovery of the liquids.

Decision Criteria

The decision criteria employed for evaluation of each closure element are expressed in both cost and non-cost factors. Cost factors include the cost for present value of operating and maintenance costs and the capital expenses. Non-cost factors include technological feasibility, environmental soundness and regulatory acceptance. Technological feasibility requires that the technology under consideration be proven at the design scale or that pilot-scale results show a good chance for success in the field. Environmental soundness is a measure of the exposure of the chemical constituents to the environment during the removal operation. This decision can be a judgmental one as in some cases environmental exposure occurs only for a short time and does not persist once the removal is complete. Regulatory acceptance is the third criterion. This factor indicates whether the closure processes under consideration are acceptable to the governing regulatory agency. Acceptance or non-acceptance depends on the pertinent regulations and the perceived environmental risk.

PRECLOSURE ENGINEERING

During development of an RCRA closure plan or a CERCLA feasibility study, several preliminary concerns must be addressed before the actual free liquid removal alternatives can be fully developed. Among these concerns are options for flow diversion, requirements for complete waste characterization and the removal alternative's impact on the overall impoundment closure plan. In the flowchart, Figure 2, these concerns are taken into consideration in the preclosure engineering element. Carefully addressing each of these concerns is required for optimization of the free liquid removal alternative.

Flow Diversion

The initial step in implementation of an impoundment closure plan is to eliminate the source of incoming waste. This is not a major concern for inactive impoundments or impoundments used for low-volume intermittent waste disposal. At active impoundments receiving continuous or semi-continuous waste streams such as process water or contaminated stormwater, careful consideration is required as dedicated treatment plants and long-term operation become potential design factors.

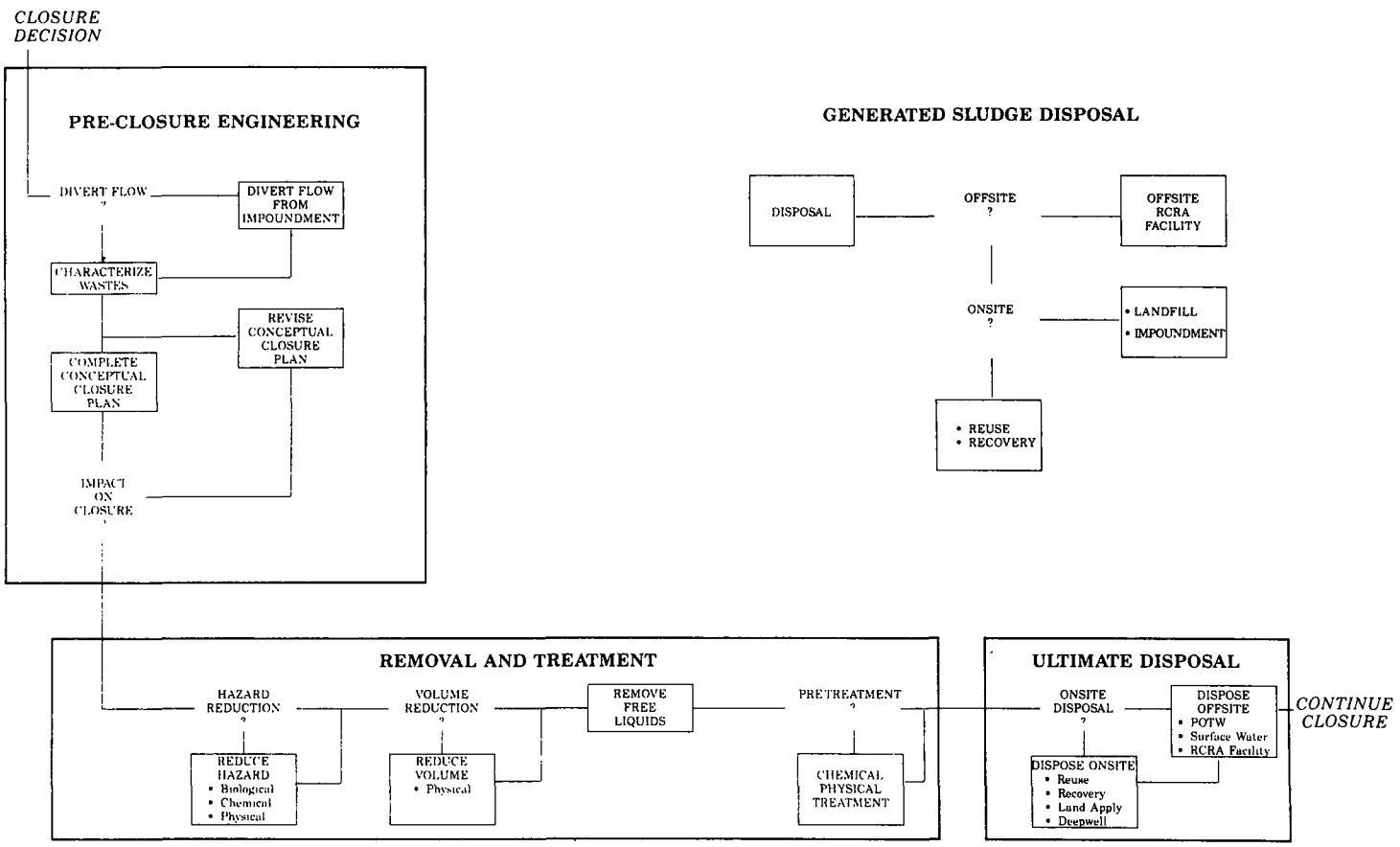

Figure 2
Free Liquid Removal Flowchart

Waste Characterization

Accurate information on the chemical constituents in the impoundment is essential, including identification of any variances in the composition as a function of depth. Each layer can require special consideration and different removal procedures; for example, a floatable oil layer can cover a relatively clear aqueous layer which in turn covers a gelatinous metal hydroxide sludge. The important physical parameters include pH, viscosity and solids content. The pH influences pump selection and treatment processes. Viscosity and solids content influence the pump type and the volume of liquid available for removal by pumping alone. Sludges with solids content greater than 8-10% must be removed either by first mixing with the other impoundment liquids to lower the solids content, or by leaving the high solids content sludge in place and dewatering by evaporation or by the addition of a solidifying agent.

Impact on the Overall Closure Plan

Consideration of the free liquid removal alternative's impact on the overall closure plan is imperative for optimizing the impoundment closure. Very often other remediation activities at the facility can influence selection of the free liquid removal alternative. These considerations are site-specific and are best illustrated through examples. Table 1 shows examples of the impact of the selected closure plan on the free liquid removal alternative.

Table 1
Impact of Facility Closure Plan on Free Liquid Removal Alternatives

Waste Type	Facility Closure Plan	Free Liquid Removal Alternative
Heavy Metals	Groundwater Treatment Program	Same Treatment Process Employed
Oily Wastes	Reclamation of Wastes	Free Liquids Reclaimed by Same Process
PCB Oils	Soil Incineration	Free Liquids Incinerated

REMOVAL AND TREATMENT

In Situ Reduction

In situ reduction is a process within the treatment and removal element (Fig. 2). It involves the reduction of the hazard or the volume of the waste present in the impoundment before actual removal. Such techniques can be used to facilitate final removal and disposal of the waste.

In dealing with very corrosive wastes such as spent pickle liquors with pH <2 or caustic washes with a pH >12, it is advantageous to add a neutralizing agent to the wastes in the impoundment. Addition of bases also can be used to remove toxicity such as the alkaline precipitation of heavy metals at pH 9-10. In small acidic ponds, a 50% solution of sodium hydroxide is best as it is easily pumped at moderate ambient temperatures and offers a high degree of neutralizing power. For larger acidic ponds or when cost is an important factor, calcium hydroxide and calcium carbonate should be examined. Multi-stage treatment with several neutralizing materials has been investigated.[3] For alkaline ponds, concentrated sulfuric acid is generally best as it is inexpensive, offers a high degree of neutralizing ability and does not pose a serious material handling problem. Other possibilities for in situ hazard reduction are the use of oil booms, reduction/precipitation techniques and activated carbon or polymer addition for organics adsorption.

The other in situ alternative is to reduce the volumetric quantity of free liquids in the impoundment. The two primary mechanisms are evaporation and seepage. Metal-containing aqueous wastes are usually more amenable to evaporation or seepage than organic wastes. Although a limited number of sites actually experience a high net evaporation rate, judicious scheduling of the liquid removal step during periods of low rainfall and high temperature can effectively reduce the total volume of free liquids. For example, at a West Coast manufacturing facility the volume of water in a stormwater retention pond varied from 3.5 million gallons during January to 2.5 million gallons during August. Determining whether seepage is a viable method of volume reduction is a less straightforward calculation than determining the evaporation potential.[4] The use of impoundments as seepage basins for concentrating wastes has been documented to be very effective with a limited impact on groundwater quality.[5]

Free Liquid Removal

Physical removal of the free liquids is accomplished best by pumping. If the waste has a high solids content, mechanical, hydraulic or pneumatic dredging may be required. This paper discusses only pumping of free liquids. Selection parameters include the type, construction materials and size of pumps. The pump type and construction materials usually depend on the waste material and its physical characteristics. Pump size is governed by the closure schedule and treatment system capacities. Table 2 delineates the generally available pump types and construction materials as a function of the waste type.

Table 2
Pump Types and Construction Materials as a Function of Waste Type

Physical Description of Waste	Pump Type
Aqueous	Centrifugal
Viscous or Oily	Rotary lobe, progressive cavity
Sludge, 1-5% solids	Centrifugal
Sludge, 5-8% solids	Positive displacement
Chemical Description of Waste	**Construction Material**
Aqueous	Cast iron
Oils, phenols	Cast iron, possibly bronze fittings
Solvents	Bronze fitted cast iron
Heavy metals	Stainless steel
Basic pH >12	SS ASTM 743, CN-7M
Acidic pH <2	SS ASTM 743, CN-7M (3% Mo)

Treatment

At this stage in the evaluation process, the free liquid treatment and disposal processes are developed. Selection of the treatment process is based on both the waste characteristics and the availability of ultimate disposal mechanisms. Relationships between the disposal processes and treatment requirements are summarized in Table 3.

Table 3
Relationship Between Disposal Processes and Treatment Requirements

Disposal Processes	Treatment Requirements
Off-site disposal On-site disposal On-site reuse or recovery	Usually requires no treatment except suspended solids removal
Publicly owned treatment works Process reuse	Suspended solid removal often required
Surface water Groundwater reinjection	Treatment to drinking water standard required

Since the treatment process and the ultimate disposal method represent the largest single capital cost items involved in free liquid removal, all alternatives need to be critically reviewed. Consideration should be given to alternatives which provide a potential for reuse or combination with other treatment needs.

Processes available for the treatment of aqueous hazardous waste are numerous.[6] The major limitation to the use of many of these processes is that many are not cost-effective or not proven at the field scale. New technologies and innovative processes are best explored when a long-term use treatment plant is required, such as in groundwater remediation programs or surface and process water treatment systems. In other cases, leasing of mobile treatment units or low-cost temporary equipment should be considered. Table 4 shows the technologies available for treatment as a function of the waste type.

Table 4
Treatment Technologies as a Function of Waste Type

Waste Type	Dedicated On-site Equipment	Mobile Equipment	Temporary System
Acidic pH<2	Alkali addition	alkali addition	alkali addition
Basic pH >12	Acid addition	Acid addition	Acid addition
Heavy metals	Precipitation/ flocculation Ion exchange	Precipitation/ flocculation	Precipitation/ flocculation
Low level organic solvents	Adsorption Air stripping Oxidation	Adsorption Air stripping Oxidation	Adsorption
High level organic solvents	Carbon adsorption Incineration	Carbon adsorption Incineration	Carbon adsorption
Oil	Separators Incineration Filtration	Separators Incineration Filtration	Separators Filtration

ULTIMATE DISPOSAL

Direct Off-Site Disposal

In direct off-site disposal of free liquids, the liquids are taken directly from the impoundment to an off-site facility. Potential off-site facilities include publicly owned treatment works and RCRA treatment facilities. If the concentrations of the hazardous compounds are within sewer discharge limits, the liquids can be pumped directly into the sewer system. If the sewer line is not within economical pumping distance, alternative means of transportation to the treatment plant must be explored. A most practical means is to employ vacuum trucks or similar tanked vehicles. Transportation costs can be as much as $1.50 per unloaded mile and $3.50 per loaded mile. Sewer discharge rates vary widely depending on waste type, quantity and treatment facility. When the pollutant concentrations exceed the influent pretreatment standards and direct off-site disposal is a potential alternative, a list of available facilities should be compiled. Many available directories list RCRA facilities, and the RCRA hotline also can provide a list of currently permitted facilities. Transportation costs are similar to the amounts given above. Disposal costs can be from $0.10/gal for low level contaminated aqueous streams to over $1/gal for liquid injection of highly organic wastes. Deep well injection, generally for acids and bases only, costs approximately $0.20/gal.

Treatment Followed by Off-Site Discharge

Employing a pretreatment process expands the number of off-site disposal alternatives to include surface water discharge and groundwater injection. Groundwater injection is predominantly used only in conjunction with other groundwater remediation programs. Discharge to surface water requires an NPDES permit as well as very low contaminant concentrations. For metals, some type of filtration will be required to attain the discharge limit.

On-Site Disposal

The alternatives to on-site disposal include construction of an on-site RCRA permitted facility. For most closures at industrial manufacturing facilities, the closed system with reuse and recovery is the most advantageous. At uncontrolled sites, on-site disposal of the liquids usually is confined to treatment processes such as landfarming, evaporation or incineration.

GENERATED SLUDGE DISPOSAL

Final consideration for free liquid alternatives is given to the disposal of sludges generated during a treatment process. Sludge is generated during alkaline precipitation of metals, filtration or solidification/stabilization processes. Potential disposal alternatives include off-site disposal in an RCRA permitted landfill, on-site disposal in a specially constructed RCRA permitted landfill and disposal in the closed impoundment.

CASE STUDIES

Three case studies of actual surface impoundment closures are presented here to illustrate some of the aspects in determining the optimal alternative for free liquid removal. The following cases are discussed:

- Stormwater retention pond containing hexavalent and trivalent chromium
- Process water storage lagoon contaminated with chlorinated solvents and nickel
- Earthen pit used for oily waste disposal

Chromium Contamination

A manufacturing facility employed an earthen pond to store stormwater runoff from its product storage area. The pond was being closed because of its ineffective liner and the presence of chromium in the underlying groundwater.

Preclosure Engineering

The pond currently was being used for storage of stormwater, and an alternative mechanism for handling future runoff was needed. Since manufacturing and storage operations were to continue at the site and no practical method of eliminating the contaminated runoff existed, a permanent treatment and disposal solution was required. An ion-exchange treatment system with surface water discharge was determined to be the best alternative for addressing the runoff. Ion-exchange produced a very low level concentration of chromium in the effluent and allowed reuse of the recovered chromium. Ion exchange also added the advantage that no hazardous waste sludge was generated during treatment as would have been produced using traditional chemical reduction and precipitation.

Results of the pond sampling activities showed that approximately 400,000 ft^3 of free liquids containing 5-10 mg/l hexavalent chromium and 1-5 mg/l trivalent chromium were in the impoundment. Underlying the free liquids were 1000 ft^3 of a chemical floc sludge containing 1000 to 5000 mg/l total chromium. The low chromium concentrations in the free liquids permitted use of the current ion-exchange system for free liquid treatment. The remaining sludge could be solar dried and fixed in-place using a solidification agent. Use of the on-site treatment system was an attractive solution for treatment as there was no negative impact on the other closure activities and no additional permitting was required for surface water discharge.

Removal, Treatment and Ultimate Disposal

Given the overwhelming advantages in using the on-site ion-exchange treatment system, the free liquids were removed using an available contractor's pump, treated to NPDES requirements and disposed via the force main to the nearby surface water stream. Judicious closure scheduling during the summer months reduced the volume of free liquids from 400,000 ft^3 to 260,000 ft^3. This timing reduced pumping time from 14 days to 9 days and saved approximately $20,000 in treatment expense.

During the alternative review phase, contractor proposals were solicited for removal and treatment of the free liquids. The contractor proposed to treat the liquids using sulfite reduction followed by alkaline precipitation. For comparison purposes, the decision criteria evaluation of the two treatment alternatives is shown below:

Alternative	Technology Feasibility	Environmental Impact	Regulatory Acceptance	Unit Cost $/1000 gal
Contractor Bid	Feasible	Sludge Generated	Acceptable	22.33
Use of On-site Treatment System	Feasible	Process Reuse	More Favorable Acceptance	5.50

Degreasers and Contamination

A metal plating and fabrication facility used an earthen impoundment for disposal of process rinsewaters. Groundwater contamination by the degreasers was forcing closure of the impoundment.

Preclosure Engineering

Due to the continuation of fabrication operations at the plant, a permanent treatment solution was needed for the waste process rinsewaters. Through water-use reductions and process modifications, the rinsewater flow rate was reduced from 300 to 50 gal/min. A 50 gal/min treatment system was put on line early during the closure plan development. Treated rinsewater was discharged to nearby surface water per the NPDES permit requirements.

The impoundment contained approximately 130,000 ft^3 of free liquids, 8,000 ft^3 of pumpable sludge and 2,000 ft^3 of unpumpable sludge. The nickel and degreaser concentrations in the free liquids ranged from 30 to 60 mg/l and 0.2 to 0.9 mg/l, respectively. Both sludge layers contained higher levels of contaminants than the free liquids, with the unpumpable sludge layer containing the bulk of nickel and degreaser.

Due to the depth of degreaser contamination in the soil, the impoundment was closed with contaminated soils in place. Laboratory studies were conducted on both sludges to determine if they were amenable to stabilization. If adequately stabilized, the sludges could be disposed of by leaving them in the impoundment. Tests showed that the addition of portland cement effectively formed a stable and solid mixture. Using the stabilization process, only the free liquids needed to be removed and disposed; the pumpable and unpumpable sludges were stabilized and left in place.

Removal, Treatment and Ultimate Disposal

The volume of free liquids in the impoundment precluded the use of the process water treatment system; the time required for treatment using the system would exceed the required 180-day schedule. An alternative mechanism was required. Due to the low level of contaminants in the free liquids, consideration was given to the use of a temporary on-site system consisting of filtration and possibly pH adjustment. Laboratory tests confirmed that with pH adjustment and settling, the contaminant levels were lowered below discharge requirements. Different treatment schemes were developed and compared using the four decision criteria. The results are summarized below.

Alternative	Technology Feasibility	Environmental Impact	Regulatory Acceptance	Unit Cost $/1000 gal
Coagulation & Settling	Feasible	Minimal	Acceptable	11.25
Pressure Filtration	Feasible	Minimal	Acceptable	8.75
Gravity Filtration	Feasible	Minimal	Acceptable	7.50

It was decided that gravity sand filtration would produce the best quality effluent at the lowest cost. To enhance operation of the filtration equipment, care was taken to maintain a low level of suspended solids in the free liquids. A floating intake was employed to minimize disturbance of the underlying sludge. In addition, when the suspended solids concentration exceeded 400 mg/l, the pump speed was decreased to further minimize resuspension. Backwash water was held on-site, and the settled material was returned to the impoundment after all the free liquids were removed.

Oily Wastes

An earthen pit located on a farmer's property had been used for the disposal of spent cutting and hydraulic oils. Closure was proceeding as a generator-directed and funded mitigation action. The site functioned with little control, and many accounts of unauthorized dumping had been recorded. However, one major generator had taken prime responsibility for closure instead of waiting for a potential enforcement action.

Preclosure Engineering

The impoundment was receiving intermittent waste streams only, and additional waste inputs were eliminated by banning all future waste disposal practices. Results of the pond sampling activities showed that three distinct layers were present: an oil layer of approximately 10,000 ft^3, an aqueous layer of 60,000 ft^3 and a viscous oily sludge layer of 4,000 ft^3. The aqueous layer contained between 0.2 and 0.5% total hydrocarbons and could not be disposed as a non-hazardous waste. However, analytical analysis of the oily layer showed that it potentially could be reclaimed.

Removal, Treatment and Ultimate Disposal

In this closure, several site-specific constraints precluded many of the normally available options; no surface water or sewer line was readily available. Due to the uncontaminated nature of the oil it allowed the potential for recovery. The oil layer was removed by vacuum trucks and taken to an oil recovery plant for recovery and reuse. Since no outlet for the treated aqueous layer was readily available, an off-site disposal alternative was required. The aqueous layer was removed by vacuum trucks and taken to the generator's manufacturing facility where it was treated in their own industrial wastewater treatment plant. Although the trucking costs were substantial, the oil recovery and generator treatment of the aqueous waste offset a portion of this cost. It was determined that disposal of the viscous sludge was accomplished best by landfilling rather than by incineration, since incineration was an order of magnitude in cost higher than landfilling.

CONCLUSIONS

A flowchart has been presented which guides in determining the optimal alternative for removal of free liquids from hazardous waste surface impoundments. The flowchart addresses each element of the closure process as a separate entity, whereas in-

dividual decision criteria are applied to each element before combining the elements to form the optimal alternative. The major elements include: preclosure engineering; removal and treatment; and ultimate disposal.

General trends identified from the case studies presented in this paper are:

- Identify site-specific constraints early during closure plan development. The combination of free liquid treatment and disposal options with soil and groundwater remediation programs can substantially reduce the cost for free liquid removal.
- Use recovery and reuse whenever possible; this alternative is attractive environmentally and to regulatory agencies.
- Employ temporary on-site treatment measures when levels of contaminants are low. This process is less expensive than off-site disposal at RCRA facilities.
- When available, use on-site process water or groundwater waste treatment equipment to treat the free liquids.

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Assessment of Chemical Treatment Technologies and Their Restrictive Waste Characteristics

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ABSTRACT

The applicability of a particular treatment technology to a given liquid waste stream depends upon the physical, chemical and biological characteristics of the waste. Waste stream characteristics which restrict a waste's applicability to a particular method of treatment are presented. With this information, the most effective treatment technology for a waste stream can be determined. The technologies evaluated include chemical oxidation and reduction, chlorinolysis, chemical fixation, ion exchange, neutralization and precipitation.

INTRODUCTION

The land disposal of many hazardous wastes may be banned within the coming years under the RCRA amendments. For those wastes which will be banned from landfill disposal, it is necessary to determine alternative methods of treatment and disposal.

A wide variety of treatment technologies exists today which can be used to treat such wastes. Treatment technologies can be classified as either chemical, physical, biological or thermal treatment. In this paper, the authors evaluate the applicability of chemical treatment technologies for hazardous liquid waste streams based on the wastes restrictive characteristics.

This analysis is part of an extensive study by the U.S. EPA to determine the applicability of alternative waste treatment technologies. The most promising types of each chemical treatment technology are discussed. The major restrictive waste characteristics determining treatment applicability for each also are presented. Finally, the final product or residue from each treatment technology and the limitations of each are evaluated.

CHEMICAL TREATMENT TECHNOLOGIES

Several chemical treatment technologies are widely used for waste treatment. The most effective technologies discussed here include:

- Chemical Oxidation
- Chemical Reduction
- Chlorinolysis
- Fixation
- Ion Exchange
- Neutralization
- Precipitation

The major restrictive waste characteristics as well as the type of applications for each of the above technologies are given below. A summary of the major restrictive waste characteristics is given in Table 1.

Chemical Oxidation

Chemical oxidation is a process which raises the oxidation state of chemical species, converting the wastes into less-hazardous or non-hazardous forms. The oxidation is accomplished by the addition of an oxidizing agent which is reduced.

Chemical oxidation has been used most commonly to treat cyanide wastes from electroplating operations. The most widely used oxidants for this application are chlorine gas and calcium and sodium hypochlorite.

Table 1
Chemical Treatment Technologies Restrictive Waste Characteristics

Chemical Treatment Technology	Major Restrictive Waste Characteristics
Chemical Oxidation	Physical form, oil and grease content, suspended solids content, viscosity.
Chemical Reduction	Physical form, oil and grease content, suspended solids content, viscosity.
Chlorinolysis	Total solids content, oxygen, sulfur, and organic content, water content.
Fixation	Physical form, organic content, ionic composition, sulfate content.
Ion Exchange	Suspended solids content, metal content, organic content, oxidizing agents, physical form.
Neutralization	Dissolved solids content, physical form.
Precipitation	Physical form, viscosity, metal solubility.

Other oxidants for cyanides include ozone, hydrogen peroxide, potassium permanganate and chlorine dioxide. A wide variety of organics and inorganics also can be treated by oxidation. The end products of cyanide oxidation are nitrogen gas and carbon dioxide. The end products of the oxidation of organics are either simpler organics or carbon dioxide and water; oxidized metals form metal hydroxides which can be precipitated out of solution by pH adjustment.

The major restrictive characteristics of a waste which are used to determine the applicability of chemical oxidation include the physical form, oil and grease content, suspended solids content

and viscosity of the waste. Chemical oxidation is most effective for dilute aqueous wastes, although certain gaseous wastes also can be treated. Since oxidizing agents will indiscriminantly attack all oxidizable material, the oil and grease content and the oxidizable suspended solids content should be low, preferably below 1%. For liquid solutions, viscosities much greater than that of pure water are restrictive because of the mixing problems encountered with highly viscous solutions.

Chemical Reduction

Chemical reduction lowers the oxidation state of chemical species, converting them into less-hazardous or non-hazardous forms. The reduction is accomplished by the addition of a reducing agent which is oxidized.

Chemical reduction is used most commonly to convert hexavalent chromium into trivalent chromium, which then is precipitated out of solution as chromium hydroxide. Mercury also can be removed from solution by reducing mercury (II) to its elemental state. Sulfur dioxide and sulfite salts are the most widely used reducing agents for chromium. Sodium borohydride is an effective reducing agent for mercury and lead.

The major restrictive waste characteristics for chemical reduction include the wastes' physical form, oil and grease content, suspended solids content and viscosity. These are the same restrictive characteristics as for chemical oxidation, since chemical oxidation and reduction are similar processes.

Chlorinolysis

Chlorinolysis involves the reaction between chlorine and liquid chlorinated hydrocarbons at temperatures of 500°C or greater and high pressure to form carbon tetrachloride, hydrogen chloride and other by-products. In the chlorinolysis process, the waste first is pretreated to remove all solids and any unwanted compounds which could result in the formation of unwanted reaction by-products. Then, the purified waste undergoes reaction with chlorine, and the reaction products are separated and recovered by distillation.

The waste to be treated by chlorinolysis ideally should contain only liquid chlorinated hydrocarbons. The presence of other compounds may produce toxic reaction by-products, which may include carbon tetrachloride, hydrogen chloride and phosgene. The restrictive waste characteristics include the solids oxygen, sulfur organic and water content. As mentioned previously, the presence of compounds other than chlorinated hydrocarbons is unwanted.

Fixation

Chemical fixation is a process in which hazardous substances are stabilized and solidified in a form which is considered non-hazardous and safe for ultimate disposal. Various types of materials can be mixed with a waste to form a solid material which effectively immobilizes the waste. The process is intended to be permanent, allowing the safe disposal of the solidified mass to a landfill or other permanent disposal facility.

Fixation is used for both inorganic and organic solids and sludges. It is possible to treat liquids, although the effectiveness of this is less certain. Fixation also is used for low-level radioactive waste. Fixation of inorganic wastes is accomplished by solidifying the waste in a cement, pozzolanic or lime based material. Fixation of organic wastes usually requires the use of a glassification, organic polymer or thermoplastic technique.

The major restrictive waste characteristics which determine the applicability of fixation include the wastes' physical form, organic content, ionic composition and sulfate content. Fixation is most effective on solids and sludges. The greater the moisture content of the waste, the more difficult fixation is, although liquids can be treated. A high organic content may limit or cause problems when fixating an inorganic waste, because the organics may interfere with the solidification of the solid product. Similarly, high ionic compositions and high concentrations of sulfate interfere with stabilization and solidification.

Ion Exchange

Ion exchange is the reversible interchange of ions between a liquid and a solid phase. Ions in a liquid waste stream and ions on the surface of an ion exchange resin are exchanged, purifying the waste stream while concentrating the waste constituent on the resin.

Ion exchange resins are either cationic or anionic. Cationic resins exchange positive ions such as $H+$ or $Na+$ for negative ions in solutions such as SO^-_3. Anionic resins exchange negative ions such as OH^- and Cl^- for positive ions in solution, such as metal cations.

After an ion exchange resin has reached its capacity for exchanging ions, it is regenerated so that it can be used again. Cationic ion exchangers are regenerated by passing dilute acid solution over the resin; anionic resins are regenerated with a weak base. During the regeneration process, a solution containing a high concentration of the original waste constituent is produced. This concentrated waste then must be treated or disposed of properly.

The restrictive waste characteristics for ion exchange include suspended solids, metal content and organic contents, oxidizing agents concentration and physical form. Ion exchange is most effective for very dilute aqueous wastes. High concentrations of solids, organics and oxidizing agents interfere with the exchange of ions between the solution and the resins.

Neutralization

Neutralization involves the addition of an acid or a base to a solution to adjust the pH, usually to between 6 and 9. Neutralization often is performed in connection with other treatment processes, such as oxidation or reduction. It can be either a final treatment or a pretreatment step.

Alkaline neutralization is commonly accomplished using lime, sodium hydroxide or soda ash. Acidic neutralization utilizes hydrochloric, sulfuric or nitric acid. Neutralization is most applicable for acidic or alkaline aqueous wastes, although it also can be used for certain organic liquids. Neutralization is a relatively simple but important waste treatment process and most often is followed by precipitation of metals from solution. This technology can be used effectively for most aqueous wastes, although wastes with very high dissolved solids content may result in the formation of complexes which are difficult to remove from solution.

Precipitation

Waste removal by precipitation involves the addition of a chemical substance to alter the equilibrium affecting dissolved and suspended solids solubility. Precipitation normally requires pH adjustment, followed by the addition of a precipitating agent, resulting in flocculation and coagulation of the solids in solution.

Precipitation is used most commonly to remove heavy metals from aqueous wastes. The precipitation process produces a sludge composed of metal hydroxides, metal carbonates or metal sulfides as well as the precipitating agent used. In some instances, precipitation can be used for organic-based liquids, although this application is very limited due to sedimentation problems in viscous media.

The major restrictive waste characteristics limiting the use of precipitation include voscosity, physical form and metal solubility constant. As mentioned before, highly viscous solutions, such as many organic solvents, may not be applicable for treatment by precipitation because of difficulties in settling the metals or other particles out of solution. For highly soluble species, pH adjustment is needed to minimize solubility and enhance precipitation.

CONCLUSIONS

The applicability of seven chemical treatment technologies for hazardous liquid waste treatment has been examined. It was found that the proper choice of treatment depends upon an understanding of the restrictive waste characteristics for each technology. Once the waste characteristics which restrict the use of a particular treatment technology are known, proper pretreatment or other treatment methods can be chosen.

Treatment Technologies for Hazardous Materials

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ABSTRACT

The nature and quantities of hazardous materials and the various technologies for treating them have grown rapidly in recent years. The efficiency and cost-effectiveness of technologies such as physical/chemical treatment, metal precipitation, biological treatment and carbon adsorption, vary enormously depending on the application requirements. In most instances, these treatment processes have been utilized to treat large volumes of mixed matrix wastes.

Transferring these technologies for effective use in groundwater treatment, with relatively low flow volume and a range of contaminants from a single substance to a complex mixture, requires special considerations in the design and operation of a treatment program. The process design for these remedial programs must utilize the optimum mix of available technologies to generate the highest degree of treatment at a reasonable cost.

This paper evaluates the process design requirements and economic considerations for application of these processes to groundwater treatment. It also examines the unique design and operating conditions encountered in groundwater treatment. The concept of "life-cycle" design is addressed to demonstrate the efficiency of optimizing the particular attributes of the different technologies available.

INTRODUCTION

There is a broad range of potentially applicable technologies for the elimination of hazardous materials. However, for each material a specific review must be performed to select the most appropriate form of treatment. During this review, consideration must be given to the type of the contamination, organic versus inorganic; the extent of the contamination, surface soil contamination alone, vadose zone, groundwater or any combination of these; also to be considered are the physical and chemical characteristics of the contaminants, the relative concentration of the contaminants and the interactive effects the contaminants may have with each other. In most instances after careful evaluation, it will be found that a mix of appropriate technologies can be implemented to produce the most efficient, cost-effective solution to treat the contamination.

Most of the conventional treatment technologies are intended for use on waterborne contaminants present in fairly constant concentrations. One of the characteristics of most groundwater contamination problems is their relatively short term nature (2-5 year treatment programs). These treatment programs initially will be treating a relatively high concentration of contaminants. With time, however, the concentration of these contaminants will decrease. This concentration decrease is due to the removal of chemicals as a result of the treatment, as well as the dilution effect of clean groundwater passing through the zones of contamination.

As contaminated water is withdrawn from the ground (in either the aquifer or vadose zone) clean water will either be drawn in from the surrounding areas of the aquifer or, in the case of the vadose zone, clean water used for flushing the contaminants will displace the chemical compounds present in the interstitial spaces. The net effect is a continuous, sometimes dramatic, decrease in contaminant concentrations. This changing chemical composition creates difficult design requirements for remedial actions. The treatment programs implemented must be flexible enough to accommodate the high concentrations initially encountered as well as successfully treat the lower concentrations near the completion of the program. In fact, most programs will see the highest concentrations of contaminants withdrawn over a relatively short time period during the initiation of the treatment program. This is a most important consideration as the efficiency and operating costs of the treatment process will be seriously affected.

TREATMENT TECHNOLOGY REVIEW

There are several types of treatment processes which can be applied to the remediation of groundwater contamination. These can be divided into three categories: physical/chemical treatment of inorganic constituents; physical/chemical treatment of organic materials and biological treatment of organic compounds. It is important to understand the difference between the use of in situ treatment as a technique for decontaminating groundwater and soils and the use of process systems for the same purpose. When using in situ techniques, materials (oxidants, microorganisms, etc.) are introduced into the treatment area via wells, borings or percolation beds. Under these conditions, there is relatively little control over the reactions or the environmental conditions under which they are occurring. Analysis of the performance of these techniques is difficult to ascertain and most certainly involves a time lag between the start of a program and any result which may be reached.

In our approach to treating contaminated groundwaters and soils, the contaminants and contaminated waters are withdrawn from the ground and treated in surface reactors. This is the case for all the technologies discussed in this paper. In most instances, there is a requirement for pumping liquid into or out of the ground. Since the surface reactors allow a much greater degree of control over the process and better measurement of the results, we find this to be much more appropriate for the treatment of contaminated materials. In some cases, the combination of both techniques will yield the most benefit and should be employed.

PHYSICAL/CHEMICAL TREATMENT—INORGANIC

The inorganic compounds most frequently encountered in groundwater contamination are heavy metals. These materials

usually are not particularly mobile in the environment. Most metals exist as a cationic species and have a tendency to adsorb onto soil particles. The characteristics of some soils also allow an "ion exchange" process to occur, thus removing the metals from groundwater passing through a formation.

Hydroxide Precipitation

The metals which are found in extracted groundwater can be treated most effectively through precipitation processes. Most of the heavy metals are insoluble as a metal hydroxide or as a metal sulfide. If they are not in a chelated form, the metals can quite readily be removed by using pH adjustment and creating the metal hydroxide. Typically, the minimum solubility of most heavy metals is in the pH range of 7.5 to 9.5.

The steps necessary to determine metal removals involve experimentally determining the solubility of a metal (or metals) at various pH levels by neutralizing a sample of the contaminated water using lime or caustic soda. An insoluble precipitate will be formed which can be physically removed, and the soluble concentrations of the metal(s) can be directly measured at each pH level.

In a full-scale treatment process, the groundwater will be withdrawn and neutralized to the optimum pH level. The metal hydroxide precipitate will be removed from the liquid stream via flocculation and sedimentation. The clarified, metal-free effluent then can be discharged. In many instances, this process must be performed prior to processing for organic compound removal.

Sulfide Precipitation

The process of sulfide precipitation of metals works in a similar fashion. The minimum solubility of any given species will vary somewhat from that exhibited during hydroxide precipitation; however, the soluble concentration of the metals after sulfide precipitation will be considerably lower, as much as two or three orders of magnitude lower than with hydroxides. For most treatment program requirements, the levels which can be achieved via hydroxide precipitation are more than adequate.

Chrome Removal

The process design for the removal of hexavalent chrome requires an additional step prior to the precipitation process. Chrome, in the hexavalent form, will not precipitate as a metal hydroxide. It must first be reduced to the trivalent state using a strong reducing agent such as sulfur dioxide or sodium bisulfite under acidic pH conditions. The pH then can be raised using either lime or sodium hydroxide and precipitation of the metal will be effected.

System Design

The design criteria used in these treatment programs usually will follow those which have long been applied in the metal plating and processing industries. The systems applied to groundwater treatment should be designed with ease of installation and operation as major considerations. Once the treatment process is developed and implemented, there is generally little in the way of process variables which need to be controlled. Automatic pH control systems can be used to control neutralization; flocculant feed rates need to be monitored and adjusted periodically, but once these systems are on line, there usually is little which can be adjusted. The use of lamella separators for liquid-solid separation can substantially reduce the space required for this operation and allow easy installation and operation of the system.

The use of metal precipitation is the first step in processing contaminated waters containing both heavy metals and organic compounds. It is important to remove the metals at this point to achieve and maintain high degrees of treatment efficiencies in subsequent groundwater treatment processes.

PHYSICAL/CHEMICAL TREATMENT—ORGANIC

Downhole Recovery

The category of physical/chemical treatment of organic compounds is a broad one. The characteristics of groundwater contamination are such that in many instances the compounds are present in very high concentrations or as a pure material floating on or settling below the groundwater. The first type of treatment process to investigate would be recovery of pure product. Every effort should be made to remove as much pure product as possible using either downhole recovery systems or surface separators. The nature of most organic materials renders them only partially soluble in water, and many compounds will physically separate from water quite readily. There are a number of downhole systems now available for recovering hydrocarbon products from both the top and the bottom of a contaminated aquifer.

The use of simple separation equipment at the surface also can be implemented. This may consist of rope-type skimmers or even separator tanks using tubes and plates. The cost of the treatment program is substantially reduced when relatively pure product can be recovered as opposed to having to process the material. In many instances, the recovered product will have some economic value and may partially offset some of the treatment costs.

There are also physical/chemical treatment processes for use on low concentrations of organics in the liquid stream. Most notable among these are air stripping, carbon adsorption, peroxide oxidation and UV/ozone treatment. These are the traditional techniques for removing (or destroying) organic constituents from contaminated groundwater.

Air Stripping

Air stripping of organic compounds uses the volatility characteristics of certain organic species, such as chlorinated solvents, to eliminate them from an aqueous stream. The contaminated groundwater is pumped to the top of a column which contains an inert packing. The water flow is downward from the top of the column against a countercurrent air flow from the bottom of the unit. The air exhausted from the column contains the volatile organic compounds and is simply exhausted from the air stripping column via exhaust ports at the top of the column.

Air stripping is an effective method for removing low concentrations of highly volatile compounds. The units are quite inexpensive to operate and require a minimum of operating attention. There are, however, potential problems associated with their use in groundwater treatment programs. Certain compounds do not have particularly high volatility characteristics and do not readily strip from water. In some instances, this problem can be overcome by increasing the temperature of the contaminated water, thus increasing the volatility of the organics, but heating can become quite expensive.

Another consideration is the potential for fouling the internal surfaces of the air strippers. The groundwaters which are heated in the strippers generally will contain bacteria capable of degrading the compounds present. Under the environmental conditions found in an air stripper, it is possible to create substantial biological growth on the internal packing surfaces as well as on the mist eliminating packing at the top of the towers. In some instances, this growth can lead to excessive maintenance requirements for the operating units.

Another major consideration when evaluating the use of air stripping is the ultimate fate of the stripped compounds. In the past, these compounds have merely been vented to the atmosphere. This is not truly a treatment technique for the elimination of the compounds but rather a relocation of the problem from the water to the air. There currently is a move by the

regulatory agencies in many areas to substantially reduce or eliminate the air emissions from these units. This control by air pollution authorities will mean implementing complex and expensive emission control technology on the air streams exiting these units.

Activated Carbon

Carbon adsorption has been used to purify water for over 100 years. It is based upon the natural process of adsorption—that is the natural affinity of a gas or liquid to be attracted to and held at the surface of a solid. This attractive characteristic is due to the surface tension of the solid holding the molecules in water at its surface. Activated carbon particles are characterized by very high surface area to volume ratios. The carbon particle has a structure with a series of pores whose diameters decrease as the pores extend into the particle so that the small molecules will migrate further into a carbon particle than a large molecule.

The adsorption of the molecule onto the carbon surface is a physical process consisting of three steps: (1) diffusion of the molecules through the liquid phase to the carbon particle; (2) diffusion of the molecules through the macropores to the adsorption site; and (3) adsorption of the molecule to the site. The characteristics of the adsorbate molecule will determine the rate of adsorption and, ultimately, the efficiency of the process.

Carbon adsorption has gained a very favorable reputation as a means of removing a broad range of organic compounds from water streams. It is quite effective at removing low level concentrations of organics, particularly chlorinated solvents. The efficiency of this process varies enormously, from as low as 3% to as high as 25% utilization efficiency. Activated carbon is an extremely effective method for polishing treated effluents to remove the last traces of contaminants.

Hydrogen Peroxide

Hydrogen peroxide is used in waste treatment applications as an oxidizing agent. It is a moderately strong oxidizer of organic compounds and is quite capable of oxidizing a broad range of compounds at almost any concentration. The reaction involves the formation of a free radical hydroxyl group. Hydrogen peroxide is a highly reactive chemical which reacts quite readily with most organic materials (except saturated alkanes). Most reactions involving the use of peroxides require the use of an iron catalyst to effect the reaction.

Peroxides can be difficult to handle from a safety perspective and are by nature unstable. Also, the reactions involved are quite exothermic and can create significant hazards when used to treat higher concentrations (>500 mg/l) of organic concentrations. The most appropriate use for peroxide oxidation may be for the treatment of highly biologically refractory materials, highly intermittent waste flows or extremely low concentrations of organics in a polishing operation.

UV/Ozone Treatment

The last major category of physical/chemical treatment techniques for organic compounds is UV/ozone. UV/ozone treatment technology seems to offer a great deal of potential for the treatment of low concentrations of halogenated solvents. The ozone is the source of a highly reactive free radical oxygen species. This highly reactive free radical readily cleaves the double bonds found in aromatic and unsaturated aliphatic compounds.

UV light increases the reactivity of the target molecules, particularly those bearing carbon-halogen bonds. The wavelength of the ultraviolet light is in the absorption wavelength of this bond and excites the bond to the point of breaking and cleaving the halide from the carbon atom.

Some of the limitations of this technology are: the cost in generating ozone; developing efficient UV light systems; reducing the necessary contact times in the reactors and thus the number of lamps and the electricity to operate them; and improving the transfer of the generated ozone gas into the water stream.

The combination of UV and ozone is an excellent method for treating extremely low levels of organics in water. This technology is still in its development phase and has not been used in more than a few pilot applications. One outstanding characteristic of this technology and of the biological processes is that they both are destructive technologies, converting hazardous organic compounds into non-hazardous mineralized products of carbon dioxide and water.

BIOLOGICAL TREATMENT—ORGANICS

The use of the biological process in waste treatment involves the creation of a growth environment in which bacteria are capable of metabolizing organic compounds for energy for cell maintenance and reproduction. Essentially, this process is the conversion of a soluble organic compound into an insoluble organic (cell protein) which can be physically removed from a water stream. This technology is truly a destructive process, as the end products of the biological process are carbon dioxide, water and additional bacterial cells (sludge).

In order to accomplish this reaction, it is important to provide a proper growth environment with consideration of inorganic nutrients (nitrogen and phosphorous), pH, dissolved oxygen (for aerobic processes) and several other process variables. The design and operating conditions for a system of this type can be quite expensive using conventional activated sludge technology. Recent developments in bioreactor and process technology have given this process the opportunity to be one of the most useful techniques for the treatment of hazardous materials.

The use of biological treatment for degrading organic chemicals has been in practice for some decades now. The use of this technology on hazardous materials, and in particular on groundwater contaminants, has not been particularly extensive until very recently.

Activated Sludge

The process of activated sludge treatment is an operator-intensive process which is sensitive to variations in influent characteristics and operating conditions and requires close, careful operator attention. One of the key elements in activated sludge treatment is the concentration of large numbers of microorganisms in a reaction vessel that effectively use an organic substance for a food source. In order to concentrate these organisms, liquid-solid separation must be effectively and carefully controlled. The use of fixed-film biological reactors instead of the suspended growth activated sludge process has eliminated the requirement for extensive operator attention and reduced the critical nature of liquid-solid separation as part of the process.

Fixed Films

The use of a fixed medium surface allows the microbes to become attached to a surface over which their food source (substrate) passes. The organisms form a biological film into which their substrate, nutrients and oxygen diffuse. In this fashion, the organisms merely grow to a film thickness consistent with the availability of substrate. As the concentration of substrate diminishes, the rate of microbe growth decreases.

In a submerged fixed-film bioreactor (rotating biological contactor), the release of air in a diffusion system beneath the medium in the tank provides the means of both oxygen transfer and mixing energy. This mixing energy creates a relatively high velocity of air and water moving past the biological film. This movement provides a means for shearing the accumulated biological growth from the fixed-film and for preventing bridging of biological growth and plugging within the medium.

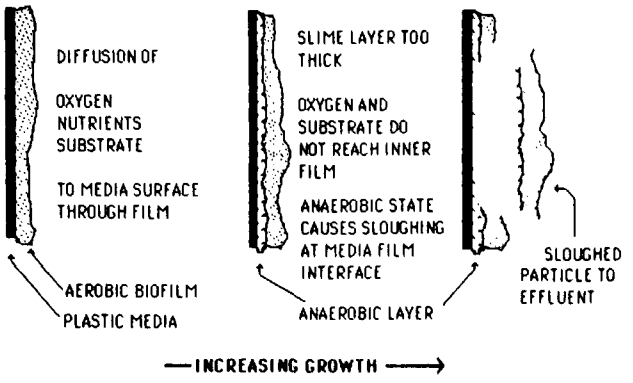

Figure 1
Biological Film Growth and Sloughing

This mechanism of sloughing (Fig. 1) of the biomass is essentially self-regulating. As the film becomes thicker due to the growth of the microbes, its ability to remain attached to the medium is reduced. Since the velocity of the air and water mixture remains constant, the shear forces are constant. When the film becomes thick enough, the shear forces are greater than the adhesive forces and the film sloughs off the medium surface.

The effective concentration of microorganisms within the reactor tank would be the equivalent of 6,000-8,000 mg/l of mixed liquor suspended solids in an activated sludge system. These biotreaters can be placed within a fairly small reactor volume and are quite readily preassembled and installed at a treatment location.

A minimum of operator expertise is required for these systems, and they are becoming increasingly popular as methods of destroying the hazardous materials. The biological process tends to complete the degradation reaction, yielding carbon dioxide. Perhaps 99% of all known organics can be effectively degraded using biological treatment.

Slightly Contaminated Streams

Recent developments in biological treatment technology now enable low concentration waste streams to be biologically treated. In the past, all biological reactors were designed using the growth characteristics of the biological populations as the limiting factors to their effectiveness. It was not considered possible to use biological processing on many wastes at a concentration containing less than 50 mg/l. This limitation is due to the nature of biological growth dynamics, the effect of biological washout from the reactors, loss of settling properties and other engineering considerations. Low concentration reactors now have been developed using acclimated populations for removal of low concentration (<5 mg/l) contaminants to low μg/l (1-3 μg/l) effluent levels. These reactors are portable, require almost no operator attention and appear capable of operating several months on the low influent concentrations before needing to be reacclimated. This technology probably will displace activated carbon in many instances for the polishing of low level organic compounds.

Soil Treatment

The use of the biological process also has been successfully adapted to the treatment of contaminated soils. It is possible, using the proper engineering designs, to create a growth environment for microorganisms in a soil environment. This process requires the same environmental conditions as the treatment of a wastewater stream, but they can be created and maintained quite readily.

The availability of commercial bacterial inocula has substantially increased the ease with which the soils can be treated, and these techniques offer substantial potential for eliminating a wide range of soil contaminants such as pentachlorophenol, creosote, hydrocarbons, pesticides and many other types of compounds. The economics of soil treatment are also very favorable, and once again this type of treatment is truly a destructive technology.

The current state-of-the-art in groundwater treatment technologies allows us to use these technologies now. However, the use of these technologies as part of a remedial program must be carefully scrutinized to ensure that they are consistent with the economics and operating considerations of each individual program. For instance, the use of a carbon adsorption process for treatment of organics at a very high concentration (>100 mg/l) can create more problems than it will solve. There are instances where highly biodegradable compounds present in a carbon system have created high degrees of biological activity within the columns and have subsequently generated substantial amounts of sulfides in the carbon column effluent. These sulfides then required an additional peroxide process to eliminate the odor and corrosion problems associated with them.

ECONOMICS

The economics of the various treatment technologies cover a considerable range. The cost of any particular process can also vary considerably depending on the degree of treatment required and the time frame of the treatment program. The technologies ranked by cost in descending order from most to least expensive are: peroxide oxidation, activated carbon, biological and air stripping.

The costs vary as a function of contaminant concentration; as a rule the cost will be higher for higher concentrations (on a $/gal treated basis); the efficiency of each process (i.e., an easily stripped compound) will cost less to treat per gallon than a less volatile compound. The duration of the treatment program also will have a significant effect on the economics of treatment since a longer term program will allow for amortization of the equipment over a longer lifespan. Also, some process equipment will have a higher residual value at the end of the program and can be sold or reused in other applications. The following example compares the economics of treating a waste stream via three different processes: air stripping, carbon adsorption and biological/carbon adsorption.

Design Basis

Flow = 5 gal/min
Organic concentration = 300 mg/l methyl ethyl ketone
Operating period = 2 years

The economic estimates are based on the process achieving 1 mg/l MEK and 100 μg/l total other organics in the effluent. The cost for all capital equipment, operations and maintenance are included in this analysis.

Carbon adsorption = $0.065/gal
Biological/carbon = $0.042/gal
Air stripping = $0.032/gal

The economics involved in the treatment of any material can vary enormously depending on the specific requirements of the application but, in general, the above figures are relatively accurate. As the concentration of the contaminants to be treated increases, the biological process becomes more economical. As the volatility of the materials increases, the cost of air stripping improves somewhat; however, this cost is difficult to lower much further.

Other economic analyses have been performed on a $/lb removed basis and have been reported to be as low as $0.40-0.50/lb removed biologically to as high as $7.50-$10.00/lb removed with carbon adsorption. A true economic evaluation of the actual costs can be performed only on a specific case-by-case basis.

The most important consideration when considering the appropriate technology is to optimize the cost advantage of each process. As can be seen from the economics, there are many possible combinations of technologies which can be put together to produce a highly efficient, cost-effective treatment process.

TECHNOLOGY TRANSFER

The treatment requirements for hazardous materials in a groundwater contamination problem are unique for several reasons:

- Relatively low and/or variable flow conditions
- Varying influent concentrations
- Short time frame projects
- Ease of operation and simplicity of design
- Stringent discharge regulations

The design and operating requirements for these treatment systems have to reconcile all these factors and at the same time offer an efficient cost-effective system. The most important consideration in designing these systems is to insure the systems will provide the necessary degree of treatment throughout the lifetime of the project while adjusting to the changing influent conditions.

Initially, the flow volume in these programs is generally quite low. They rarely exceed 100-150 gal/min and quite often are in the 10-20 gal/min range. The actual flow over the course of the treatment program may vary considerably due to seasonal conditions, the transmissivity characteristics of the aquifer and percolation rates of the overlying soils.

The concentration of the contaminants will also vary with a general trend to decreasing concentrations. There periodically may be increased contaminant levels as pockets of material are freed, but the concentration will decrease over the life of the treatment program. It is important to use a process design that will cover the entire life-cycle of the project.

The time frame of most groundwater cleanup programs is generally between 2-5 years. Most treatment systems for permanent operation are designed on a lifespan of 10-20 years. It is much easier to justify the costs of installing a major process on a long-term system than on a relatively short-term system. It is most important to minimize the amount of capital required to install a short-term remedial project.

The systems being used in these treatment situations are generally unfamiliar to many of the industries and individuals involved in cleanup programs. There are many industries which, until recently, merely discharged their wastewaters to public treatment facilities and, as a result, have limited experience in wastewater processing and the actual operation of wastewater treatment facilities. In many instances, there is a minimal amount of manpower available for operating a treatment system, or the locations of the treatment facilities are remote and not frequently attended.

Taking all these factors into account, it becomes apparent that the design of a treatment facility to be used in these situations is indeed quite different than a typical wastewater treatment plant. It is important to optimize the benefits of each technology. For instance, it can be quite costly to provide a carbon adsorption system to treat 50 gal/min of groundwater contaminated with 300 mg/l of adsorbable solvent which will ultimately contain only a few mg/l of organics near the end of the treatment.

Preferable is a combined system using either air stripping or biological treatment before the carbon system to reduce the organic loading on the carbon and hence reduce the amount of carbon which will be used. Both air stripping and biological treatment are less expensive than the use of activated carbon for the removal of high concentrations of organics.

In most cases, using modular, life-cycle designs will tend to lower the costs and increase the efficiency of the tretment process. For instance, the use of two fixed-film bioreactors to handle a given flow and loading is preferable over using one large unit. As the concentrations decrease, one of the units can be taken off line and the operating costs and maintenance requirements will be decreased substantially. Similarly, a carbon tank which is sized for a certain flow and organic concentration may become an operational problem if the flow and concentrations in the influent drop substantially. Problems with carbon treatment include: (1) channeling and carbon bed may develop biological growth which can cause anaerobic conditions and subsequent sulfide problems. When properly designed for life-cycle operation, the treatment systems can provide a highly efficient, cost-effective process.

CASE HISTORIES

Phenol Contaminated Groundwater Treatment

An example of life-cycle design is the following treatment program on the U.S. Gulf Coast. At the initiation of treatment, the influent organic concentration was approximately 1,300 mg/l as TOC with phenol concentration at 400 mg/l. Over the lifespan of the treatment program, it is known that the concentration of the influent stream will decrease substantially until it is below 100 mg/l TOC. It would be quite difficult to design and operate a system that functions as effectively on 1,300 mg/l as on 100 mg/l. Obviously, activated carbon treatment alone would be prohibitively expensive and would still require the disposal of large quantities of spent carbon. The use of an air stripping process also is not possible since the organic compounds present are not readily strippable. In order to meet all the needs of this particular program, the life-cycle design as shown in Figure 2 was implemented.

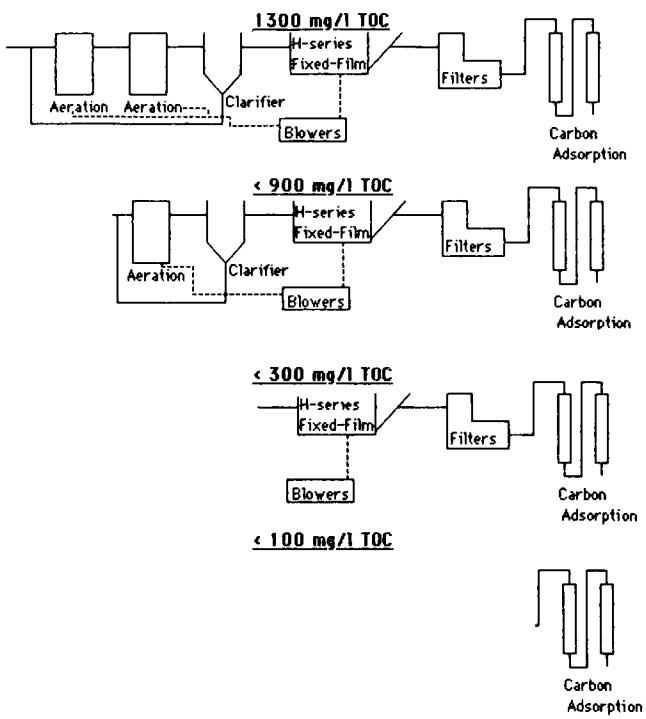

Figure 2
Life-Cycle Design for Phenol Contaminated Groundwater Treatment

In this installation, the aeration tanks were converted storage tanks which, when coupled with a clarifier, were used as an activated sludge process. As the concentrations decreased only one tank was used for the treatment program. Eventually, that tank was also removed from service and the fixed-film biotreater was the remaining biological unit in operation. Throughout the duration of this program, the process design and equipment used were changed to meet the prevailing conditions.

The cost of operating the system and the attention required for its operation also diminished with time. Throughout the design of the treatment process, those technologies used were applied to provide the most economical operation. The activated sludge process (using existing equipment) provided bulk organic removal; the fixed-film unit provided additional treatment (below about 300 mg/l TOC the activated sludge process would not be particularly effective) to reduce the organic loading to the carbon adsorption system; and, ultimately, the carbon was used to remove the lowest level of contaminants.

The nature of this program required that the effluent be treated to a TOC concentration less than 18 mg/l so that it could be used for reinjection to force additional contaminated water toward the withdrawal wells. Once biological activity was established in the system, TOC was consistently biologically reduced by 75-85%. Effluent phenol levels were consistently reduced by 99%. This biological oxidation of organics substantially reduced the amount of carbon required to attain the 18 mg/l TOC effluent requirement. The influent to the system has decreased to less than 800 mg/l TOC, and parts of the activated sludge system have been taken off line. There is now a requirement for the removal of arsenic from this particular waste. An arsenic precipitation system is being added so that the arsenic can be co-precipitated with iron. This system is being added at a minimal cost.

The economics involved in this particular case were based on the use of carbon adsorption alone as compared to the cost of using biological processing. Assuming 23,000 gal/day flow at a TOC of 1,300 mg/l, 249 pounds of organics need to be removed from the water. Using a carbon cost of $0.75/lb and an operating efficiency of 1 lb organics removed/10 lb carbon, the operating cost for just carbon is $1,875/day. This cost does not include the cost of capitalizing the equipment or other costs of operation such as electricity and personnel.

The anticipated cost for the operation of a biological system alone, including capitalization of the equipment, electricity, but not personnel, is approximately $0.46/lb of organic material removed. This is $115/day plus the cost of carbon for polishing the effluent (assuming 50 lb/day TOC is removed via carbon polishing) of $370/day. The total costs of operating this system are $485/day. This system has been in operation for over two years, resulting in a cost savings of $834,000. The actual costs of daily operation should continue to diminish over the remainder of the program.

Chemical Disposal Facility Leachate

The optimization of several technologies in combination has been investigated to treat the leachate from a chemical disposal facility. It has been determined that a plume of high TOC material was migrating off-site and required treatment. A process design using carbon adsorption alone and in conjunction with biological treatment was evaluated in a pilot program.

Initially, 300 gal of sample were collected from the well at the site. Analysis revealed 2,000 mg/l TC (to compensate for inorganic carbon, this value was reduced by 10% to compute a TOC value). N,N- dimethyl formamide and propionic acid were specifically identified.

A series of four carbon columns, each designed for a surface loading of 2 gal/min ft^2, processed the waste liquid. The utilization efficiency of the carbon was found to be 25% (1 lb organics removed/4 lb activated carbon used). The apparent attainable effluent level was 90 mg/l as TC. The carbon was highly efficient in its removal capabilities in this instance and was quite able to lower the contaminant levels in the effluent. Even at this high efficiency, the cost for treatment in replacement carbon costs alone is about $4/lb organics removed.

A second series of evaluation was performed to determine the viability of using biological treatment in conjunction with the activated carbon in order to attain similar effluent levels at a reduced cost and, in addition, provide a destructive treatment of the contaminant compounds. A simple biological reactor was designed to provide degradation of the bulk of the organics present. This reactor was followed by carbon adsorption for final polishing and removal of refractory organic compounds. The biological reactor was able to remove an average of 76% of the organic concentration of the liquid. The carbon adsorption system removed the remainder of the TOC down to a level of 40-70 mg/l with the carbon system providing a utilization efficiency of about 16%. The economics for the treatment of this waste stream break down as follows:

Treatment System	Cost ($/lb TOC removed)
Activated Carbon	
1 gal/min	8.50
2 gal/min	6.90
Biological/Activated Carbon	
1 gal/min	4.50
2 gal/min	3.50

These costs include both capital and operating expenses for the treatment program.

On the basis of this economic analysis and the needs of this particular treatment program, a combination of biological/carbon treatment likely will be used at this facility.

CONCLUSIONS

The adaption of conventional treatment technologies for the treatment of hazardous materials in groundwater situtations is clearly possible. However, the use of these technologies requires a design basis unique to each application as well as an economic justification unique to each application. Each application must be evaluated independently to determine which technology or combination of technologies is most appropriate for producing the desired level of treatment on a cost-effective basis.

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Update on the PACT Process

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ABSTRACT

This paper is an updated discussion of a 40 million gal/day plant which uses the du Pont developed PACT* process to provide combined secondary/tertiary treatment to industrial wastewater.

Reasons for selecting the PACT process are discussed. Special features of the plant are reviewed including a 40 ton/day multiple hearth furnace to regenerate powdered activated carbon and an on-site, double-lined, secure hazardous waste landfill where primary sludge from the plant is deposited. Operating data are presented which demonstrate the effectiveness of the PACT process including data on removal of priority pollutants.

Because of under-utilization of the plant in recent years, a successful outside wastewater treatment business has developed. This aspect is discussed as an example of the financial, technical and environmental advantages of using a large, advanced treatment facility to treat industrial wastewaters from a variety of sources.

INTRODUCTION

This paper is an updated case study of a 40 million gal/day design industrial wastewater treatment plant (WWTP); several papers discussing the initial years of operation of this plant were presented in the early 1980s. This WWTP was built to treat the waste from du Pont's large Chambers Works site located on the Delaware River estuary in southern New Jersey. The Chambers Works site produces a large variety of organic intermediates, mainly substituted aromatic compounds; tetraethyl lead; Freon fluorocarbons; textile treating chemicals; fuel additives; and miscellaneous other products. During the initial years of WWTP operation, the site also made dyes, dye intermediates, sulfuric acid and isocyanates. In addition, the WWTP treated acidic waste from du Pont's adjacent Carney's Point nitrocellulose plant, since shut down.

Because the WWTP was greatly under-utilized by 1983, the site began to actively seek outside aqueous wastes for treatment to help reduce the fixed cost burden of the WWTP on the remaining operations on the site. The last section of the discussion reviews various aspects of this very successful venture.

The PACT process was invented specifically to treat the original Chambers Works-Carney's Point waste stream. It added powdered activated carbon to a conventional activated sludge aerator and achieved a higher degree of treatment than could be obtained with activated sludge alone. Table 1 summarizes the composition of the waste stream expected to be treated during the design stages of the WWTP.

*PACT is an acronym for Powdered Activated Carbon Treatment. The PACT technology is now owned by Zimpro, Inc., which is making the process available under license. "PACT System" is a registered trademark of Zimpro, Inc.

Table 1
Design Load (Average) for Chambers Works WWTP

Flow	26,400 gal/min
Soluble BOD	88,700 lb/day (280 mg/l)
Color	1000 APHA
Acidity	454,000 lb/day* (1430 mg/l)
Dissolved Organic Carbon	65,000 lb/day (205 mg/l)
Total Dissolved Solids	2000 to 5000 mg/l
Total Suspended Solids	80,000 lb/day** (258 mg/l)

*Acidity expressed as $CaCo_3$ equivalent throughout this paper.

**Included 56,000 lb/day by product solids from lime neutralization.

This wastewater was salty, acidic (pH between 1 and 2) and highly colored. In terms of organic concentration, the wastewater was only medium strength; because of the high flow, the absolute pounds loading was very large. Similarly, the total amount of acid to be neutralized was high. The loading of dissolved organics was highly variable, both in terms of composition and amount, in part due to the batch nature of many Chambers Works processes. The organic compounds to be treated included many not normally amenable to biological treatment.

The first and third sections of the discussion review the factors leading to selection of the PACT process and the subsequent performance of the plant. The second section is a description of the equipment, including the multiple hearth regeneration furnace for activated carbon, to our knowledge the only use of this equipment for powdered carbon regeneration in the world; the double-lined, secure hazardous waste landfill for storage of primary sludge is also described.

TECHNICAL AND ECONOMIC CONSIDERATIONS IN SELECTING THE PACT PROCESS

The PACT process developed from technical studies of treatment processes for Chambers Works-Carney's Point wastewater. Compared to a conventional activated sludge process, the PACT process with a dosage of 150 mg/l virgin carbon at an 8-day sludge age:

- Gave consistent BOP removals of over 95%
- Increased DOC removal from 62% to 85%
- Reduced color
- Minimized foaming during aeration
- Improved sludge settling and filtration properties
- Protected the microorganisms from shock loadings of organics

Data from typical continuous laboratory unit tests are shown in Table 2. Table 3 shows similar data demonstrating the effect of increasing carbon dose on system performance. The carbon used in these tests had an iodine number between 800 and 1,000. Sig-

nificantly different performance would have been obtained with carbon of different quality, although any PACT unit generally will outperform a parallel activated sludge unit. Note in Table 2 that color actually was increased by activated sludge treatment.

By 1970, when design work on the Chambers Works WWTP started, it had become obvious that proposed limits on DOC and color would require some form of tertiary treatment. Review of available technology showed the most promising alternatives to PACT was granular carbon columns located either before or after a conventional biological reactor. These options were studied in detail.

Table 2
Typical Laboratory PACT Unit Performance*

Feed Concentration		
BOD_5	296 mg/l	
DOC	203 mg/l	
Color	1960 APHA	
Effluent	**PACT Unit**	**Biological Unit**
BOD_5: Conc.	11.5 mg/l	26.1 mg/l
BOD_5: Removal	96.1%	91.2%
DOC: Conc.	29.1 mg/l	91.2 mg/l
DOC: Removal	85.3%	62.1%
Color: Conc.	395 APHA	2280 APHA
Color: Removal	79.9%	−16%
Operating Conditions		
Sludge Age, days	8.0	8.0
Carbon Dose, mg/l	148	0
Temp. Range, °C	15-24	15-24
Aerator Hydraulic Res. Time (hr)	7.4	7.3

* Data for time period 1/22/77 thru 5/6/77.

Table 3
Laboratory Data Showing Effect of Carbon Dose

		Effluent		
	Feed	Activated Sludge	PACT 25 mg/ Carbon Dose	PACT 100 mg/l Carbon Dose
Soluble BOD_5, mg/l	111	7.5	6.6	6.1
BOD Removal	---	93.2%	94.1%	94.5%
DOC, mg/l	86	31.9	21.7	13.1
DOC Removal	---	63%	75%	85%
Color, APHA	820	700	320	170
Color Removal	---	20%	63%	80%

Data represent three months' operation of continuous, laboratory 7 5 l units. Temperature range for all units was 18 to 25 °C, and hydraulic resident time was 8 hr

In laboratory studies, neither process with carbon columns performed as well as PACT. When carbon columns were placed after the activated sludge unit, in the more conventional arrangement, the biological system constantly experienced upsets caused by shock loads of organics. With carbon columns before the biological unit, the carbon was used inefficiently. Much of its comparatively expensive adsorption capacity was occupied by easily biodegradable compounds. Further, as the composition of the feed changed, it had a chromatographic effect on the carbon column. Thus, there were surges in the concentration of specific organics in the effluent from the column, and the biological unit did not receive the expected protection from organic shocks.

Investment costs for the PACT system were lower than for either of the carbon column systems. Very generally, the investment difference was caused by the added expense for separate carbon columns as well as the expense for twice the clarification capacity in the biological portion of the carbon column systems. Because of the superior settling properties of PACT sludge, the PACT system requires less clarifier capacity than conventional activated sludge systems.

PACT process economics were compared with a conventional activated sludge process for the Chambers Works, even though the latter was not a viable alternate in this case. Cost estimates for PACT secondary/tertiary treatment vs. secondary treatment by a conventional activated sludge plant were within 10% of each other. The extra PACT investment for carbon handling and regeneration facilities was mostly offset by the additional clarifier capacity and sludge disposal facility needed for the activated sludge plant.

In effect, the PACT process at Chambers Works was expected to provide tertiary treatment quality effluent at a cost close to that for secondary treatment alone. In one piece of equipment, the aerator, the PACT process destroyed most of the organic wastes relatively cheaply by biological action, while using expensive carbon efficiently to remove only difficult to biodegrade or normally non-biodegradable substances.

DESCRIPTION OF THE WWTP

Figure 1 is a flow diagram of the WWTP. It is easiest to consider the plant in two sections: (1) primary section, where the acidic wastewater is neutralized, most heavy metal removal occurs and primary solids are settled, filtered and disposed of in the secure landfill; and (2) secondary/tertiary PACT treatment section where color and dissolved organics are removed.

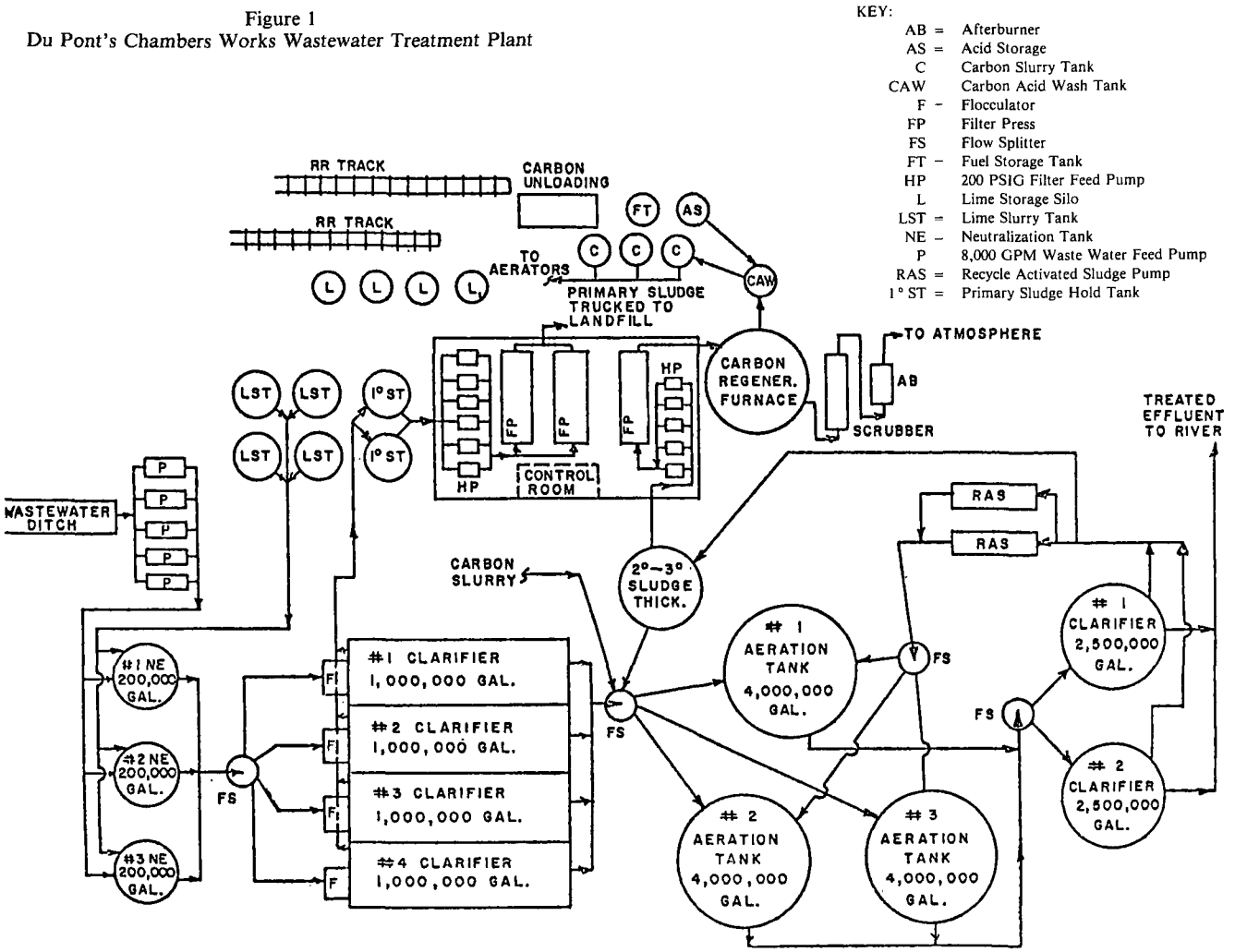
Primary Treatment

The acidic water is neutralized with lime in a single stage neutralization using three, stirred 200,000-gal reactors operated in parallel. The WWTP receives powdered lime by rail car or truck. Powdered lime is stored in 4 large silos and is slaked to 8-10% concentration as needed. Lime slurry is fed to the neutralizers by an automatic control system that maintains pH at any preset level. The WWTP currently consumes approximately 60 tons/day of dry lime to treat 100 tons/day acid. The plant has enough capacity to treat 240 tons/day acid. The highest monthly average load treated to date is 220 tons/-day.

The neutralizers overflow to four primary clarifiers, each 1 million gallons in size. The rectangular clarifiers operate in parallel and are 230 ft long, 55 ft wide and 12 ft deep. Solids in the wastewater feed, as well as byproduct solids formed during neutralization, settle and are removed as a 6-10% slurry in the clarifier underflow. After filtration to a 45 to 50% solids cake, the solids are hauled to the secure landfill. Two or three (depending on the load) high-pressure (210 lb/in^2 at end of cycle) large recessed chamber filter presses make approximately 7 tons of wet press cake per 30 to 60 min cycle.

The WWTP currently generates from 100,000 to 200,000 lb/day (dry basis) solids, equivalent to 43,000 to 85,000 yd^3/year of landfill volume. The solids are mainly inorganic, primarily calcium and magnesium salts, as well as silica compounds from river water silt. These solids also contain small amounts of heavy metals and a variety of organic compounds. The solids are an inevitable byproduct of the primary treatment process, and because they are primarily inorganic compounds, the only feasible disposal method is landfilling.

Figure 1
Du Pont's Chambers Works Wastewater Treatment Plant



A diagram of the landfill is shown in Figure 2. It is located on the Chambers Works site, and primary sludge is hauled there by truck. A double liner of a chlorosulfonated polyethylene material, Hypalon, covers the entire bottom and part of the sides of the landfill. Collection pipes between the liners serve as leak detectors and drain to sumps outside the landfill. The sumps are sampled on a regular basis for any signs of contamination. Above the top liner is a similar collection system for leachate which is pumped back to the WWTP. The landfill ultimately will become a 70-ft high pyramid with a 15-acre base.

As outer sections of the landfill are filled, the edges and top are covered with a 2-ft layer of essentially impervious, permeability of less than 1×10^{-7} cm/sec, clay and 12 in. of top soil. Newer sections of the landfill also may be required to have a Hypalon liner under the clay cap.

A controlling factor in the operation of the primary filter presses is that the filter cake must meet rigid soil stability criteria. These solids have to support the weight of heavy earth-moving equipment. Further, the allowable slope of the landfill sides, and hence the volumetric capacity of the landfill, is closely regulated to assure a large safety factor against any possible slippage along the slopes.

As backup protection, there are 26 monitor wells located around the landfill; and in the very unlikely event of a double liner failure, interceptor wells would be utilized to prevent any harm to the environment while the problem was corrected.

PACT Secondary/Tertiary Treatment

PACT treatment starts at the flow splitter which feeds neutralized primary effluent to the aerators. The activated carbon is added here as a 1 lb/gal aqueous slurry. The three, 185-ft diameter, 4,000,000 gal aerators operate in parallel and provide 5 to 9 hr hydraulic resident time.

Air is used to suspend the mixed liquor suspended solids (MLSS) which are an approximate 50/50 mix of biomass and activated carbon. Initially, there were approximately 1150 static mixers in each aerator to improve oxygen transfer. These aerators have since been removed, leaving just air holes on the bottom of the injection air laterals. The BOD loading to the WWTP was never high enough to require the added gas transfer claimed for the mixers. At low BOD loadings more air was required than needed for the bacterial metabolism alone; the extra air flow was needed to keep the MLSS well mixed, as the mixers appeared to hinder gross solids circulation.

After aeration, water is fed through two parallel, 172-ft diameter, 2,500,000 gal clarifiers. Feed enters through a centerwell, flows through a flocculating zone and then beneath a ring into the annular area bounded by the clarifier wall. The treated wastewater overflows into a circumferential trough and then to the plant effluent trench. It goes to a settling basin where it mixes with approximately 1½ times its volume of non-contact cooling water before discharge to the Delaware River estuary.

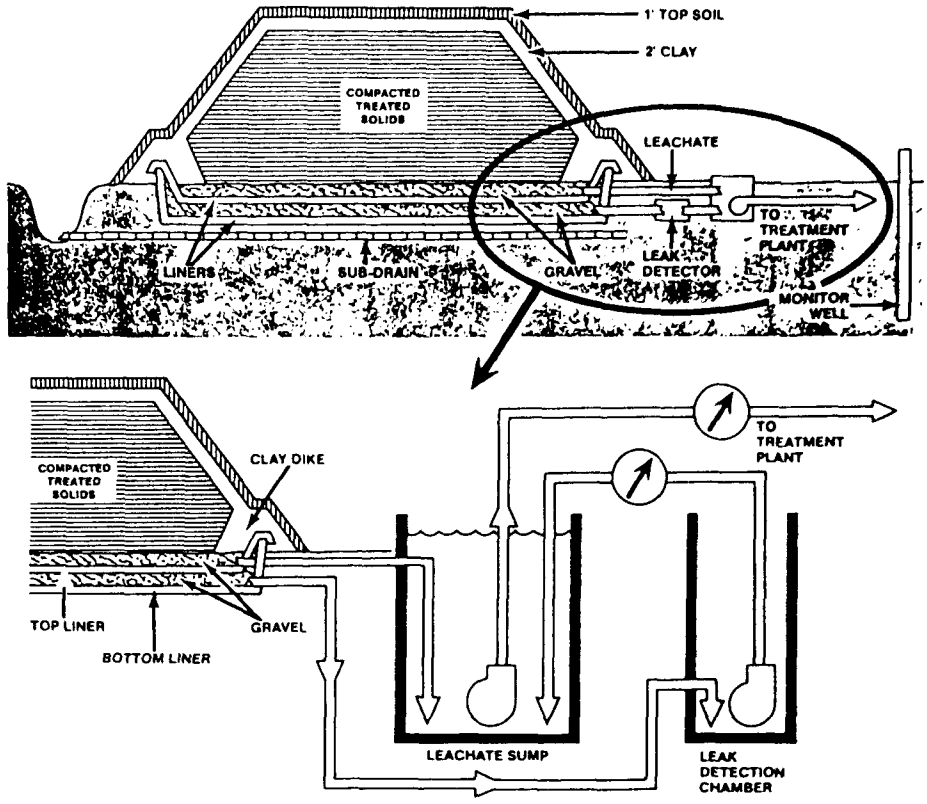


Figure 2
Secure Landfill

Rim drive bridges support rakes which push settled solids to the center of the clarifiers; from there the solids flow via underground lines to the recycle activated sludge (RAS) pumps. Two 78-in. diameter screw pumps of 10,000 to 12,000 gal/min capacity each are provided to pump the clarifier underflow or RAS back to the aerators. Solids may be wasted from either the RAS stream or the more dilute aerator discharge.

The WWTP can regenerate activated carbon from the wasted MLSS. When the plant is regenerating carbon, the wasted slurry is pumped through a thickener. Underflow from the thickener at 5 to 12% solids concentration is pumped to a 250 lb/in^2 filter press. The 64-in. diameter press has 112 recessed chambers 1 in. deep. Each press cycle produces approximately 12,000 lb of 38 to 45% solids press cake. This press is similar to the two other presses used in primary service. In fact, one of the other two presses is a "swing" press which also can be used to filter PACT sludge. When not regenerating carbon, all three presses may be used in primary service. The filtered PACT sludge is conveyed by a series of drag flite, screw and belt conveyors to the top of a 26-ft diameter, 40-ft high multiple hearth regeneration furnace.

There are five hearths in the furnace. Hot gases flow up the furnace countercurrent to the sludge. The furnace has a rotating centershaft with two rabble arms extending over each hearth. Filter cake drops onto the top hearth and is raked from hearth to hearth down through the furnace. From the fifth (and last) hearth, the incandescent regenerated carbon drops into a water-filled quench tank.

Some of the furnace's unique design features reduce upward gas velocity and minimize entrainment of carbon particles. The general principle of operation is that water is evaporated on the first and second hearths at gas temperatures of 480 to 700 °C. On the third hearth, biological solids and adsorbed organics are volatilized by 750 to 870 °C gas. On the bottom two hearths, at gas temperatures of 870 to 1020 °C, the powdered carbon is thermally regenerated in the presence of water vapor.

Off-gas from the first hearth passes through a two-stage water scrubbing system and then to an oil-fired afterburner which destroys odors and any organics at temperatures of 650 to 760 °C.

Continuous water flow to the product quench tank is adjusted to give a product slurry concentration of approximately 5%. The regenerated carbon is washed in acid to remove inorganic ash. Washings from this step are returned to primary treatment where removed ash precipitates and is trapped in the primary sludge. The washed, regenerated carbon slurry is transferred to a 60,000-gal storage tank prior to recycle to the aerators. Three of these tanks are provided to hold virgin and/or regenerative carbon.

In recent years, organic loading to the WWTP has decreased; therefore, less activated carbon is needed. It has become more economical to use only virgin carbon on a throw away basis. Currently, waste MLSS are returned to the influent steam to primary treatment. The carbon and biomass are removed in underflow from the primary clarifiers, making up about 10% of the filtered solids deposited in the secure landfill.

WWTP PERFORMANCE

During the first years of operation, the PACT process exceeded expectations in terms of BOD and color removals and approximately equalled design in DOC removal. Data for early years are shown in Table 4; in this period, the system was most heavily loaded. Performance in subsequent years has been comparable, but inlet DOC and BOD concentration have been significantly lower. The flow rate also has decreased to approximately 20,000 gal/min.

Table 4
PACT System Performance, 1978 & 1979

	24-Month Avg.	Design Flowsheet
Flow (gal/min)	25,000	26,400
BOD		
Inlet Soluble BOD_5, mg/l	171	280
Effluent Soluble BOD_5, mg/l	6.7	21
Removal (%)	96	93
Color		
Inlet Color, APHA	1,530	1,000
Effluent Color, APHA	483	500
Removal (%)	66	50
Aerator		
Aerator MLSS (mg/l)	25,000	8,000
Sludge Age (days)	41	8
Carbon		
Carbon Dose (mg/l)	120	170
Virgin (%)	53*	30
Regenerated (%)	47*	70

*The low ratio of regenerated to virgin carbon reflects start up problems with the filtration and regeneration systems. In 1980 and 1981, the ratio was 70% regenerated/30% virgin at similar total carbon dose.

The initial BOD load was less than expected because the mix of organics to be treated shifted and became less biodegradable than anticipated. The design ratio of BOD/DOC was 1.3 to 1.4, which was the then current ratio in Chambers Works waste. However, extensive waste reduction efforts prior to WWTP startup removed a disproportionate amount of biodegradables. As can be seen in Table 4, the BOD/DOC ratio in 1978 and 1979 was approximately 1.0.

The activated carbon in the aerator allowed the WWTP to treat this difficult waste. One result of the lower BOD load was that the minimum air flow to the aerators was set by the amount needed to keep the biomass and carbon well suspended. This was about 13 ft^3/min per static mixer. It had been expected that minimum air flow would be set by the need to maintain a minimum dissolved oxygen concentration of 0.5 mg/l in the aerator. As was mentioned earlier, this was the reason the static mixers were removed from the aerators in 1981. This allowed the air flow to be reduced from 15,000 ft^3/min per aerator to 8,000 ft^3/min or lower, while still maintaining 0.5 mg/l oxygen levels.

The influent was more highly colored than was assumed during design. However, color removal efficiency was better than anticipated, and the site was able to meet permit standards for color.

Average DOC removal was equal to design, so effluent quality was slighly better than predicted, reflecting the lower influent concentration.

In terms of meeting NPDES permit limits, variation in performance is often more critical than long term average. Most permits specify a daily maximum limit as well as a monthly average, and consistently meeting the daily maximum is often the more demanding task for the process. The consistency of the PACT process at Chambers Works is outstanding. Figures 3 and 4 are histograms showing the distribution of feed and effluent DOC and soluble BOD respectively in 1978 and 1979. Note the narrow distribution of effluent concentration, particularly of BOD.

Analyses for the removal of U.S. EPA-designated priority pollutants are in Table 5. Volatile organics and acid extractable compounds generally are removed very well; base neutral compounds are removed with a lesser amount of success. Some metals removal occurs across PACT treatment, although the process is not designed for this purpose.

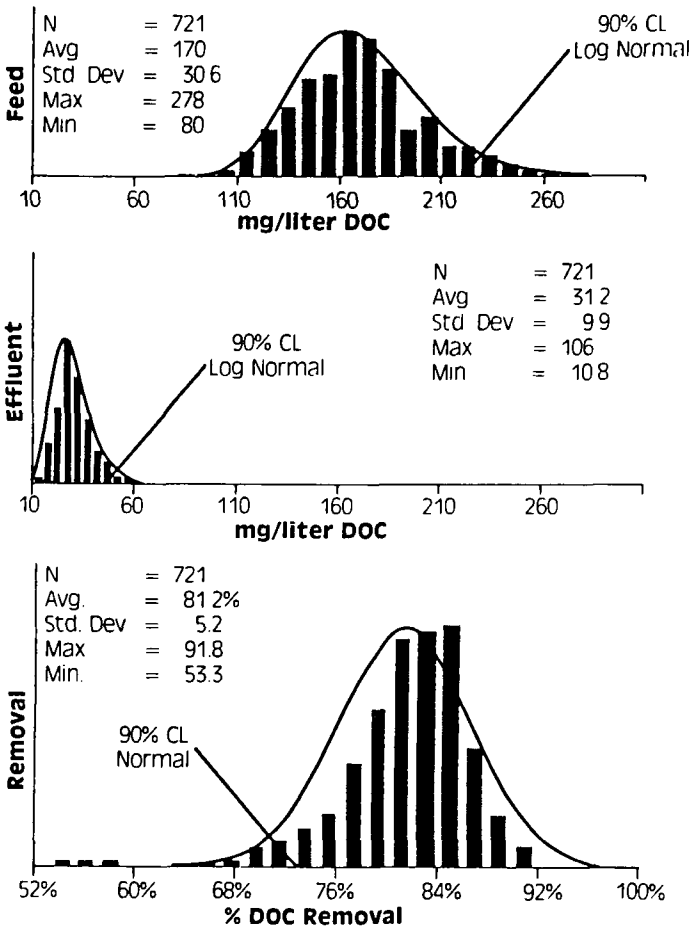


Figure 3
DOC Histogram (1978 and 1979 Data)

A major reason for selection of PACT was the protection afforded the biosystem from upsets caused by shock loadings of organic wastes. Because of the large number of batch processes at Chambers Works, it was not impossible for the WWTP to see 20,000 to 50,000-lb slugs of various organics in a 1- to 4-hr period. The biosystem handled documented spills to the WWTP of 50,000 lbs of an aromatic diamine and 30,000 lb of o-toluidine with no ill effects. No equalization is provided before the WWTP because pilot plant studies showed no significant improvement in performance with equalization.

The demise of dyes manufacture on the site ended a major source of organic shock loads. However, the increasing amounts of trucked in outside wastes actually have made the overall problem more severe. A 5,000 gal truck is discharged into the 20,000 gal/min influent stream within 30 min. The PACT process has tolerated the resultant shock loads when wastes with relative high DOC content are received.

Initially, the WWTP operated at higher sludge ages, 20 to 60 days, than the 8 to 15 days specified in design. Organic removals were improved at higher sludge age, with the result that the WWTP operated at an average carbon dose of 120 mg/l. This compares with a design dose of 170 mg/l. Because of lower organic loadings, since 1983 the plant has operated at sludge ages of 8 to 30 days with virgin carbon doses of 10 to 50 mg/l.

Because of the initial high solids concentrations in the aerators, 10,000 to 30,000 mg/l, the secondary clarifiers were heavily overloaded. They were designed for a solids flux rate of 63 lb/day

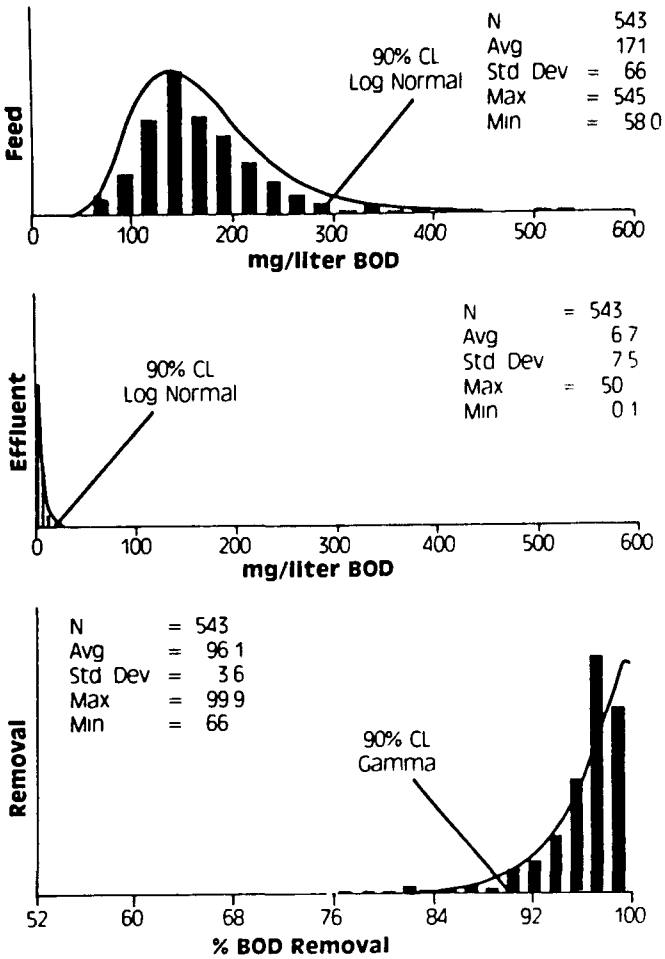


Figure 4
BOD Histogram (1978 and 1979 Data)

Table 5
Priority Pollutant Removals Across PACT System

	Concentration		
	Feed (µg/l)	Effluent (µg/l)	Removal (%)
VOLATILE ORGANICS*			
Benzene	105	0.9	99
Carbon Tetrachloride	94	1.4	99
Chlorobenzene	1720	30	98
Chloroethane	280	12	96
Chloroform	201	21	90
Ethylbenzene	41	1.7	96
Methyl Chloride	1770	Nil	99
Tetrachloroethylene	24	1.7	93
Toluene	519	1.7	99
1,1,1-Trichloroethane	13	0.6	95
Trichloroethylene	41	1.9	95
Trichlorofluoromethane	155	3.0	98
BASE-NEUTRAL EXTRACTABLES*			
1,2-Dichlorobenzene	259	120	54
2,4-Dinitrotoluene	1900	243	87
2,6-Dinitrotoluene	1640	575	65
Nitrobenzene	454	2	99
1,2,4-Trichlorobenzene	523	169	68
ACID EXTRACTABLES*			
2-Chlorophenol	11	1.6	85
2,4-Dinitrophenol	161	5.0	97
4-Nitrophenol	1020	10	99
Phenol	489	38	92
METALS			
Antimony	24	24	Nil
Arsenic	19	21	Nil
Beryllium	1.4	1.0	29
Cadmium	5.6	5.4	4
Chromium	26	15	42
Copper	72	75	Nil
Lead	112	54	52
Mercury	.02	.01	50
Nickel	77	59	23
Selenium	29	23	21
Zinc	602	360	40

*The values in Table 5 are averages of data which show significant day-to-day variations in removals. Results were obtained by GC/MS analyses of plant samples and are subject to analytical error. The figures represent only estimates of average percent removals for these materials.

ft² at an underflow concentration of 3.6%. They actually operated at solids flux rates from 200 to 350 lb/day ft² at underflow concentrations of 4 to 8%. The carbon in the sludge greatly enhanced the thickening abilities of the clarifiers.

Part of the reason for such heavy solids loading were initial problems with the PACT sludge filter press and, surprisingly, the conveying system to carry filtered sludge into the regeneration furnace. During 1978 and 1979, the inability to remove solids from the liquid train by normal wastage methods forced solids to exit the system as total suspended solids (TSS) in the treated effluent overflowing the secondary clarifiers. Effluent TSS averaged about 100 mg/l vs. a design level of 30 mg/l. These solids settled in the polishing basin and ultimately were dredged to the primary treatment section of the WWTP.

From 1978 through March 1982 when the regeneration furnace was shut down, there was a steady series of mechanical improvements in the PACT sludge filtration and conveying systems. Not all portions of the system reached design rates, and some added and/or redesigned equipment had to be installed.

The expected improvement in sludge filterability with the addition of carbon to the biomass was achieved. Filter cake solids averaged 45% vs. a predicted 35% to 38% level. Press capacity was below forecast because of: (1) lower dosage of carbon needed with longer sludge age operation, and hence less carbon in the sludge to aid filtration, and (2) operating problems with the filter press, particularly with cloth life, cloth changing procedure and high pressure feed pumps. The original steel press plates are being replaced with lighter weight fiberglas or plastic plates that are easier to dress and are expected to dramatically improve PACT sludge filtration if the furnace resumes operation.

As anticipated, the regeneration furnace incurred relatively high maintenance costs. There have been several failures of he brick hearths. The combination of the above, plus numerous design problems of the type often associated with a pioneering chemical processing venture, limited furnace in time to just over 50% in the first two years of operation. In time of furnace operation improved from 55% in 1978-79 to 66% in 1980-81. Much of the furnace downtime was caused by problems with the feed conveyors and not with the multiple hearth furnace itself.

When operating, the furnace produced an average of 24,000 lb/day regenerated carbon in 1978-79. In 1980-81, production was raised to 38,000 lb/day. Recovery of virgin carbon properties averaged just over 60% for the high activity carbons needed for Chambers Works waste. Weight yield recovery was over 80% after acid washing. As expected, the acid washing step was needed to prevent buildup of inorganic ash on the carbon with successive regenerations. However, during the last months of furnace operation, ash levels increased in regenerated carbon. Revisions to the acid washing system to better remove iron and silica were scheduled when the decision was made to shut down the furnace.

Despite significant equipment improvements, it appears the solids train will continue to incur relatively high maintenance costs. As a result, alternate technologies have been considered.

One which shows great theoretical promise is wet air oxidation. It would eliminate both filtration and sludge handling and replace the furnace with a high pressure reactor. Whether this high pressure/lower temperature liquid phase treatment can regenerate Chambers Works spent carbon to the quality necessary to treat this type of waste is not certain. Experience at other locations suggests it may be able to do so, however there has not been sufficient justification yet to do the large scale pilot studies necessary to test the process for Chambers Works.

OUTSIDE WASTE BUSINESS

Operating experience at the Chambers Works WWTP over the past 4 years has demonstrated the advantages of transporting aqueous wastes to a large, central, advanced wastewater facility for treatment. In the early 1980s, du Pont began aggressively seeking outside wastes for treatment as it became apparent that the WWTP was going to be under-utilized because of declining production at the site. A marketing study showed this large PACT plant had unique advantages in treating outside wastes.

Because of the great volume of wastewater being treated, the WWTP had essentially an unlimited volumetric capacity for trucked waste. Four tankers simultaneously discharging 5,000 gal each in only 20 min increase influent flow less than 5%. Highly acidic wastes are no problem. The WWTP has treated 2,500 gal of almost pure chlorosulfonic acid in only 4 hr by direct discharge into the influent trench with no release of fumes.

The tremendous dilution provided by over 20,000 gal/min flow is a major protection against organic shock loads from a tank truck discharge. The PACT system was selected specifically because of its ability to handle varying loads of industrial waste. Therefore, this plant is almost ideally suited to treat batch discharges of aqueous wastes containing organics, especially those which would pass through or be inhibitory to a conventional biological treatment system.

The Chambers Works already had logistics in place to handle a large number of truck deliveries each day and excellent interstate highways leading to the site. This was vital because of the volume of incoming tank trucks. Deliveries of over 50 trucks a day are routine.

Because of other activities on the site, there were "in-house" environmental and technical groups to support this activity. A major technical effort is needed to evaluate wastes proposed for treatment both in terms of their suitability to the PACT process and the estimated costs of treatment. A strict protocol must be established to approve a waste for treatment, and subsequent deliveries must be monitored closely to assure that the waste actually received is what was contracted for. Because of the amount of hazardous waste treated, there are frequent contacts with state and federal regulatory authorities regarding operation of the WWTP. A state inspector is at the site every 1 to 2 weeks, and it is important that a competent environmental staff is available to represent the plant.

From a regulator's point of view, it is advantageous to treat wastes at a central site. The disposition of a large number of individual wastes can be monitored conveniently by a single inspector. The single, large plant usually will be better controlled than a variety of small separate facilities, often operated by those less than expert in waste treatment. The quality of the treated effluent can be assured by a detailed analytical evaluation of a single effluent stream; such analyses might be impractical and prohibitively costly for a large number of individual sites.

Another advantage of this site is the receiving water. Chambers Works main outfall discharges into an estuary, so salt content of the stream is not critical. There are no downstream withdrawals for drinking water purposes. The volume of flow at the Delaware River estuary is immense, and so for a given absolute quantity of residual waste the effluent concentration will be very low. Any aqueous waste treatment facility will discharge some residual material. It is an obvious advantage if the receiving water flow is high; then the resultant concentrations of any residual pollutants are low, and there is no adverse impact on downstream water use.

Since 1980, the outside waste business has grown rapidly. Currently, over 75% of the organic load to the WWTP is from non-Chambers Works wastes. Over 50% of the outside waste originates in New Jersey; 35% comes from Pennsylvania, Delaware and Maryland. However, it has been cost-effective to ship aqueous wastes surprisingly long distances. There are routine contracts originating as far away as Maine, Florida and Colorado. The freight-logical area has been extended by offering rail car service to transport wastes, and the potential exists for barge deliveries.

Wastes from a variety of sources have been treated. Some are listed in Table 6. No one type of waste makes up more than 20% of the total.

Table 6
Typical Industrial Wastewaters Treated at Chambers Works

- Tank Truck & Tank Car Washings
- Pharmaceutical Wastes
- Water from Oil-Water Separation Processes
- Textile Treating Wastes
- Metals Treating Wastes
- Bio-sludges from Industrial Wastewater Treatment Plants
- Electronics Industry Waste
- Landfill Leachates
- Lagoon Cleanups
- Miscellaneous Chemical Process Wastes
- Latex Wastes
- Chemical Cleaning Rinse Waters
- Waste Acids or Bases
- Food Processing Wastes
- Paint & Dye Wastes

Initially, treatment of outside waste was limited to streams which could be discharged directly into the WWTP influent as rapidly as they flowed from the truck. This limitation precluded certain aqueous wastes. For instance, wastes containing sulfide or cyanide could not be accepted because of the possibility of releasing toxic H_2S or HCN gas when the waste mixed into the acid influent.

The WWTP has limits on most of the heavy metals. It is capable of removing those present in the original wastewater feed to meet NPDES permit limits. Initially, some outside wastes which were evaluated had to be rejected because they contained metals in amounts such that permit limits might have been exceeded had the waste been added directly to the WWTP influent.

Recently, heavy metals pretreatment facilities have been installed and are now being expanded to allow the WWTP to accept aqueous waste streams containing higher amounts of heavy metals. Similarly, the plant is developing treating techniques for waste containing higher concentrations of sulfide and cyanide.

Facilities also are being installed for oil-water separation, with the aqueous phase to be discharged to the WWTP and the oil to be handled separately. Other expansions are being studied which involve separate pretreatments which themselves generate aqueous waste that could be handled by the WWTP. This might give du Pont a competitive advantage over other stand alone facilities.

This outside waste treatment has been successful enough that du Pont is expanding the business beyond the Chambers Works WWTP. In recognition of their expanded charter, the outside waste business group was recently renamed du Pont Environmental Services and is actively seeking other waste treatment opportunities.

CONCLUSIONS

- PACT is an excellent, advanced treatment process for many wastewaters containing normally non-biodegradable or slowly biodegradable materials. The process can treat highly colored wastes. At du Pont's Chambers Works chemical complex, a PACT plant removes over 96% of the BOD and over 80% of the DOC from 30 to 40 million gal/day of wastewater.
- A PACT process is resistant to toxic upset, can tolerate shock loads of organic compounds and is tolerant of rapid changes in waste composition.
- The presence of carbon in the mixed liquor suspended solids in a PACT system dramatically increases settling in the clarifier and improves filtration rate. Solids concentrations of approximately 40% have been achieved with PACT sludge in a conventional pressure filter.
- Conventional wastewater treatment equipment can be used for a PACT system with a minimum amount of design changes.
- Powdered activated carbon has been successfully regenerated from PACT sludges in a multiple hearth regeneration furnace at a rate of 20 tons/day. Maintenance costs for the entire filtration, conveying and regeneration unit are high, and to date the best system in time has been about 65%.
- The Chambers Works PACT plant is successfully treating a large variety of off plant wastes delivered by tank truck or railroad car. Over 30% of the current organic load to this plant is from outside wastes. Particular, demonstrated advantages of a large central wastewater treatment are:
  (1) An advanced treatment process is used.
  (2) High quality "in house" high quality technical and environmental staffs can be afforded.
  (3) It is sited on optimum receiving waters.
  (4) It is easier for regulatory authorities to monitor the disposal of the wastes.
  (5) It can treat aqueous, organic waste streams which might upset conventional municipal plants.

Treatment of PCB-Contaminated Soil in a Circulating Bed Combustor

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ABSTRACT

A trial burn of PCB-contaminated soils was completed in GA Technologies' 16-in. Pilot Plant Circulating Bed Combustor (CBC). More than 4000 lb of soil containing 1% PCB were treated in three identical 4-hr runs at 1800°F. The results showed excellent compliance with TSCA requirements. Destruction and removal efficiencies (DREs) were greater than 99.9999%, and PCB in combustor ash was less than 200 ppb. No chlorinated dioxins or furans were detected in the stack gas, bed ash or fly ash. In addition, no significant concentrations of other Products of Incomplete Combustion (PICs) were detected. Combustion efficiencies were greater than 99.9%, with CO concentrations less than 50 ppm and NO_x concentrations less than 75 ppm. Particulate emissions were generally below 0.08 grain/dscf, and HCl emissions were maintained below 4.0 lb/hr by introducing limestone directly into the combustor.

These results demonstrate that the CBC is an environmentally acceptable means of treating contaminated soil containing PCB and other organic wastes. In addition, the high thermal efficiency of the CBC, the absence of afterburners or scrubbers and the use of simple feed systems make CBC treatment competitive with soil removal and transport to landfills and other potential treatment/disposal options.

INTRODUCTION

Of the many hazardous chemicals found in waste sites around the country, perhaps none has received the scrutiny conferred on polychlorinated biphenyls (PCBs). This group of 209 synthetic chlorinated organic compounds found wide use as a dielectric fluid in utility transformers and capacitors and as a high-temperature heat transfer medium.[1] However, because of their exceptional resistance to degradation in the biosphere and apparent toxicity, the manufacture and sale of PCBs were banned in 1976 for virtually all purposes. The control, treatment and disposal of PCBs were mandated by TSCA and currently are handled through the U.S. EPA's Office of Toxic Substances.

Until recently, it has been common practice to remove PCB-contaminated soils for burial in a secured landfill. However, this option is becoming less desirable since landfill costs are escalating, the number of available landfill sites has decreased and generators or potential responsible parties (PRPs) retain the liability associated with the contaminated soil, even in a secured landfill. Treatment of PCB-contaminated soil by incineration in the CBC can eliminate or significantly reduce the potential liability of generators or PRPs at a cost competitive with current landfill prices.

CBC units are designed to burn a wide variety of fuels such as coal, peat, wood, municipal wastes and oil while treating hazardous wastes. Over 25 units are operating or under construction worldwide. Three units are currently in operation in the United States. In 1983 GA began concentrating its efforts on the application of GBC technology to incineration of hazardous wastes. Table 1 presents examples of wastes that have been burned in the CBC. It was the successful treatment of this diversity of wastes that provided assurance that PCBs could be destroyed in a CBC at a lower temperature than used in conventional incinerators.

Table 1
Circulating Bed Test Results[1] for the Destruction of Hazardous Wastes

Waste	Form	Destruction Efficiency, %	HCl Capture, %	Ca/Cl_2 Ratio[2]
Carbon Tetrachloride	Liquid	99.9992	99.3	2.2
Freon	Liquid	99.9995	99.7	2.4
Malathion	Liquid	>99.9999		
Dichlorobenzene	Sludge	99.999	99	1.7
Aromatic Nitrile	Tacky solid	>99.9999		
Trichloroethane	Liquid	99.9999	99	1.7

[1]Results obtained in GA pilot plant CBC.

CBC DESCRIPTION

The CBC is a new generation of incinerator that uses high velocity air to entrain circulating solids in a highly turbulent combustion zone. This design allows combustion along the entire length of the reaction zone. Because of its high thermal efficiency, the CBC is ideally suited to treat low heat content feed, including contaminated soil. Figure 1 shows the major components of a CBC for soil treatment.

Soil is introduced into the combustor loop at the loop seal where it immediately contacts hot recirculating soil from the hot cyclone. Hazardous materials adhering to soil are rapidly heated when introduced into the loop and continue to be exposed to high temperatures throughout their residence time in the CBC. Upon entering the combustor, high velocity air (14 to 20 ft/sec) entrains the circulating soil which travels upward through the combustor into the hot cyclone. Retention times in the combustor range from 2 sec for gases to approximately 30 min for larger feed materials ($<$1.0 in.).

The cyclone separates the combustion gases from the hot solids which are returned to the combustion chamber via a proprietary non-mechanical seal. Hot flue gases and fly ash pass through a convective gas cooler and on to a baghouse filter where fly ash is removed. Filtered flue gas then exhausts to the atmosphere. Heavier particles of purified soil remaining in the combustor lower bed are removed slowly by a water-cooled ash conveyor system.

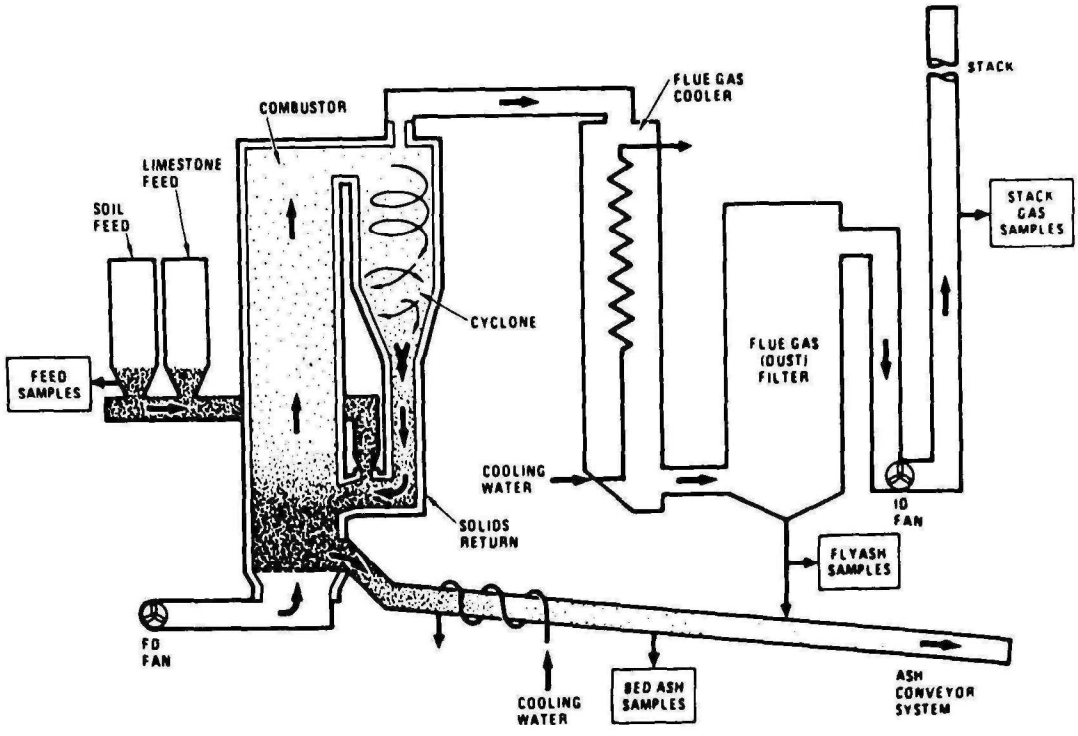

Figure 1
Schematic Flow Diagram of Circulating Bed Combustor for Soil Treatment

As a consequence of the highly turbulent combustion zone, temperatures around the entire combustion loop (combustion chamber, hot cyclone, return leg) are uniform to within ±50°F. The uniform low temperature and high solids turbulence in the CBC also help avoid ash slagging encountered in other types of incinerators.

Acid gases formed during destruction reactions are rapidly captured by limestone added directly into the combustor. The reaction of limestone and HCl, released during PCB incineration, forms dry, benign calcium chloride. The rapid combustion and quick neutralization of the acid gases within the combustion chamber eliminate the need for afterburners and add-on scrubbers to complete destruction and acid gas capture. Emissions of CO and NO_x are controlled to low levels by excellent mixing, relatively low temperatures (1450 to 1800°F) and staged combustion achieved by injecting secondary air at higher locations in the combustor. Because of its efficient combustion and highly turbulent mixing, the CBC is capable of attaining required DREs for both hazardous wastes (99.99%) and toxic wastes (99.9999%) at temperatures below those used in conventional incinerators (typically >2000°F).

TEST DESCRIPTION

A variety of requirements are imposed prior to and during a PCB trial burn.[2] The key target of a trial burn is to ensure that PCB DREs are ≥99.9999% at the operating conditions chosen for the incinerator. In addition, the concentration of PCB in ash from the unit must not exceed 2 ppm. The potential formation of PICs also is carefully evaluated, with particular attention given to polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzo-p-furans (PCDFs). The combustion efficiency of the unit must be ≥99.9%, and particulate emission must not exceed 0.08 grain/dscf.

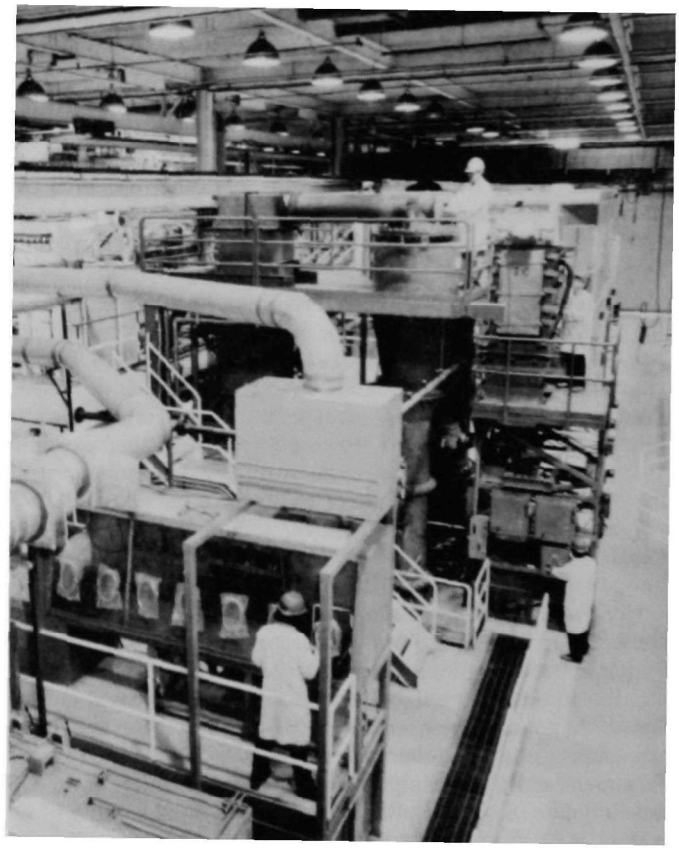

Figure 2
Pilot Plant CBC and Feed Preparation/Handling Equipment

The CBC trial burn was carried out in GA's 16-in. pilot plant unit shown in Figure 2. This is the smallest CBC offered by GA for commercial application. The glovebox in the foreground was used to prepare contaminated soil prior to transport to the feed system and CBC shown behind the glovebox. Soil treated in the test was obtained from a former chemical processing site known to contain pockets of PCB up to 6000 ppm as well as other organic and inorganic wastes. To ensure that the CBC would be permitted to treat all likely site concentrations of PCB, uncontaminated soil from the site was "spiked" with liquid PCB to 10,000 ppm. Spiking was carried out by blending a 50:50 commercial mixture of PCB "1248" and trichlorobenzene with a ribbon blender in 1000 lb lots. Approximately 4000 lb of soil were spiked for the three burns required by the TSCA trial burn permit.

While the CBC was maintained at 1800°F using natural gas as the auxiliary fuel, several barrels of clean soil from the site were treated in the combustion system prior to the addition of spiked soil. During this time, all operating parameters and system components were confirmed to be in the required operating ranges. Process parameters monitored included:

- Temperature around the loop
- Pressure drop across the loop
- Soil feed rate
- Primary air flow
- Secondary air flow
- Loop seal air flow
- Total air flow
- Methane flow
- CO concentration
- CO_2 concentration
- Excess oxygen level
- NO_x concentration

Spiked soil was pneumatically transported to a bunker and screw feeder. Soil feeding, limestone addition and stack gas monitoring were started simultaneously. A U.S. EPA Modified Method 5 sample train[3] was used to sample stack gas emissions.

Table 2
PCB Trial Burn Operational Data and Test Results

Parameter	TSCA Requirement	Test Number 1	2	3
Test Duration, hr	~4	4	4	4
Operating Temperature, °F		1800	1800	1800
Soil Feed Rate, lb/hr		328	412	324
Total Soil Feed, lb		1592	1321	1711
PCB Concentration in Feed, ppm		11,000	12,000	9,800
DRE, %	>99.9999	99.999995	99.999981	99.999977
PCB Concentration				
- Bed Ash, ppm	<2	0.0035	0.033	0.186
Fly Ash, ppm	<2	0.066	0.0099	0.0032
Dioxin/Furan Concentration				
Stack Gas, pp		ND[a]	ND	ND
Bed Ash, ppm		ND	ND	ND
Fly Ash, ppm		ND	ND	ND
Combustion Efficiency, %	>99.9	99.94	99.95	99.97
Acid Gas Release, lb/hr	<4.0	0.16	0.58	0.70
Particulate Emissions, grain/dscf	<0.08	0.095[b]	0.043	0.0024
Excess Oxygen, %	>3.0	7.9	6.8	6.8
CO, ppm		35	28	22
CO_2, %		6.2	6.0	7.5
NO_x, ppm		26	25	76

[a]ND Not detected.
[b]Derived from 2-hr makeup test.

In addition, a separate Volatile Organic Sampling Train (VOST)[4] was used to sample for volatile organic PICs. Feed, bed ash and fly ash samples also were gathered throughout the test (see Fig. 1 for sample port locations). Three identical tests of spiked soil (4 hrs each) were carried out over two days in late May 1985. Each test was observed and/or audited by U.S. EPA personnel or representatives. All feed, ash and stack gas samples were subsequently analyzed for PCBs, PCDDs and PCDFs. Fly ash, bed ash and stack gas samples also were analyzed for other PICs (both volatile and semivolatile). Stack gases were analyzed for fly ash and chloride release as well.

RESULTS

Table 2 presents a summary of the trial burn operational data and test results gathered during the tests. Near-identical conditions were maintained for each test. In each case, PCB DREs were well in excess of the U.S. EPA-required 99.9999%. PCB concentration in the bed ash and the fly ash was well below the required 2 ppm and, in fact, did not exceed 200 ppb. No PCDDs or PCDFs were detected in the stack gas, bed ash or fly ash. Combustion efficiencies were greater than 99.9%, and acid gas release was well below the required 4 lb/hr. Particulate emissions were generally less than the required 0.08 grain/dscf. Only the grain loading from the first test, obtained from a 2-hr makeup test after the completion of Tests 1 through 3, showed a value slightly higher than the limit. This higher than normal value is attributed to off-normal process conditions for the baghouse (i.e., excessive blowback air pressures along with a higher-than-normal number of blowback cycles). Nitrogen oxides and CO levels remained low as a result of the staged combustion utilized in the CBC and the relatively low combustion temperature (1800°F).

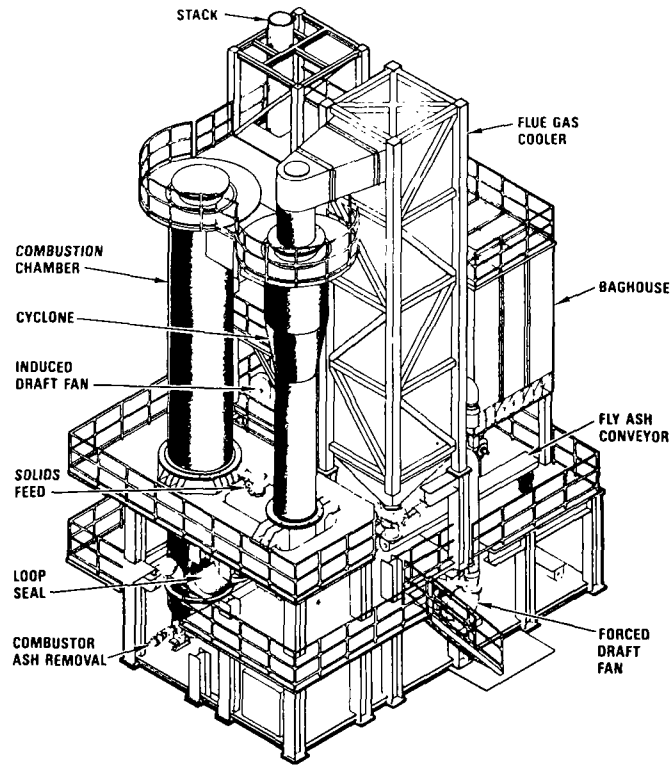

Figure 3
Isometric of Site-Assembled Circulating Bed Combustor

These results demonstrate that the CBC is an effective means of destroying PCBs contained in a soil matrix without the need for high temperatures, afterburners or wet scrubbers. In particular, the absence of undesirable combustion byproducts (i.e., dioxins and furans) is important in ensuring that effective treatment of soil can be accomplished in an environmentally acceptable manner.

These results confirm the design of GA's transportable CBC shown in Figure 3. The combustion and all other plant components are designed as modular units which can be transported by truck or rail. These units are assembled at the site into an operating unit in 4 to 6 weeks. The major components of this CBC plant include the combustor loop, feed system, pollution control and air induction equipment. GA's 36-in. transportable CBC is capable of processing up to 18,000 lb/hr of dry soil on a 24-hr basis requiring an operating crew of only two persons per shift. Soil treatment costs may be as low as $100/ton at a large site. For smaller sites or sites having unique treatment requirements, costs may approach $400/ton.

CONCLUSIONS

The results of the PCB soil trial burn in GA's CBC demonstrate compliance with TSCA requirements: stack emissions are well within regulatory requirements and bed ash and fly ash contain PCBs well below the regulatory requirements. The superior thermal efficiency, high throughput and small staffing requirements of the CBC provide a soil treatment option that is cost-competitive with landfill disposal while at the same time reducing overall liability of the generator or PRP.

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2. "Polychlorinated Biphenyls (PCBs) Manufacture, Processing, Distribution in Commerce and Use Prohibition," 40 CFR 761.70.
3. "Test Methods for Evaluating Solid Waste," U.S. EPA Report SW-846, 2nd Edition, 1984.
4. "Proposed Sampling and Analytical Methodologies for Addition to Test Methods for Evaluating Solid Waste: Physical/Chemical Methods (SW-846, 2nd Edition)," U.S. EPA Report PB85-103026, 1984.

Treatment of Hazardous Waste Leachate

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ABSTRACT

The nature of hazardous waste leachate varies greatly from site to site and over time. Thus, leachate treatment systems must be designed on a case-by-case basis. This paper presents profiles of seven unit treatment operations which can be applied in varying combinations to effect the desired degree of contaminant removal: (1) equalization (to dampen influent flow and concentration fluctuations); (2) air stripping (to remove ammonia and volatile organic compounds); (3) precipitation/flocculation/sedimentation (to remove soluble heavy metals and suspended solids); (4) neutralization (to adjust pH); (5) activated sludge treatment (to remove aerobically biodegradable organic matter); (6) carbon adsorption (to remove dissolved organics and certain inorganics); and (7) reverse osmosis (to remove dissolved inorganics and high molecular weight organics). These technology profiles emphasize process applicability and limitations, treatment effectiveness and capital and operating costs.

INTRODUCTION

Leachate is generated by the percolation of water (from precipitation, groundwater flow or liquid wastes) through a waste disposal site. The leachate can be expected to contain soluble toxic components of the waste as well as soluble chemical and biochemical reaction products. Leachate collection systems are designed to collect this contaminated liquid and to channel it away from the disposal site before it can contaminate the surrounding soil, groundwater or surface water. The collected leachate then can be treated to reduce the level of contaminants prior to its discharge into a stream, to groundwater recharge or to a municipal or industrial wastewater treatment system.

The composition and volume of leachate vary highly from site to site and over time. Factors contributing to this variability include: the nature of the waste; the age of the land disposal unit; the amount of precipitation; and the porosity, permeability and adsorption characteristics of the soil. Table 1 presents leachate characterization data from three land disposal sites.

The high strength and widely varying nature of hazardous waste leachate complicate its treatment. Under contract to the U.S. EPA's Hazardous Waste Engineering Research Laboratory, PEI Associates, Inc., Cincinnati, Ohio, is preparing a comprehensive handbook to guide in the planning and design of leachate treatment systems. Technology profiles emphasizing process applicability and limitations, treatment effectiveness and capital and operating costs are being developed for both demonstrated and potential technologies. Six highly developed unit treatment operations (equalization, air stripping, precipitation/flocculation/sedimentation, neutralization, activated sludge tretment and carbon adsorption) and one potentially applicable technology (reverse osmosis) were selected for presentation here from the more than 20 technologies to be profiled in the handbook.

Table 1
Leachate Characterization Data: Concentration of Contaminants

Parameter	Love Canal[a]	Stringfellow Acid Pits[b]	G.R.O.W.S. Landfill[c]	Range
Biochemical oxygen demand (5-day)(BOD_5)	NR[d]	<60	4,500-13,000	<60-13,000
Chemical oxygen demand (COD)	5,900-11,500	3,600	11,200-21,800	3,600-21,800
Total organic carbon	1,800-4,300	NR	NR	1,800-4,300
Total suspended solids	200-400	6,300	500-2,000	200-6,300
Total dissolved solids	15,700	24,900	11,200-14,200	11,200-24,900
pH, s.u.	5.6-6.9	3.37	6.6-7.3	3.3-7.3
Alkalinity (as $CaCO_3$)	NR	NR	4,800-5,700	4,800-5,700
Hardness (as $CaCO_3$)	NR	NR	3,100-5,100	3,100-5,100
Total Kjeldahl nitrogen	5	30	600-1,700	5-1,700
Ammonia-nitrogen	1	10	700-2,000	1-2,000
Nitrate-nitrogen	<0.1	14.0	NR	<0.1-14.0
Nitrite-nitrogen	<0.1	<0.5	NR	<0.5
Total phosphorus (as P)	<0.1-3.2	NR	NR	<0.1-3.2
Phosphate (as P)	<0.1	2.5	2.6-3.0	<0.1-3.0
Sulfate	240	NR	110-680	110-680
Sulfide	<0.1	NR	NR	<0.1
Chloride	9,500	300	3,100-4,800	300-9,500
Calcium	2,500	400	650-900	400-2,500
Magnesium	NR	540	250-650	250-650
Sodium	1,000	NR	1,200-1,500	1,000-1,500
Potassium	NR	NR	950-970	950-970
Cadmium	0.01	NR	0.04-0.10	0.01-0.10
Chromium	0.27	NR	0.16-0.43	0.16-0.43
Copper	0.54	NR	0.32-0.44	0.32-0.54
Iron	30-330	NR	180-380	30-380
Nickel	0.24	NR	0.55-2.0	0.24-2.0
Lead	0.3-0.4	NR	0.4-0.8	0.3-0.8
Zinc	0.48	NR	8.7-31	0.48-31
Mercury	<0.001	NR	0.005-0.012	<0.001-0.012

aReference 1.
bReference 2.
cReference 3.
dNR = not reported.
eAll data except pH are in mg/l.

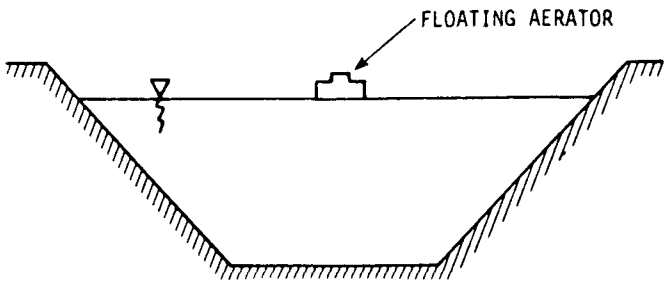

Figure 1
Equalization Basin Geometry

UNIT TREATMENT OPERATIONS

Equalization

The objective of equalization is to dampen influent flow and concentration fluctuations to improve performance of downstream processes. Because the composition and volume of leachate from a given landfill fluctuate with time, equalization should be considered in the planning and design of all leachate treatment facilities.

Equalization basins may be of concrete, steel or (lined) earthen construction. With in-line equalization, the entire daily flow passes through the basin; with off-line equalization, only that portion of the flow outside of an acceptable concentration range is diverted into a basin. When the goal is equalization of the pollutant mass loading (as in the treatment of hazardous waste leachate), the in-line arrangement must be used. Typical basin geometry is illustrated in Figure 1.

Mixing and aeration of equalization basins should be provided to prevent both the deposition of solids and the onset of septic conditions. As with any process using aeration, volatile components can be stripped from the wastewater, which results in air emissions of potentially toxic substances.

Table 2 presents capital and operating and maintenance (O&M) equalization costs. These costs are based on the use of a concrete basin with a 24-hour retention time. In general, capital costs of equalization systems are moderately high because of the size of the basins. For large basins, power costs for operating the aeration system contribute significantly to the overall O&M costs.

Table 2
***Leachate Treatment Costs*[a]**
(1985 dollars)

	25 gal/min		50 gal/min		100 gal/min	
Unit operation	Capital	O&M[b]	Capital	O&M	Capital	O&M
Equalization	101,000	0.422	118,000	0.243	144,000	0.172
Air stripping	34,500	0.472	76,000	0.236	127,000	0.118
Prec/floc/sed	115,000	2.66	140,000	1.62	191,000	1.03
Neutralization	10,000	0.09	15,000	0.08	23,000	0.07
Activated sludge	137,000	0.792	183,000	0.517	242,000	0.328
Carbon adsorption	79,400	2.35	104,800	1.72	202,800	1.18
Reverse osmosis	582,000	6.92	885,000	3.60	1,342,000	2.10

aReference 4.
b$/1000 gal based on 300 day/yr operation.

Air Stripping

Air stripping is a mass-transfer operation that uses forced air to remove pollutants from a liquid phase. Applications of this process include the removal of ammonia from wastewater and, more recently, the removal of volatile organic contaminants from drinking water. In the treatment of leachate, air stripping can be used ahead of biological processes (to reduce toxic concentrations of ammonia) or ahead of adsorption processes (to reduce the organic loading and thereby extend the life of the sorbent).

Among the various aeration devices that can be used in air stripping are diffused aerators, mechanical aerators, spray towers and countercurrent flow packed towers. Packed towers provide the greatest gas-liquid interfacial area for mass transfer but the shortest contact time. Removal efficiencies are dependent on the height of the tower and the air-to-liquid ratio.

Figure 2 is a schematic diagram of a packed-tower air stripping unit. The unit consists of a vertical column with randomly dumped packing on a packing support. Common packings include the Raschig ring, Berl saddle, Intalox saddle and Pall ring. Liquid is distributed uniformly on the top of the packing with sprays or distribution trays and flows downward by gravity. Air is blown upward through the packing and flows countercurrently to the descending liquid. Depending on the concentration and volatility of the contaminants, air-to-water volumetric ratios may range from 10 to 1 up to 300 to 1.[3] Air stripping of ammonia is carried out at elevated pH (above 11).

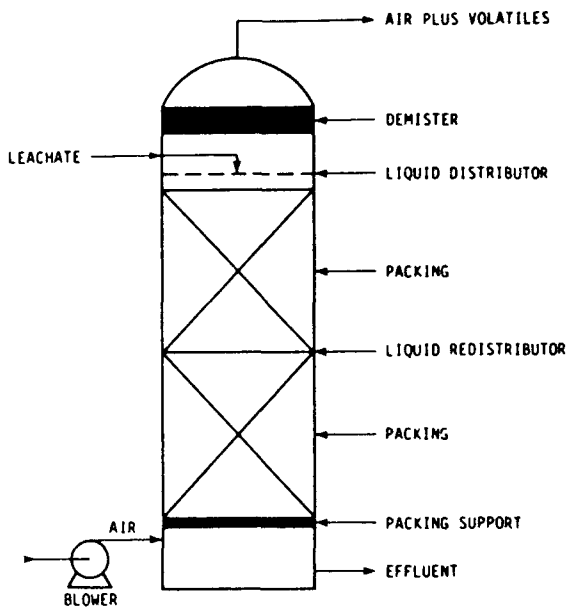

Figure 2
Schematic Diagram of Air Stripping in a Countercurrent Packed Tower

The volatile organics or ammonia stripped from the leachate during treatment in a packed tower subsequently may be removed from the off-gas to prevent air emissions of toxic compounds or, possibly, for economic recovery. It also may be necessary to pretreat the leachate for removal of suspended solids and dissolved metals that are oxidized to an insoluble form when aerated to prevent fouling of the packed bed.

Capital and O&M costs for air stripping, presented in Table 2, are based on the use of a countercurrent packed tower and include influent pumping and an ammonia recovery section. Costs for labor, materials and power comprise the O&M costs of this system. Because air requirements, and hence power requirements, increase at lower temperatures, operation of packed towers at temperatures below freezing may be cost-prohibitive.

Precipitation/Flocculation/Sedimentation

The most common method of removing suspended solids and soluble heavy metals (including arsenic, lead, cadmium and chromium) from leachate is by combined precipitation/flocculation/sedimentation. Precipitation involves the addition of chemicals to leachate to form insoluble precipitates from soluble species. Flocculation promotes agglomeration of suspended solids, which makes them easier to remove. Sedimentation is the removal of suspended particles by gravity settling.

The processes of precipitation, flocculation and sedimentation can be carried out in separate basins, as shown in Figure 3, or in a single basin (e.g., an upflow solids-contact reactor-clarifier) with separate zones for each process. Precipitation requires rapid mixing (10 to 60 sec) to disperse the chemical, whereas flocculation requires slow and gentle mixing (15 to 30 min) to promote particle contact. Ancillary equipment requirements for these processes include mixers/paddles, chemical storage tanks and chemical feed pumps. Packaged plants are available for low flow rates (10,000 gal/day to 2 million gal/day), but these may require extensive modifications to enable them to handle the high level of precipitated solids characteristic of hazardous waste leachates.

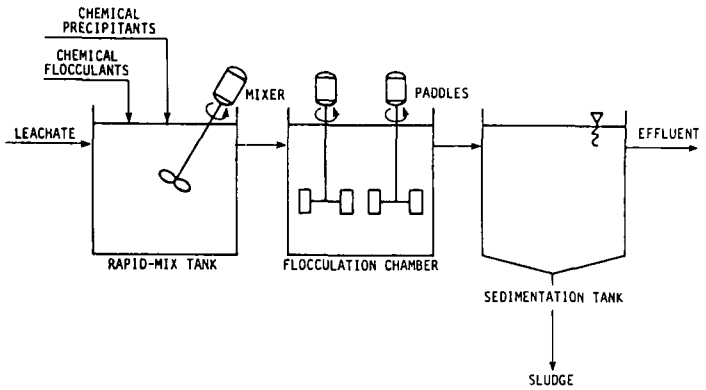

Figure 3
Schematic Diagram of Precipitation/Flocculation/Sedimentation

Metals can be precipitated from leachate as hydroxides or sulfides through the addition of lime or ferric sulfide. Hydroxide precipitation with lime at high pH is the most commonly used method. The presence of complexing agents such as ammonia or cyanide in the leachate, however, will inhibit precipitation of some heavy metals as hydroxides. Flocculants such as alum, ferric chloride or polyelectrolytes often are added to the rapid-mix tank along with the chemical precipitant to reduce repulsive forces between particles and bring about particle aggregation and settling.

Precipitation/flocculation produces large amounts of wet sludge that may be hazardous because of its heavy metals contents. This sludge, which is settled in a sedimentation unit, must be treated further (e.g., by dewatering or fixation/stabilization) before it is landfilled.

Fluctuating leachate quality requires frequent jar testing to determine appropriate chemical dosages and removal efficiencies. Available data indicate that precipitation/flocculation/sedimentation can provide good removal of suspended solids (80 to 90%) and moderate removal of BOD_5 (40 to 70%) and COD (30 to 60%).[6] The additional treatment required will depend on effluent discharge limitations.

Table 2 presents costs of a packaged precipitation/flocculation/sedimentation system that includes a granular filtration unit. Operation of these systems is labor-intensive, as reflected by the moderately high O&M costs.

Neutralization

Neutralization involves the addition of an acid or a base to an aqueous waste stream to adjust its pH to the desired level (usually between 6.0 and 9.0). Neutralization may be required as a pretreatment step to optimize the performance of downstream treatment, to protect pH-sensitive processes (particularly biological teatment operations) or as a final step to meet effluent criteria. The technology is inexpensive, highly developed and widely used in the treatment of hazardous waste leachate.

Typically, neutralization is carried out in completely mixed corrosion-resistant tanks as shown in Figure 4. The tanks may be operated in batch or continuous mode; however, the latter is only suitable for flow rates greater than about 100,000 gal/day. The neutralization process usually is controlled automatically by feedback, feedforward or multimode controllers. Common bases used for neutralization include lime, calcium hydroxide, caustic, soda ash and ammonium hydroxide; common acids include sulfuric acid, hydrochloric acid and nitric acid. Reagent selection is based on cost, speed of reaction and the reaction byproducts formed.

Equalization usually precedes neutralization in the treatment process train to control fluctuations in influent flow and concentration. The neutralization process can produce heat and toxic gases (ammonia, hydrogen sulfide and hydrogen cyanide) if the chemicals are not properly added to and mixed with the waste. Treatment to remove precipitated solids (flocculation/sedimentation or filtration) often is required after neutralization. If the removed solids are hazardous, secure disposal will be required.

Table 2 presents costs of a neutralization system consisting of an agitated tank with a 3-min retention time, a metering pump for acid or caustic and a pH control loop and valve. Both capital and O&M costs are low in comparison with other unit treatment operations.

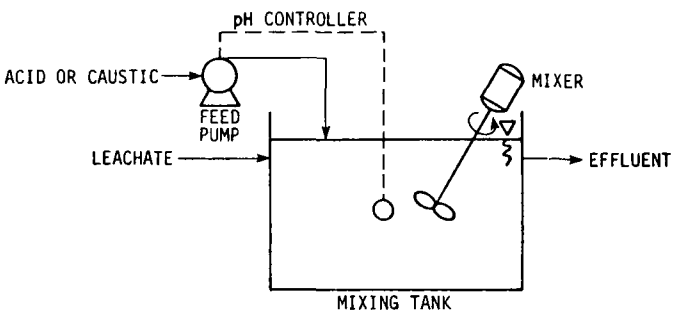

Figure 4
Schematic Diagram of Neutralization

Activated Sludge

Activated sludge is a biological treatment process in which an active mass of microorganisms (bacteria, protozoa, rotifers and fungi) is used to stabilize biodegradable organic matter under aerobic conditions. Activated sludge can reduce concentrations of a wide variety of organic compounds, including many toxic and hazardous compounds. It is widely used in municipal and industrial wastewater treatment applications (typical BOD_5 concentration of 200 mg/l) and can effectively treat leachate with organic concentrations one to two orders of magnitude higher (up to 10,000 mg/l BOD_5.[4]

Conventional activated sludge systems, illustrated in Figure 5, include two stages. The first stage involves aeration of the waste in an open tank and maintenance of an active biomass. Aeration is accomplished by mechanical-surface, diffused-air or sparged-turbine aerators. The second stage entails separation of the solids in a secondary clarifier. A portion of the solids is recycled back to the aeration basin to maintain the desired concentration of organisms, and the remaining portion is wasted.

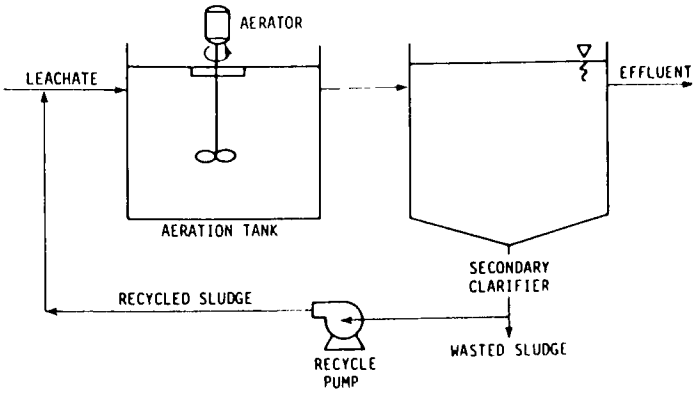

Figure 5
Schematic Diagram of Conventional Activated Sludge

Variations of the conventional activated sludge system have been developed to provide greater tolerance for shock loadings, to improve sludge settling characteristics and to achieve higher BOD_5 removals. Process modifications include complete-mix, step aeration, extended aeration, contact stabilization and the use of pure oxygen.

Because of the sensitivity of biological systems, pretreatment requirements for high-strength leachate are extensive and may include equalization to buffer hydraulic and organic load variations; sedimentation/flotation to remove suspended solids, oil and grease; neutralization to adjust the pH to near neutral; and nutrient addition to provide adequate levels of nitrogen, phosphorus and trace elements. Acclimation of the biological system to the influent waste stream is necessary prior to full-scale operation of the process. The presence of refractory or biologically toxic compounds (e.g., ammonia or heavy metals) in the leachate may necessitate the use of other physical/chemical processes in conjunction with biological treatment.

Process residuals from activated sludge treatment of leachate include waste activated sludge, which may be high in metals and refractory organics, and air emissions of volatile organic compounds that are stripped from the waste during aeration.

In general, biological processes such as activated sludge treatment are the most cost-effective means for removing organics from high-strength leachates. Table 2 presents costs of a conventional activated sludge system consisting of an aeration tank with a 6-hr retention time and a mixed liquor suspended solids concentration of 2000 mg/l, a secondary clarifier and a sludge recycle pump. The O&M costs of activated sludge treatment are comprised principally of labor and materials.

Carbon Adsorption

Carbon adsorption is a separation technique for removal of dissolved organics and certain inorganics (e.g., cyanide and chromium) from aqueous waste streams. This well-developed process has numerous full-scale applications including treatment of domestic and industrial wastewaters, cleanup of spilled hazardous wastes. In leachate treatment applications, carbon adsorption can be used in the pretreatment, intermediate or polishing steps.

Treatment of leachate by carbon adsorption involves passing the waste stream through beds of granular activated carbon. Activated carbon is an amorphous form of carbon characterized by a large internal surface area. Contaminants are adsorbed from the waste onto the carbon surface by physical and chemical forces. When the adsorptive capacity of the carbon has been reached, regeneration or disposal of the spent carbon is required.

Most carbon adsorption systems use cylindrical pressure vessels arranged in series or parallel and operated in a downflow, upflow or pulsed-bed mode. The downflow mode can handle a higher concentration of influent suspended solids than can the other modes; however, frequent backwashing of the carbon beds may be required to prevent excessive pressure drop. A schematic diagram of an alternating, two-column, downflow system is presented in Figure 6.

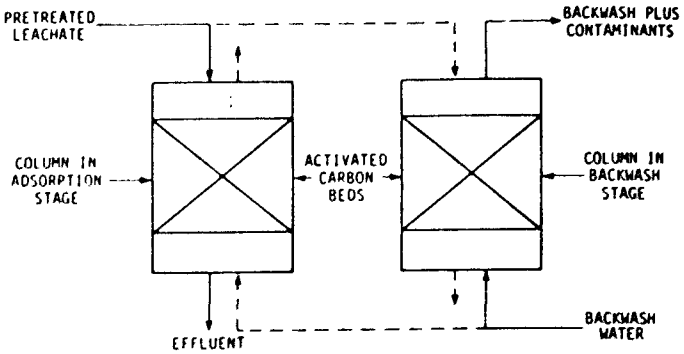

Figure 6
Schematic Diagram of Alternating, Two-Column, Downflow, Carbon Adsorption System

Carbon adsorption is applicable to the treatment of many toxic and refractory organics; consequently, it often is used in combination with biological treatment. Because the carbon beds are susceptible to clogging, leachate must be pretreated to remove high concentrations of suspended solids, oil and grease. In general, influent concentrations are limited to 10,000 mg/l total organic carbon, 1,000 mg/l total inorganics, 2,000 mg/l suspended solids (downflow), 50 mg/l suspended solids (upflow) and 10 mg/l oil and grease.[4] With proper pretreatment, removal efficiencies greater than 99% can be obtained.[3]

Table 2 presents capital and O&M costs of a carbon adsorption system. The O&M costs of this system are governed by the organic loading, which is assumed to be 10 lb organics per 100 lb of carbon. These costs do not include the costs of disposal or regeneration of the spent carbon. For plants using less than 200 lb/day of carbon (or, equivalently, for plants treating less than 800,000 gal/day of leachate), on-site regeneration of carbon probably is not economical.[4] Most leachate treatment facilities will fall into this range.

Reverse Osmosis

Reverse osmosis is a membrane separation technique which primarily is utilized for the demineralization of water. Potentially, this technique could be used as the final polishing step in the treatment of leachate to separate dissolved solids [inorganic salts and high (>120) molecular weight organics] from secondary treatment effluent. With current technology, reverse osmosis is not practical for the treatment of raw leachate because of rapid fouling of the membrane and poor selectivity for low molecular weight organics.[3]

In reverse osmosis, water is separated from dissolved solids in solution by filtering it through a semipermeable membrane at pressures of 200 to 1200 lb/in^2.[3] Basic components of a reverse osmosis unit are the membrane, a membrane support structure, a containing vessel and a high-pressure pump; these are illustrated schematically in Figure 7.

All commercially available membranes are structured asymmetrically, with a thin (0.1 to 1.0 μm) dense surface ("skin") supported by a porous substructure. This design promotes high

water transport across the membrane.[8] Cellulose acetate and aromatic polyamides are common membrane materials.

Membrane support structures are of four types: tubular, spiral-wound, hollow-fiber and plate-and-frame. The tubular configuration, which consists of a rigid-walled porous tube lined on the inside with a membrane, is recommended for use with wastewater effluents.[6] Reverse osmosis units can be arranged in parallel (to increase hydraulic capacity) or in series (to effect the desired degree of separation).

For optimal performance, feed water to the reverse osmosis unit must be pretreated to remove gross amounts of solids and to prevent fouling by scaling or biological growth inside the device. In addition, compounds that are incompatible with the membrane must be removed during pretreatment. Because the composition and strength of hazardous waste leachates vary widely, pilot testing will be necessary to determine pretreatment requirements and separation performance. A major disadvantage of this technology is that it produces a highly concentrated reject stream that requires further treatment or disposal.

Table 2 presents costs of a reverse osmosis unit operating at 800 lb/in^2. The O&M costs of this unit do not include the costs of disposing of the concentrated reject stream. Regardless, reverse osmosis is an extremely expensive technology and should be considered only for leachate treatment applications when an effluent of extremely high quality is required.

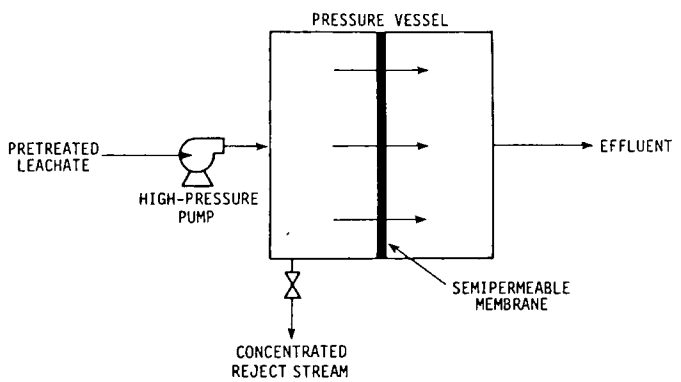

Figure 7
Schematic Diagram of Reverse Osmosis

CONCLUSIONS

The highly variable, complex nature of hazardous waste leachate often requires that several unit treatment operations be applied in combination to effect the desired degree of contaminant removal. Equalization is used to buffer influent flow and concentration fluctuations and to improve the performance of more costly downstream operations. Air stripping, neutralization and chemical precipitation often are used ahead of biological treatment (activated sludge) to remove biologically toxic compounds such as ammonia and heavy metals and to adjust the pH to near neutral. Carbon adsorption and reverse osmosis are used as polishing steps to remove refractory organics and to meet final effluent criteria. Unit treatment costs range from $0.07/1000 gal for neutralization to $2.10/1000 gal for reverse osmosis.

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Innovative Techniques for the Evaluation of Solidified Hazardous Waste Systems

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ABSTRACT

Hazardous wastes solidified or stabilized by mixing with cementing materials are described as complex composite materials with microstructures and microchemistries which determine their properties. The behavior of these materials and their possible long-term effect on the environment can be determined by examining them with the tools common to studies in materials science and engineering. Several of the microscopic and microanalytical techniques useful in these investigations are described and selected results are shown. These techniques, together with measurements of bulk physical properties, currently are being utilized by the present authors to determine the mechanisms of waste stabilization. The results are being used to design effective methods to handle real-world organic and inorganic hazardous industrial wastes.

INTRODUCTION

Certain types of hazardous wastes can be converted into a manageable form by solidification. For example, aqueous sludges containing inorganic metal ions can be combined with various cementing mixtures to form solids which are often disposable in a secure landfill. Several advantages are potentially afforded by solidification, including little or no free-standing liquids and reduced hydraulic pressures which might cause failure of the liner system. If the permeability of the solidified waste is low, then the leachate from monolithic structures may be free of toxic ions after their initial depletion from exposed surfaces.

In the most desirable situation, the metal ions react chemically with the matrix thereby forming a complex which is insoluble in aqueous media and which is stable when leached by solutions with a pH near those common in the environment or in a landfill. Therefore, under the ideal situation, the waste is rendered effectively non-hazardous. Consequently, solidification/stabilization is potentially an important management alternative which may be attractive for many hazardous wastes.

Unfortunately, little is known about the mechanisms of waste solidification and even less about stabilization. Until recently, system design was essentially empirical and based on industrial research which usually remained proprietary. The relevant information in the open literature dealt with nuclear waste stabilization[1] or cement admixtures[2] and, although useful, it more often than not concerned the interaction of cementing matrices with compounds which are not important to hazardous chemical waste management.

Recently, however, it has been recognized that advances can be made toward understanding the mechanisms of solidification and stabilization by regarding the products as "complex composite materials" with a "microstructure".[3] Mechanistic information which might result from this viewpoint is essential to establishing a fundamental basis for the *a priori* design of a solidified or stabilized waste.

A material science point of view suggests that the measurable properties (e.g., unconfined compressive strength and toxic ion leachability) of the waste/matrix systems depend on the microstructure and the microchemistry. The experimental techniques commonly used by the materials scientist offer ways to examine the waste/matrix systems which may provide information about the mechanisms of solidification and/or stabilization.

In this paper, the authors discuss the techniques that they have found useful in their recent studies of solidified inorganic sludges and of solidified organics.[4] The methods can be conveniently grouped into those which provide morphological information and those which provide chemical information. They are briefly described and representative results are presented.

SAMPLE PREPARATION

The authors' investigations primarily have involved mixtures of hazardous chemical wastes and Type I Portland cement. Portland cement was chosen because it is a common component of many solidification formulae which have been proposed and of many which currently are being used by industry. Mixtures of pure Portland cement and hazardous wastes are unlikely to be environmentally, technically or economically practical, but they do offer some of the laboratory control that is important to a basic study. Other, more complicated, matrices presently are being examined in the authors' laboratories as part of a study of interference mechanisms. The work is funded by the U.S. EPA and the U.S. Army Corps of Engineers.

A second application of the methods is part of an investigation of test methods for evaluating real solidified wastes. The latter is a cooperative study involving the U.S. EPA, Environment Canada and several vendors in the United States, Canada and abroad.

Weighed amounts of waste and water were mixed with 10 g of Portland cement, contained in capped vials and stored at room temperature in a darkened room to avoid photochemical reaction of the organics. Samples were allowed to cure for various times ranging from 1 week to over 1 year.

Three organics have been investigated: p-bromophenol, p-chlorophenol and ethylene glycol. The reasons for selection of these compounds and detailed descriptions of their morphology, microchemistry and leaching behavior have been described elsewhere.[5,6]

MICROSTRUCTURE

The microstructure of a solidified waste depends on the following factors:

- The chemical composition of the waste
- The chemical composition of the solidifying matrix components (cement, fly ash, clay, etc.)
- Relative amounts of waste and matrix components
- Amount of water
- Extent of mixing
- Temperature of mixing
- Time and temperature of set

In the studies performed by the authors, these factors have been considered and maintained constant when appropriate, even though in actual practice most of the factors can vary considerably. It will be important, therefore, for researchers to establish how strongly these factors affect the gross properties of the final product.

Optical Microscopy

Microstructure can be observed at several microscopic levels. For example, entrained air can form bubbles ranging in size from 0.1 to 1 mm in diameter. These bubbles may be important in the development of mechanical strength in the solidified product. Air bubbles also can be the source of carbon dioxide to the matrix. Carbonation can affect the hydration of cement paste by promoting the formation of calcium carbonate which then decomposes to a mixture of calcium carbonate and hydrated silica.[7] Microstructural features of this size are resolved easily with the optical microscope.

There are several types of optical microscopes. They are conveniently categorized according to the branch of science which they serve (e.g., the biological microscope, the petrographic microscope and the metallographic microscope). The petrographic microscope and, to a lesser extent, the metallographic microscopes are the most useful for examining microstructures in solidified and stabilized wastes.

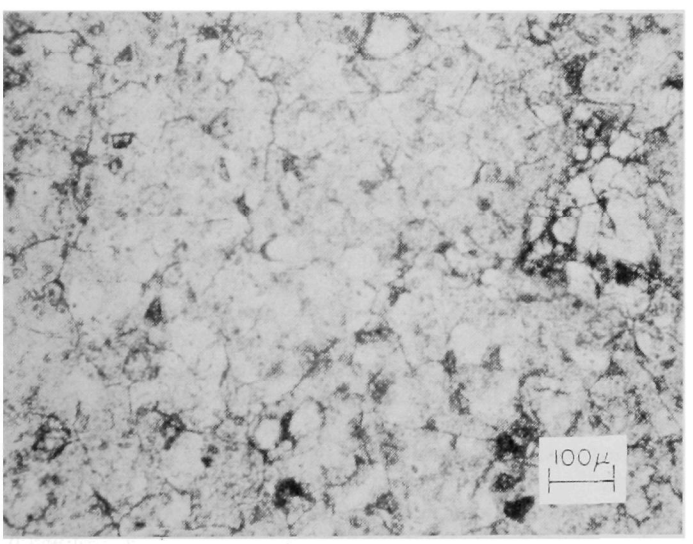

Figure 1
An Optical Micrograph of a Solidified P-Bromophenol Sample. A Bimodal Grain Structure is Revealed.

Thin sections can be prepared, using methods standard to geological practice, so that light can be transmitted directly through a small piece of solidified material. Using this method, the grain structure can be observed. Figure 1 is an optical micrograph which reveals the polycrystalline structure of solidified p-bromophenol. The Portland cement matrix material is apparent in the microstructure with small grain-like hydration phases. There is an equiaxed grain structure which is clearly visible at 100X magnification, and the presence of several mineral phases is apparent. If polarized light is used, the crystalline and noncrystalline components of the solidified system can be distinguished. It also is possible to do phase analysis of the crystalline components using index of refraction liquids. It is, therefore, in principle, possible to determine the compounds formed due to the presence of the hazardous waste. In practice, this determination can be very difficult and the researcher likely will more successfully identify than locate the waste containing phases. This identification is illustrated in Figure 2 where the arrow indicates a mineral, i.e., crystalline, phase which contains hazardous p-bromophenol.

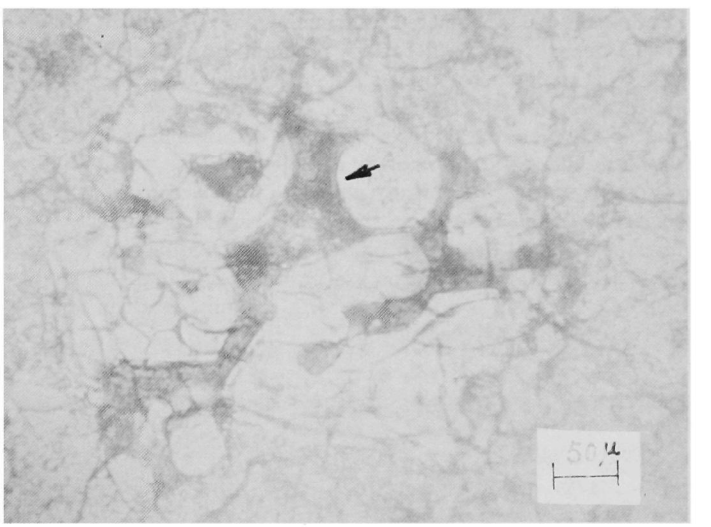

Figure 2
A Higher Magnification Optical Micrograph of the Material Shown in Figure 1. The Arrow Points to a Phase Which is Concentrated in P-Bromophenol.

When only morphological information is required, such as in studies of air entrainment, the metallurgical microscope is useful. With the metallurgical microscope, light is directed down the microscope tube and is reflected off of the specimen surface. Reflected light travels back up the tube and through the ocular to be detected by the operator's eye or to be recorded on a photographic plate or film. The chief advantage in the use of the metallurgical microscope over the petrographic microscope is in specimen preparation. Since light is not transmitted through the specimen, only a polished surface is required.

Scanning Electron Microscopy

Microstructure on a smaller scale is apparent when the several minerals formed upon hydration of Portland cement are considered. For example, calcium hydroxide crystallites are formed and often are observed as hexagonal plates several microns in extent. Even smaller crystallites of ettringite are observed in young cement pastes. Ettringite usually appears as rod or needle shaped, single-crystals. They contain sulphur and are only a few microns long. The ettringite group of minerals form the AFt (A = Al, F = Fe and t = three moles of $CaO.SO_3$) phases.[8] Both the calcium hydroxide and the AFt phases are observed best by scanning electron microscopy (SEM).

In the scanning electron microscope, a primary electron beam is focused onto a specimen surface and rastered over a small area. Primary electrons interact with the waste and matrix atoms contained in the specimen producing additional electrons. These electrons are released from the specimen atoms themselves and can be

released through several mechanisms. The two electron generation mechanisms particularly useful for waste studies are secondary electrons and backscattered electrons. A secondary electron detector or a backscattered electron detector placed near the specimen can be used to produce an image of the variations in their generation as the primary beam is rastered across the specimen surface. The utility of the SEM is related to the following characteristics of its use and image contrast mechanisms:

- Magnification variable from 10X to ca. 100X with a resolution of up to 5 nm or less
- Magnification variable
- Large depth of field
- East of specimen preparation

Specimens can be prepared by grinding and polishing in a manner identical to that used for the preparation of specimens for the petrographic microscope or for the metallurgical microscope. The authors, in fact, frequently use the same specimen for both types of examination. If three mutually orthogonal sections are examined, the researcher usually can eliminate the possibility of mistaking textured for uniform structure. Polished sections must be carefully studied, however, to eliminate artifacts caused by the preferred removal of certain phases during grinding and polishing. Fractured surfaces can be useful in assuring that this is not occurring. Figure 3 is an example of a scanning electron micrograph of solidified ethylene glycol.

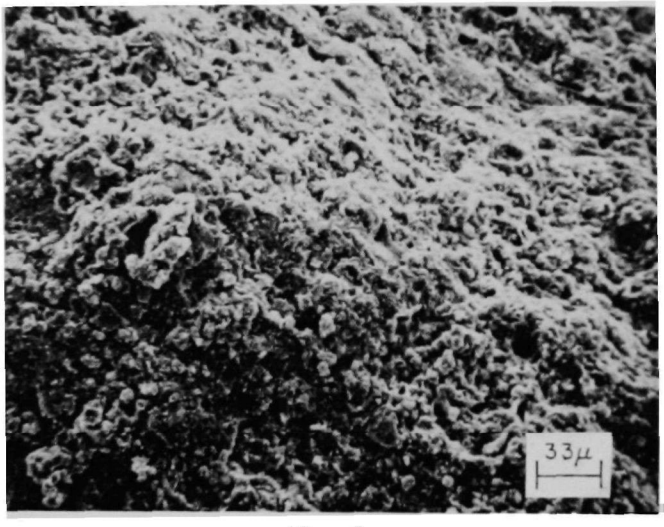

Figure 3
A Scanning Electron Micrograph of a Solidified Ethylene Glycol Sample

Transmission Electron Microscopy

When Portland cement is a component of the solidification or stabilization matrix, a major hydration product is calcium silicate hydrate (CSH). CSH is a poorly crystalline material which, like the AFt phases, is comprised of several different compounds which are mineralogically similar. When viewed by the optical microscope or the SEM, CSH appears as the dominant or matrix phase of a solidified hazardous waste. The SEM sometimes is able to resolve its morphology but frequently reveals it as a featureless, but sometimes nodular or grainy, material in which well developed crystals like calcium hydroxide or AFt grow.

The transmission electron microscope (TEM) is the instrument of choice for studying the morphology of CSH and other very small structures. The TEM is capable of resolving features as small as a few angstrom units in cementitous materials. Unfortunately, specimen preparation usually is more difficult than for either optical or scanning electron microscopy.

A stationary electron beam is focused onto a specimen which intersects the optical axis of the instrument. The transmitted beam is scattered and produces an image with contrast which is primarily a function of the mass-thickness of the noncrystalline components. Crystalline components scatter the specimen in more complex ways due to diffraction. Figure 4 is a transmission electron micrograph of a small crystalline phase in a solidified waste.

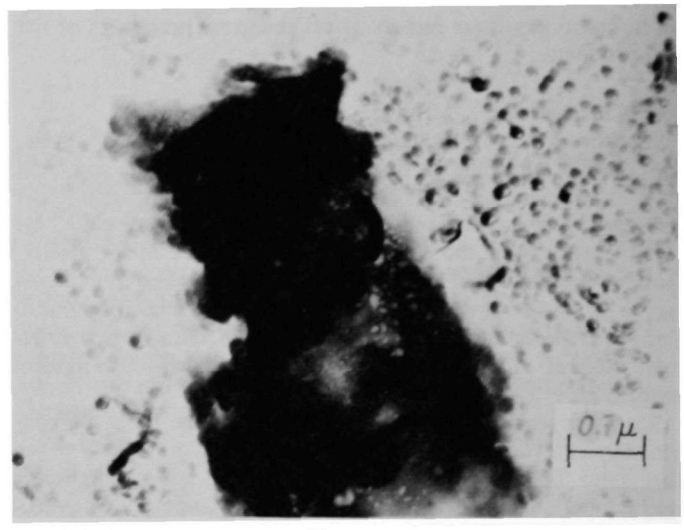

Figure 4
A Transmission Electron Micrograph of a $Ca(OH)_2$ Crystal (the large dark structure at the center of the micrograph) in a Solidified Ethylene Glycol Sample

MICROCHEMISTRY

Bulk analytical instruments are an important and necessary part of any investigation of the solidification and stabilization of a hazardous chemical waste. If mechanistic information is desirable, it is useful to have chemical analyses of the small phases present in the solidified material. Consequently, special methods must be used.

Electron Diffraction

The high resolution images obtainable from the transmission electron microscope and the ability to photograph diffraction patterns make the TEM very useful for solidification/stabilization research. Chemical identification of mineral components of the solidified waste is possible by analysis of the electron diffraction patterns.

Figure 5 is an example of the results which can be obtained from examination of a solidified hazardous waste by transmission electron microscopy. The dark structure indicated by the arrow is a calcium hydroxide crystal as revealed by the diffraction pattern.

Energy Dispersive and Wavelength Dispersive X-Ray Analysis

Specimens examined in the SEM emit x-rays in addition to electrons. The x-ray energies are characteristic of the elements from which they come. This means that they can be used to determine the elemental composition of the specimen. The method is known as energy dispersive x-ray analysis (EDS). Most EDS spectrometers will detect elements with atomic number 11 (Na) or greater.

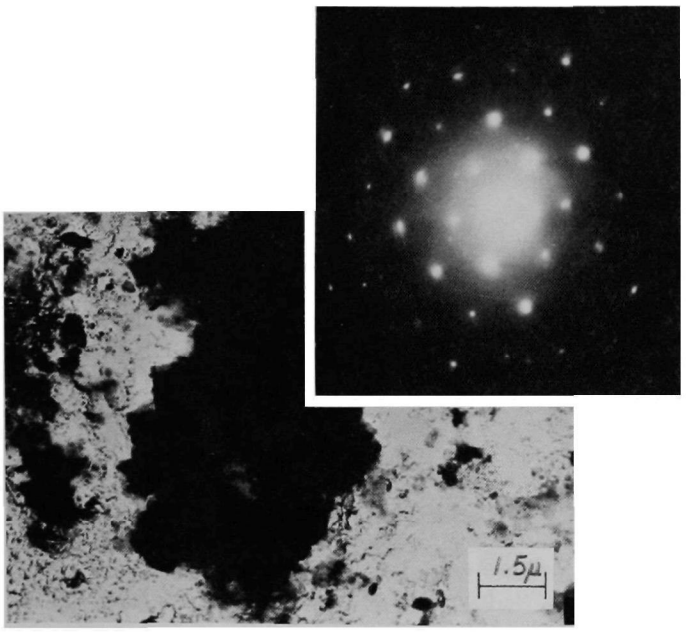

Figure 5
A Transmission Electron Micrograph of a Ca $(OH)_2$ Crystal in a Solidified P-Bromophenol Sample. The Diffraction Pattern was Used to Confirm the Composition of the Crystal.

Those spectrometers equipped with a windowless detector can detect even lighter elements and are particularly useful for carbon and oxygen determination. A similar technique is commonly associated with electron probe microanalysis (EPMA) and is known as wavelength dispersive x-ray analysis (WDS).

It is obvious that EDS and WDS would be useful in studies of inorganic metal ion stabilization, but in certain cases they also can be used in studies of organic waste solidification and stabilization. The authors have used the techniques to study the partitioning of selected organics to the hydration products of Portland cement. Two organics, p-bromophenol and p-chlorophenol, were selected because they were molecules which contained a heavy element which could be detected by EDS and WDS. The crystalline phase shown by the arrow in Figure 2 was determined by WDS to contain large amounts of Br and, therefore, to be rich in organic.

X-Ray Power Diffraction

X-ray powder diffraction (XRD) is very useful for studies of waste solidification. A bulk analytical technique, XRD often can be used to identify the exact chemical compounds present in the solidified system. This technique is generally familiar, so it will not be discussed in this paper.

CONCLUSIONS

Studies of hazardous waste solidification/stabilization are complicated by the fact that cementing mixtures are used as cementing matrices. Upon hydration, a complex composite material is formed. The microstructure of this material has structure at levels which vary from that visible to the eye to that which can only be resolved by electron microscopy. The properties of the solidified system are determined by the microstructure and the microchemistry.

Incorporation of hazardous wastes into the matrix by mixing prior to hydration introduces the possibility that the wastes themselves are chemically involved with the hydration reactions and therefore are stabilized by the process. In addition, there is a possibility that the wastes are physically contained by the matrix in pores or interstitial spaces. These sites of physical entrapment may be so small that they are difficult to locate even by microscopic methods.

These characteristics suggest the use of microscopic and microanalytical methods for studying the mechanisms of waste solidification and stabilization. The various methods used by the present authors have been discussed. Some of the results of these studies have been shown in the form of photomicrographs which reveal selected characteristics of cement/organic waste solidification mixtures.

ACKNOWLEDGEMENTS

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Site Characteristics and the Structural Integrity of Dikes for Surface Impoundments

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ABSTRACT

Before a land disposal facility is developed for hazardous wastes, the site characteristics need to be determined. The information obtained for the geological and hydrogeological features is carefully used in the design of the surface impoundment. Special design provisions need to be chosen if the site conditions are poor.

The damage due to the failure of dikes containing the wastes in surface impoundments poses severe risk of contamination of surrounding areas. The requirements of RCRA seek to ensure the structural integrity of dikes by requiring certification of these structures by registered engineers. The evaluation of site characteristics and the structural integrity of dikes is a complex subject. For the benefit of those involved in dike certification and review of permit applications, the essential steps involved in these evaluations are summarized in this paper.

INTRODUCTION

A surface impoundment design requires adequate data on the site characteristics, geometry of the dike and properties of the soils forming the dike. In addition, information on groundwater conditions is required to complete the design. Thus, for proper water disposal techniques, the identification of various features at the site is an important step. Subsequent to the determination of site characteristics, a detailed laboratory testing program needs to be undertaken to determine the remaining engineering properties of soils.

The geometry of the problem is defined based on specifications or field survey results, and the structural integrity of dikes is determined using the appropriate analysis procedure. The structural adequacy needs to be ensured for different stages of the life of the surface impoundment and shear strength properties appropriate for these stages need to be used in the analyses. Thus, adequate understanding and recognition of all fundamental principles of geotechnical engineering and hydrogeology are necessary to successfully complete the above steps of engineering analyses.

SITE CHARACTERISTICS

The first step is the site reconnaissance in which all pertinent information is obtained. An efficient and economical way to begin the site investigation is to review all available literature. This process involves a review of past and present land uses, review of site aerial photography and assessment of the site topography, cultural landmarks, surface hydrology and surficial geology. The location, accessibility, general area topography, past and present ownership and/or use of a site are determined from maps acquired from the local assessor's office and/or from the U.S. Geological Survey (USGS). The USGS and the Soil Conservation Service (SCS) may be utilized as sources of preliminary information regarding the surficial geology of the site under investigation. Site-study reports, as well as previous plans and specifications, may be available from area contractors, consultants and government agencies. Any construction activity in the project area should be visited. A site survey should be performed to familiarize the engineer with the area. High water marks and vegetation can indicate the nature of the soil. Recent changes in topography also can be helpful in design procedures.

Geological conditions and project objectives will dictate the type of drilling needed to meet the job requirements. It is not always possible or cost-effective to use a single drilling method to complete a project. This is one reason why, prior to specifying a drilling method, an analysis of the project requirements is done. Selection of a drilling method most suited to the particular job can be based on the following factors:

- Type of formation
- Depth of drilling required
- Availability of drilling equipment
- Special and/or other specific requirements

The use of a backhoe or shovel is a very simple and quick means of determining shallow soil conditions and shallow groundwater conditions. Advantages are the low cost, mobility and ease of operation. The main disadvantages are the depth limitation and sample disturbance.

Surface Geophysical Techniques

The application of geophysics to hazardous waste management combines proven technology with new technology to form an integrated systems approach. This process is efficient and cost-effective. Several types of geophysical exploration techniques are now available for a rapid evaluation of subsoil characteristics. Definite interpretation of the results requires correlation with standard subsurface exploration methods. Geophysical methods can be divided into two categories: (1) surface techniques and (2) downhole techniques. A few of these surface geophysical techniques are described below.

Ground Penetrating Radar

Ground penetrating radar (GPR) uses high frequency radio waves to acquire subsurface information. Energy is radiated downward from a small antenna which is moved slowly across the surface of the ground. The energy is reflected back to the receiving antenna, where variations in the return signal are continuously recorded. Radar responds to changes such as bedding, cementation, moisture, clay content, voids, fractures, intrusions and man-made objects. Depth of penetration is site-specific.

GPR is limited in depth by attenuation. Better overall penetration is achieved in dry, sandy or rocky areas. Poor results are obtained in moist, clayey or conductive soils. Radar penetration to 30 ft is common.

Electromagnetic Measurements

The electromagnetic method provides a means of measuring the electrical conductivity of subsurface soil, rock and groundwater. Electrical conductivity is a function of the type of minerals in the formation, its porosity and permeability and the fluids which fill the pore space. Often the conductivity of the pore fluids dominates the measurements.

Natural variations in subsurface conductivity may be caused by changes in soil moisture content, pore fluid conductance, depth of soil and thickness of formation layers. The absolute values are not necessarily diagnostic; it is the variations that are significant.

Seismic Refraction and Reflection

Seismic refraction and reflection techniques are used to determine the thickness and depth of geologic layers by using the velocity of seismic waves which is an indication of the soil and rock's engineering properties. Reflection can be used effectively to depths ranging from about 50 ft to several thousand feet. Structural and formation boundaries can be detected. Refraction commonly is applied to shallow investigations up to a few hundred feet. Depth to bedrock and the layer thickness of the overlying unconsolidated material can be determined.

Seismic waves transmitted into the subsurface travel at different velocities in various types of soil and rock. The waves travel in all directions from the source and are reflected and refracted when they impinge on an interface. The combination of pattern and velocity will affect travel time. An array of geophones on the surface measures the travel times of the seismic waves from the source to the geophones. The refraction and reflection techniques use the travel times of the waves to provide data on subsurface layers, including the number of layers, the thickness of the layers and their depths.

Resistivity Method

The resistivity method is used to measure the electrical resistivity of the section which includes the soil, rock and groundwater. The method may be used to determine lateral changes and vertical cross-sections.

The procedure requires that an electrical current be injected into the ground by a pair of surface electrodes. The resulting potential field is measured at the surface between a second pair of electrodes. The subsurface resistivity can be calculated by knowing the separation and geometry of the electrode positions, applied current and measured voltage.

In general, most soil and rock minerals are highly resistive, hence the flow of current is conducted primarily through the moisture-filled pore spaces within the soil and rock. Therefore, the resistivity of soils and rocks is predominantly controlled by the porosity and the permeability of the system. Electrical sounding is used to reveal the variations of apparent resistivity with depth. Horizontal profiling is used to determine lateral variations in resistivity.

In Situ Measurement Techniques

The determination of soil properties by in situ measurement techniques also has advanced greatly. A few of these methods are described below.

Standard Penetration Test

The standard penetration test is the oldest and most widely accepted method for obtaining shear strength properties. This involves counting the number of blows required of a 140-lb hammer dropped from a height of 30 in. to move a split spoon sampler 12 in. through the soil. The resultant number is termed the "N" count and is at present the most widely used index of subsurface soil conditions. Advantages of the standard penetration test include economy of use, simplicity of procedure and widespread acceptance.

Cone Penetration

Cone penetration devices are useful because of simplicity of testing, reproducibility of results and ease of correlating results to other test results. The drawback of the test is that no soil sample is obtained.

The test procedure involves advancing vertically, at a constant rate, a penetrating cone of about 10 cm^2 base area and about 60° apex angle. The force needed to penetrate a given distance in a soil is used in measuring shear strength.

Vane Shear

In contrast to methods which determine strength parameters from empirical correlation, the vane shear test attempts to measure undrained shear strength directly. The test procedure is to advance a vane configuration to a desired soil depth and measure the applied torque as the vane is rotated at a constant rate.

Shearing resistance is considered to be mobilized on a cylindrical failure surface of rotation, corresponding to the top, bottom and sides of the vane assembly. The vane shear test possesses the advantages of economy of use and reduced soil disturbance.

Pressuremeter

The pressuremeter is used by lowering the apparatus into a borehole or, if the machine is self-boring, by drilling to the required depth. Increments of hydraulic pressure are applied to the test cell which acts against the borehole wall. The resulting deformation of the borehole wall is determined by monitoring the volume change of the test cell.

The relationship between pressure increment, volumetric expansion and time is examined to determine strength characteristics. No soil sample is obtained if the self-boring pressuremeter is used.

Iowa Borehole Shear Test

The Iowa borehole shear test is performed by lowering a shear head consisting of two opposing horizontally grooved shear plates to the required test position in an uncased borehole. The two shear plates are expanded until seated in the borehole walls at a selected pressure. After a time period allotted to allow for consolidation to occur, the shear head is either pulled upward or pushed downward at a steady rate of 2 mm/min. The required forces for shearing are measured, and the shearing stress is plotted against the normal pressure. By performing a number of tests at different seating pressures, the soil strength can be calculated.

Soil strength may be expressed in a number of ways, and the particular strength parameters to use in design will depend on the nature of a specific problem.

SHEAR STRENGTH OF COHESIVE SOILS

The shear strength behavior of cohesive soils differs considerably from that of cohesionless soils. This section presents the details of the shearing resistance of cohesive soils under various loading and drainage conditions. In order to obtain meaningful results from a laboratory test program for the shear strength parameters of cohesive soils, it is necessary to test good quality samples representative of the in situ soils or compacted soils proposed for the project. For in situ soils, the samples to be used

should be undisturbed as far as possible and must be tested at the in situ water content and dry density. For compacted soils, it is necessary to match the following three factors between the laboratory samples and the soils used in the field:

- Method of compaction
- Dry unit weight, γ_d
- Water content, ω

It is necessary to relate shear strength to compaction at an elementary level in this section. A typical compaction curve showing the dry unit weight-water content relation for a cohesive soil is given in Figure 1(a). The variation of shear strength with water content is shown in Figure 1(b). Although a cohesive soil can be compacted at the same dry unit weight at points A and B in Figure 1(a), the water content at these points would differ considerably. Thus, the shear strength of the compacted soil at A would be higher than that at B. Therefore, it is necessary to prepare samples in the laboratory at values of water content and dry unit weight comparable to those of the field compacted soils. Furthermore, the structure of a compacted clay is highly dependent upon the method of compaction, and the structure has a significant influence on the shear strength and drainage properties of the clay. Therefore, it is also important to use a laboratory compaction procedure that would yield compacted test samples with a structure similar to that of the field compacted soils.

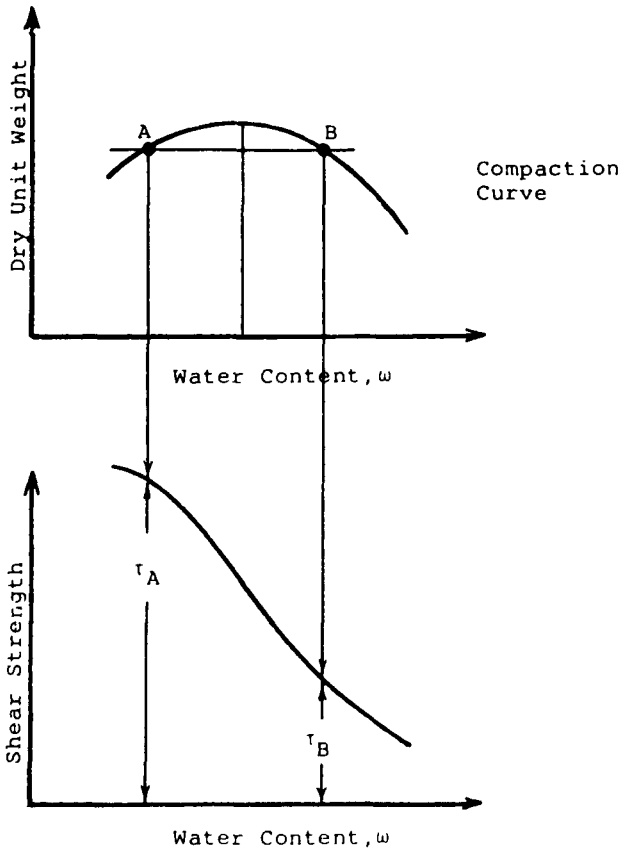

Figure 1
Compaction Curve

Shearing Resistance, Cohesion

The shearing resistance of cohesive soils differs from that of cohesionless soils due to the following differences in soil factors:

- Particle size
- Particle shape
- Permeability
- Angle of internal friction
- Plasticity

The sizes of particles forming cohesive soils are significantly smaller than those of cohesionless soils. Cohesionless soils are made of angular to rounded shapes of particles, whereas cohesive soils are made of platey shaped particles. Cohesive soils drain much more slowly than cohensionless soils due to the fact that the coefficient of permeability of cohesive soils is lower than that of cohesionless soils. The angle of internal friction of cohesive soils generally is slightly lower than that of cohesionless soils. Furthermore, the small particle sizes of cohesive soils have attractive forces giving the plastic behavior for cohesive soils; this factor does not apply to cohesionless soils. Due to the above factors, the shear strength behavior of cohesive soils is expressed by the equation:

$$\tau = c + \sigma \tan \phi \qquad (1)$$

where c is cohesion and ϕ is the angle of internal friction.

The Mohr-Coulomb failure envelopes for clays and sands are shown in Figure 2 for comparison. The value c indicated on the shear stress, also referred to as the "Cohesion Intercept," is due to the attractive forces between the platey shaped particles forming cohesive soils such as clays.

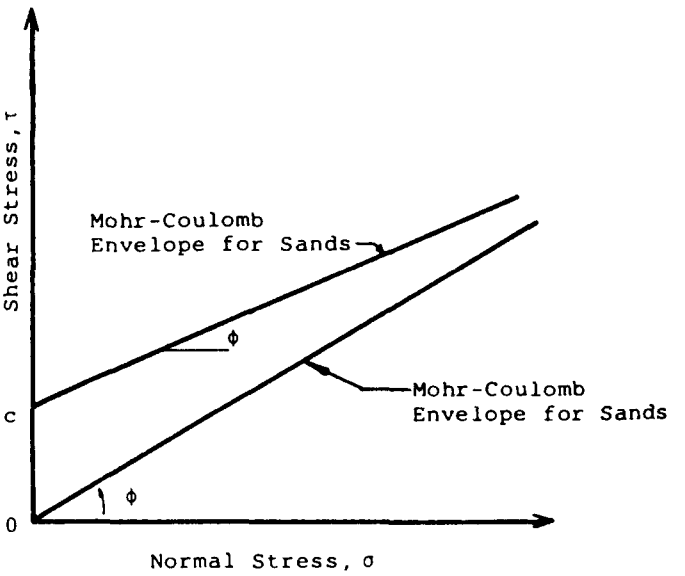

Figure 2
Strength Envelopes

Pore Pressure Parameters

The low permeability of clay causes pore water pressure to build up during laboratory or field tests and control the shear strength properties measured for use in design computations. Therefore, it becomes necessary to understand the mechanisms of pore water pressure changes in cohesive soils before making an attempt to understand the shear strength behavior of cohesive soils.

When a sample of clay is loaded in a triaxial test initially by an equal all around confining pressure, σ_3, followed by a deviator stress, $\sigma_1 - \sigma_3$, a total pore pressure change, Δu, occurs as shown in Figure 3, under undrained conditions. The above two types of

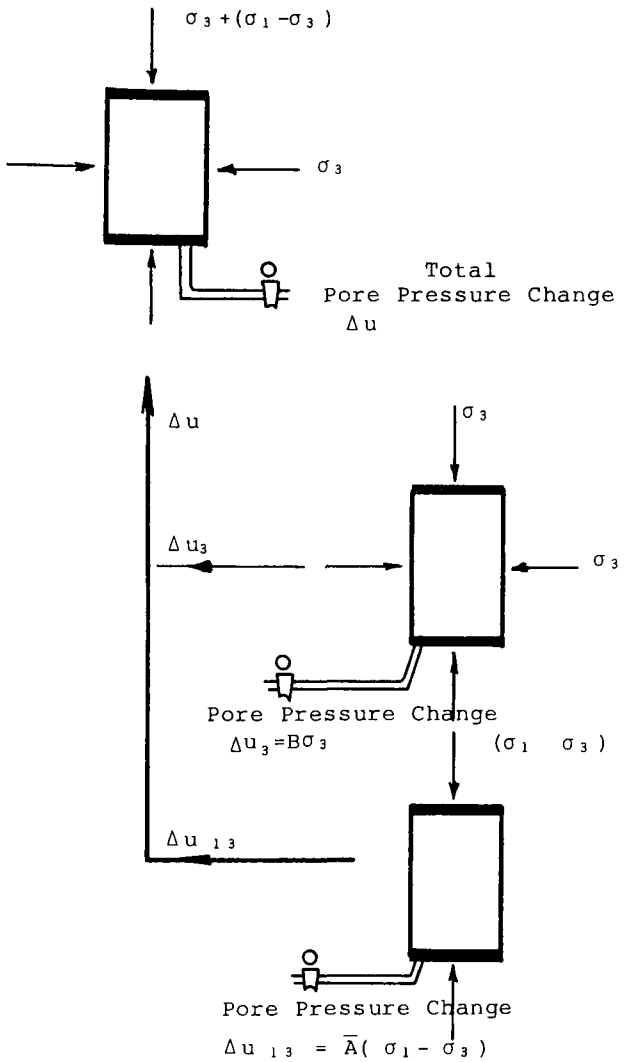

Figure 3
Pore Pressures

loading independently cause two increments of pore pressures, Δu_3 and Δu_{13}, given by:

$$\Delta u = \Delta u_3 + \Delta u_{13} \quad (2)$$

where:

$$\Delta u_3 = B\sigma_3 \quad (3)$$

and

$$\Delta u_{13} = \bar{A}(\sigma_1 - \sigma_3) \quad (4)$$

as shown in Figure 3. In Equations 2 and 4, B and $\bar{A}$ are referred to as the "Pore Pressure Parameters." By knowing these pore pressure parameters, the excess pore water pressures developed in a triaxial test can be estimated. Conversely, by measuring the changes in pore pressures, Δu_3 and Δu_{13}, in a laboratory test for known values of σ_3 and $(\sigma_1 - \sigma_3)$, the values of B and $\bar{A}$ can be computed.

The pore pressure parameter, B, is a function of the coefficient of volume compressibility, m_v, of the soil sample shown in Figure 4(a) and the degree of saturation, S, indicated in Figure 4(b). The coefficient of volume compressibility increases as the stiffness of the soil skeleton decreases and, as a result, the value of B increases for the same value of saturation as shown in Figure 4(b). When the sample is dry due to air being far more compressible than the soil skeleton, the pore water pressures developed are zero and, therefore, the value of B is regarded as zero. Since the pore water will carry the entire confining pressure under undrained loading conditions for a saturated sample of clay, the pore pressure parameter, B, becomes 1.0. The pore pressure parameter, $\bar{A}$, is a function of stress ratio, σ_1/σ_3, as shown in Figure 4(c). For normally consolidated clay, $\bar{A}$ is approximately 1.0; for overconsolidated clays, it is between -0.3 and 0.8.

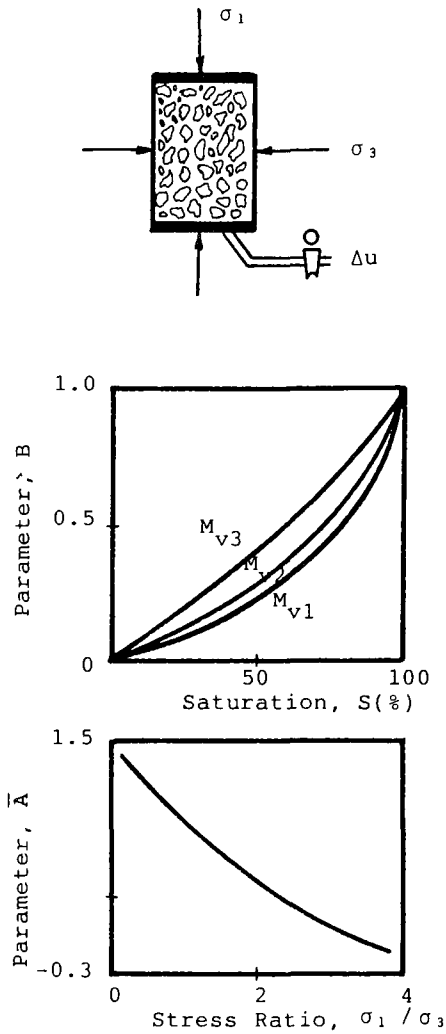

Figure 4
Pore Pressure Parameters

Unconsolidated-Undrained Test

The Unconsolidated-Undrained, U-U, Quick or Q Test usually is performed to obtain strength parameters, c and ϕ, corresponding to a fast loading of the soils at sites where drainage is poor. In this test, the soil sample is trimmed and placed in a thin membrane as shown in Figure 5(a). The confining pressure, σ_3, is applied to simulate the confinement available to the sample in the field while the drainage value is closed. The sample is sheared while the drainage valve is closed, not allowing any excess pore pressures built up in the sample to dissipate, as shown in Figure 5(b).

Since it is impossible to saturate the sample without consolidating, pore pressures are never measured in the U-U test. The Mohr-Coulomb envelope for a saturated sample of clay in a U-U test is horizontal, as shown in Figure 6(a), since the deviator stress at failure is independent of the confining pressure applied to the

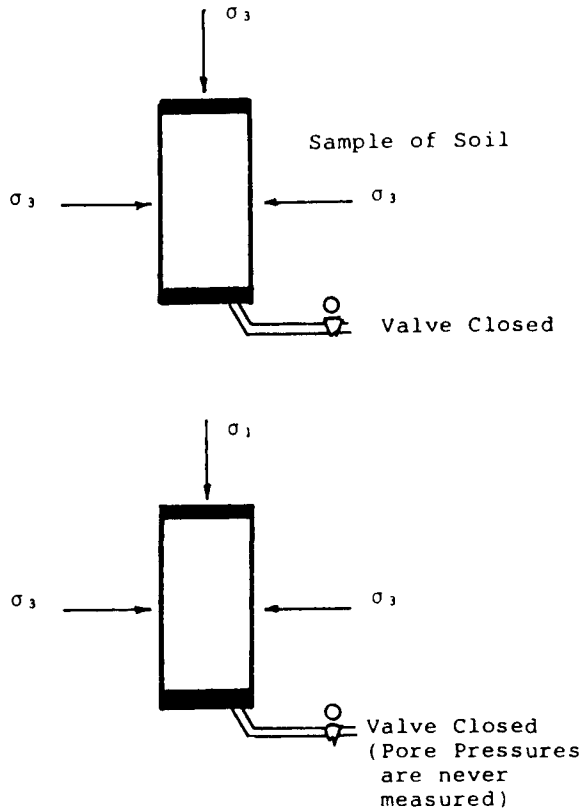

Figure 5
Unconsolidated-Undrained Test

sample. For a saturated sample of clay yields the U-U test gives the following strength parameters:

$$c = S_u \tag{5}$$

$$\phi = O \tag{6}$$

where S_u is the undrained shear strength of the clay.

Since the deviator stress is independent of the confining pressure, it is possible to perform a test with a confining pressure of zero and obtain the undrained shear strength, S_u, of the soil from the diameter of the failure Mohr's circle as shown in Figure 6(b). This test is referred to as the "Unconfined Compression Test," where the sample is sheared by a compressive load, σ_1, without the use of a confining cell. The diameter of the Mohr's circle q_u, in Figure 6(b) is called the "Unconfined Compressive Strength" of the sample.

When a partially saturated sample of clay is sheared in a U-U test, the size of the Mohr's circle increases with increasing confining pressure as shown in Figure 7. Once the confining pressure reaches a high enough value to cause the pore air to dissolve in pore water, the sample becomes saturated. Beyond this value, the sample yields a horizontal Mohr-Coulomb envelope as shown in this figure. Thus, in order to obtain the strength parameters, c and ϕ, corresponding to a confining pressure, σ_3^* (of interest in the partially saturated range), it becomes necessary to draw a tangent at $\sigma_3 = \sigma_3^*$ on the envelope and read values for c^* and ϕ^* as shown in Figure 7.

The strength parameters obtained from a U-U test are useful for analyzing geotechnical engineering problems where the soils did not consolidate appreciably and the drainage conditions were poor. An example of such an application is the slope stability evaluation for the dike for the end-of-construction loading condition.

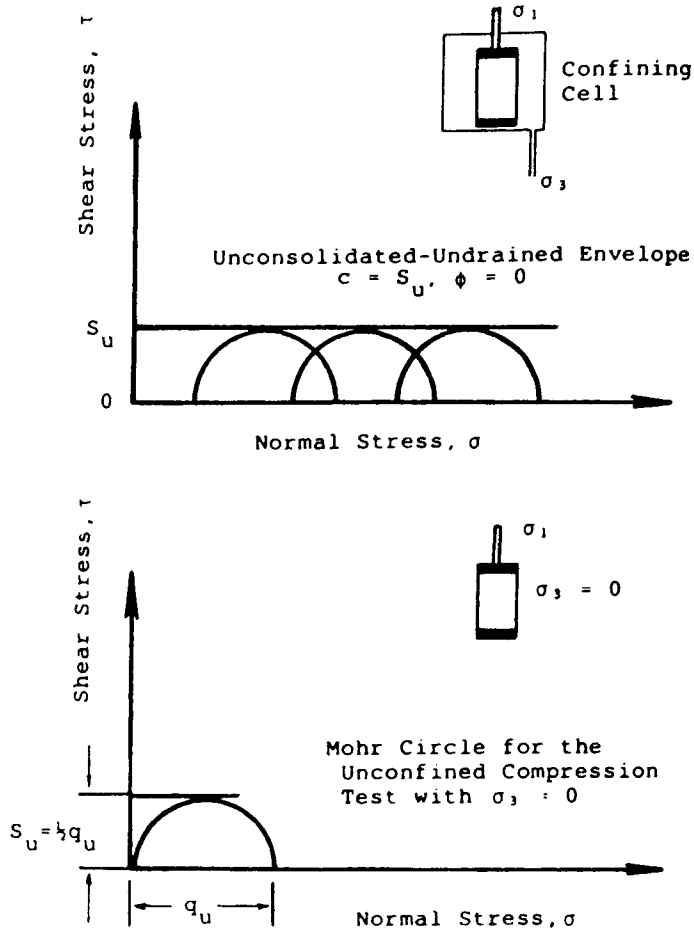

Figure 6
Strength Envelopes

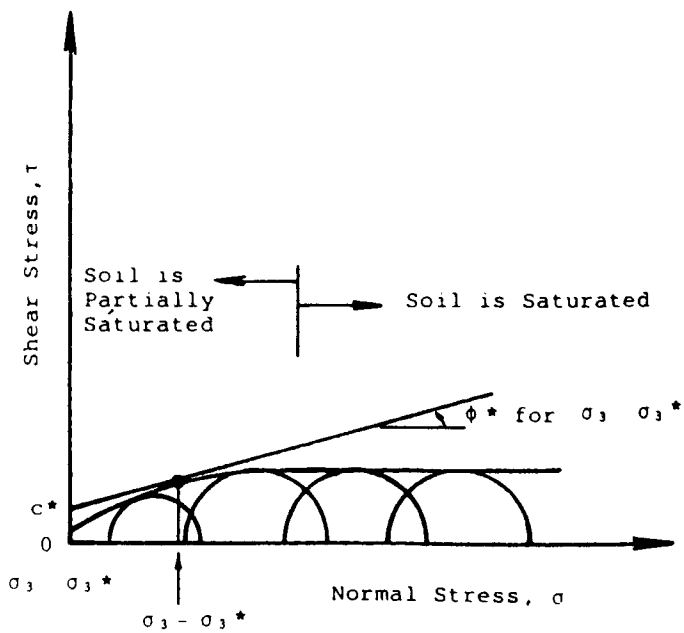

Figure 7
Strength Envelopes

Consolidated-Undrained Test

The Consolidated-Undrained, C-U or R Test usually is performed to obtain strength parameters, c and ϕ, corresponding to a fast loading of the soils at a site where drainage is poor and the site has undergone consolidation. In this test, the drainage valve is left open during the application of the initial confining pressure, σ_3, to allow the sample to consolidate and gain strength. For this reason, the initial confining pressure is also referred to as the "Consolidation Pressure, σ_c" as shown in Figure 8(a). The pore pressures are measured in the sample during application of the deviator stress. The back-pressure technique is used to saturate the sample in order to make the measured pore pressures meaningful.

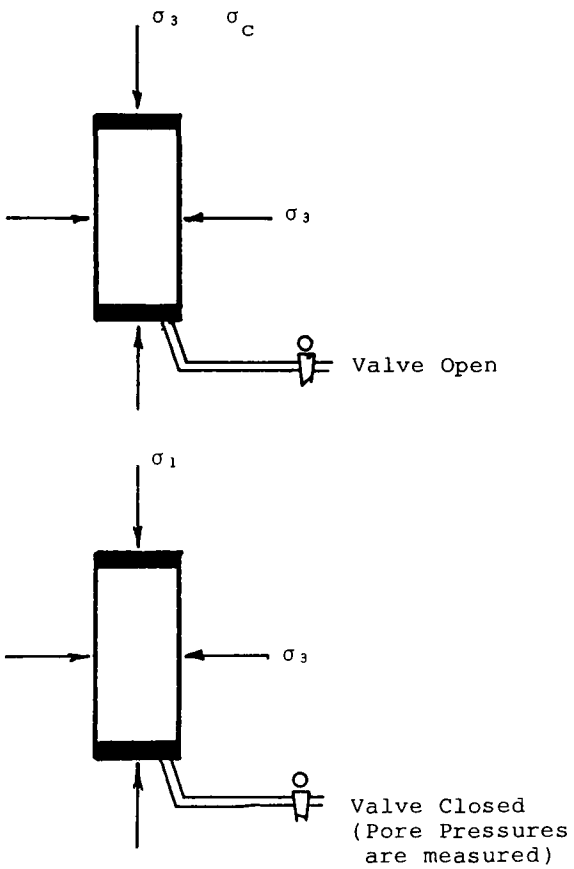

Figure 8
Consolidated-Undrained Test

The total stresses at failure from Tests I and II can be used to construct the failure Mohr circles and the total stress strength envelope as shown in Figure 9(a). By using the pore water pressures at failure, effective stress Mohr's circles and the failure envelope can be drawn as shown in Figure 9(b) to obtain the effective stress strength parameters, c' and σ'.

The strength parameters obtained from a C-U test are useful for analyzing the stability of dikes for steady state seepage or long term conditions and rapid draw down conditions. It is necessary, however, to know the pore water pressures in the field problem before the effective stress strength parameters can be used in the computations.

Consolidated-Drained Test

The Consolidated-Drained, C-D, Slow or S Test is performed for obtaining c' and ϕ' under drained loading conditions. The rate of loading in this test is slow enough to dissipate the excess pore

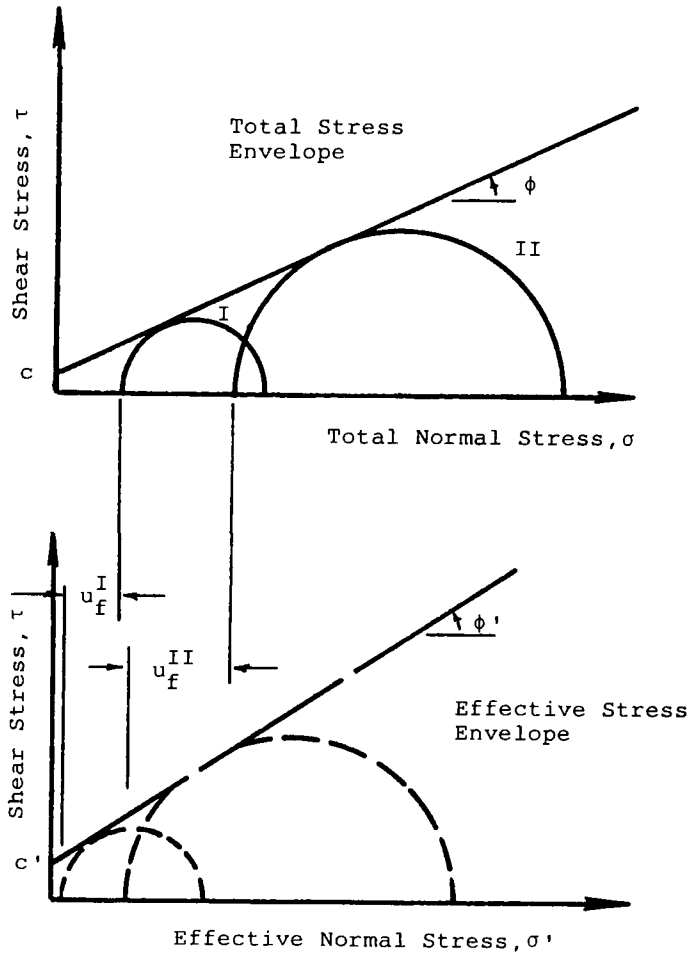

Figure 9
Strength Envelopes

water pressures as they build up during the application of the shear load. The strength parameters obtained from this test provide the data necessary for long-term stability calculations of slopes and embankment dams.

EVALUATION OF STRUCTURAL INTEGRITY OF DIKES

It is necessary that the dike be stable for the following loading conditions:

- End-of-construction or short-term
- Steady seepage or long-term
- Rapid drawdown
- Seismic

The factor of safety against any form of slope failure usually is determined using the following:

- Slope geometry
- Shear strength of soil
- Method of analysis

There are more than 30 methods of slope stability analysis. Among these, Bishop's modified method, Ordinary Method of Slices and Spencer's method are most commonly used. Bishop's Method and the Ordinary Method of Slices are used with circular failure surfaces, and the Spencer's Method is used for noncircular slope surfaces. These methods can be applied for dike stability evaluation using:

- Hand computations
- Computer programs
- Stability charts

Hand Computations

The hand computations are almost never used in practice at the present time for slope stability calculations. These are tedious and time-consuming.

Computer Programs

Computer programs for IBM personal computers and main frame computers are available from the authors for performing dike stability evaluation. These computer programs have various desirable options to handle even the most difficult site conditions.

Stability Charts

The stability of slopes can be analyzed efficiently using the stability charts shown in the manual by Duncan and Buchignani.[1] Although the charts assume simple slopes and uniform soil conditions, they can be used to obtain reasonably accurate answers for most complex problems if irregular slopes are approximated by simple slopes and average values of unit weight, cohesion and friction angle are used.

MINIMUM FACTOR OF SAFETY

When detailed analyses of slope stability are performed using the computer programs based on either Ordinary Method of Slices, Bishop's Modified Method or Spencer's Method, a number of slip surfaces must be examined to locate the most critical failure surface with the lowest factor of safety. The slope stability charts yield minimum factors of safety when properly applied. Under most conditions, the uncertainties due to approximations and assumptions in the method of analysis are smaller than the uncertainties due to inaccuracies in measuring the shear strength. Approximations in the analysis usually amount to 15% or less, but the margin for error in evaluating shear strength may be considerably greater. The minimum allowable value of factor of safety for a slope in a dike depends on several factors; some guidance is given in Table 1 for static and seismic conditions.

Table 1
Recommended Minimum Values of Factor of Safety

	Uncertainty of Strength Measurements	
Costs and Consequences of Slope Failure	Small[1]	Large[2]
Cost of repair comparable to cost of construction. No danger to human life or other property if slope fails.	1.25 (1.2)*	1.5 (1.3)
Cost of repair much greater than cost of construction, or danger to human life or other valuable property if slope fails.	1.5 (1.3)	2.0 or greater (1.7 or greater)

[1] The uncertainty of the strength measurements is smallest when the soil conditions are uniform and high quality strength test data provide a consistent, complete and logical picture of the strength characteristics.

[2] The uncertainty of the strength measurements is greatest when the soil conditions are complex and when the available strength data do not provide a consistent, complete, or logical picture of the strength characteristics

* Numbers without parentheses apply for static conditions and those with parentheses apply for seismic conditions

(After Duncan and Buchignani[1])

EVALUATION OF BEARING CAPACITY OF DIKE FOUNDATIONS

If the foundation of a proposed dike is composed of low strength soils, the factor of safety against any type of bearing capacity failure should be evaluated. The bearing capacity consideration will control the base width of the dike, especially when the foundation contains a seam of weak material, as shown in Figure 10. In this figure:

$$q'_w = \gamma H. \tag{7}$$

Using stress influence charts, the influence factor, I, is obtained corresponding to the dimensions, a and b.

Using I, the stress, q_w, applied to the seam of weak soils can be calculated as:

$$q_w = I q_w \tag{8}$$

The ultimate bearing capacity of the weak material is evaluated using the equation:

$$q_u = cN_c + \frac{1}{2}\gamma BN_\gamma + Z\gamma N_q \tag{9}$$

where N_c, N_γ and N_q are bearing capacity factors obtained from bearing capacity charts corresponding to the angle of friction, ϕ, of the soil. In this equation, B and γ refer to the width of the stress distribution as shown in Figure 10 and the unit weight of the soil, respectively. The factor of safety against bearing capacity failure is calculated using:

$$F_s = \frac{q_u}{q_w} \tag{10}$$

and F_s should be higher than 2.5 to 3.

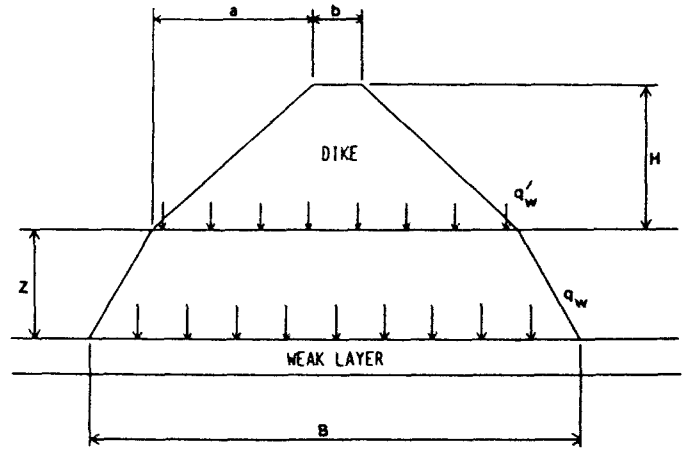

Figure 10
Bearing Capacity Failure

CONCLUSIONS

The RCRA regulations require that the surface impoundments must have dikes that are designed, constructed and maintained with sufficient structural integrity to prevent massive failures of the dikes. Thus, the engineers involved in certifying dikes need to use appropriate engineering procedures to determine site characteristics and dike integrity. Some guidance is given in this paper to accomplish these tasks undertaken by engineers involved in the preparation and review of permit applications for surface impoundments, waste piles and other land disposal units.

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APPENDIX I — NOTATION

The following symbols used in this paper:

U-U	Unconsolidated-Undrained
C-U	Consolidated-Undrained
D	Drained
c	Cohesion
ϕ	Angle of Internal Friction
S_u	Undrained Shear Strength
σ_c	Effective Consolidation Pressure
γ	Unit Weight
b	Dike Slope Angle
H	Dike Height
γ_w	Unit Weight of Shear
N	Blow Count
q_c	Cone Resistance
F_s	Factor of Safety

Use of X-Ray Radiographic Methods in the Study of Clay Liners

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ABSTRACT

X-ray radiography has been widely used in soil investigations to study the distribution of layers in soil cores and the effects of changing conditions (loading or impact) on soil structure. X-ray radiographic techniques also can be useful in studying clays or clay soils used in liners.

Laboratory investigations were undertaken to demonstrate that X-ray radiographic techniques could be used to detect density and soil structure changes that usually accompany variations in hydraulic conductivity of clay liners. An example of a real-time test of a simulated bentonite and sand liner attacked with acid lead nitrate and examples of radiographic examination of clay soil (non-calcareous smectite) samples that have been permeated by lead acetate or lead nitrate are presented. The changes in density and structure can be related to changes observed in hydraulic conductivity during permeation.

X-ray radiography easily can be applied to field samples of soil or clay liner materials to detect density and structural changes that occur as the liner and permeating fluid interact. X-ray techniques have applications in both understanding failure mechanisms and forecasting liner performance.

INTRODUCTION

X-ray radiographs of soil cores have been employed in geotechnical investigations for many years because radiographs provide a unique technique for detecting changes in the physical arrangement of soil particles without disturbing a soil core. In many soil cores, X-ray radiographs will detect subtle differences in soil density that might have escaped notice during the visual examination of core sections. The X-ray image displays variations in the absorption of X-ray photons in different parts of the object examined. Differences in absorption can be related to changes in sample thickness, density or chemical composition.[1] When the sample geometry is controlled by preparing cylinders or slices of cylinders for examinations, patterns observed in the radiographs can be reliably related to the differences in sample density and chemistry.

This study examined the use of X-ray radiographic techniques in identifying changes in the density and composition of samples of simulated clay or other soil liners that have been exposed to permeants that could be encountered in groundwater beneath an industrial or hazardous waste disposal site. Two approaches were used: (1) examining the real-time invasion of a bentonite-sand liner using a lead nitrate-nitric acid solution; and (2) examining the condition of soil samples after the samples have been permeated with simulated industrial waste solutions.

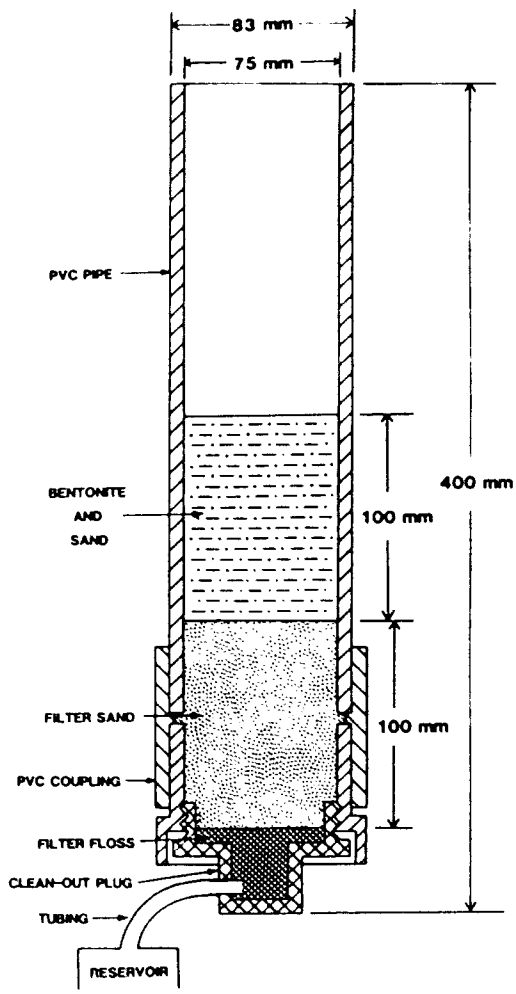

Figure 1
Cross-Section of the Test Cell Used in the Real-Time Liner Test

REAL-TIME STUDY OF LINER PERMEATION

A simulated waste pond liner was prepared by mixing one part of a commercially available bentonite (Aquagel from Baroid Petroleum Services of N.L. Industries, Houston, Texas) with four parts by volume of coarse filter sand. The mixture follows typical procedures for producing a bentonite liner.[2] The sand and

bentonite were mixed in a dry condition and water was gradually added with continued mixing to assure that the bentonite was completely hydrated. The wet mixture was permitted to settle for 24 hours, and excess water was decanted. A test cell was prepared from a 400-mm length of 75-mm ID schedule 40 PVC pipe (Fig. 1).

The bottom of the test cell was fitted with a plastic plug and a hole was drilled through the plug so that a drainage line could be attached. The bottom of the test cell was packed with Dacron filter floss, and a 100-mm thick layer of coarse filter sand was poured into the test cell. The bentonite and sand mixture was poured in on top of the filter sand, and the test cell was gently shaken to assure that the bentonite and sand layer settled and no air bubbles formed in the simulated liner. Clean water was placed on top of the bentonite and sand layer to verify that the simulated liner would not leak. To initiate the testing, the clean water was decanted, and a simulated waste formed by saturating a 10% nitric acid solution with reagent-grade crystalline lead nitrate was added above the bentonite and sand layer. The saturated acidic lead nitrate solution was approximately 140 mm deep over the simulated liner. This depth of waste is less than the 300-mm depth permitted under disposal guidelines.[3]

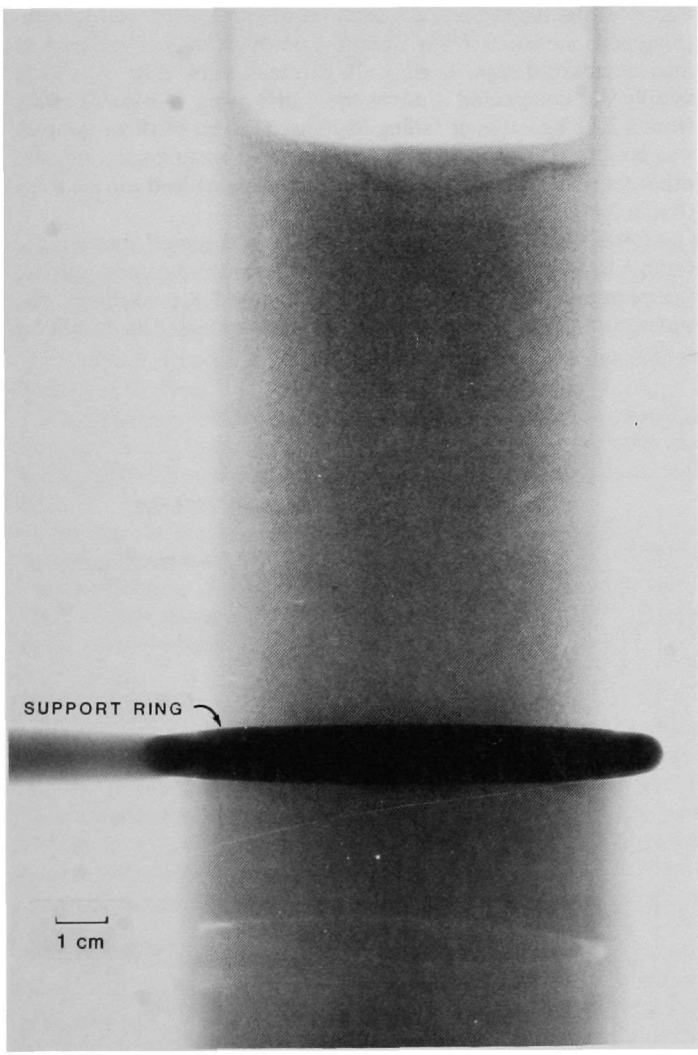

Figure 2
Print of Radiograph of Simulated Liner Before Application of Acidic Lead Nitrate Solution

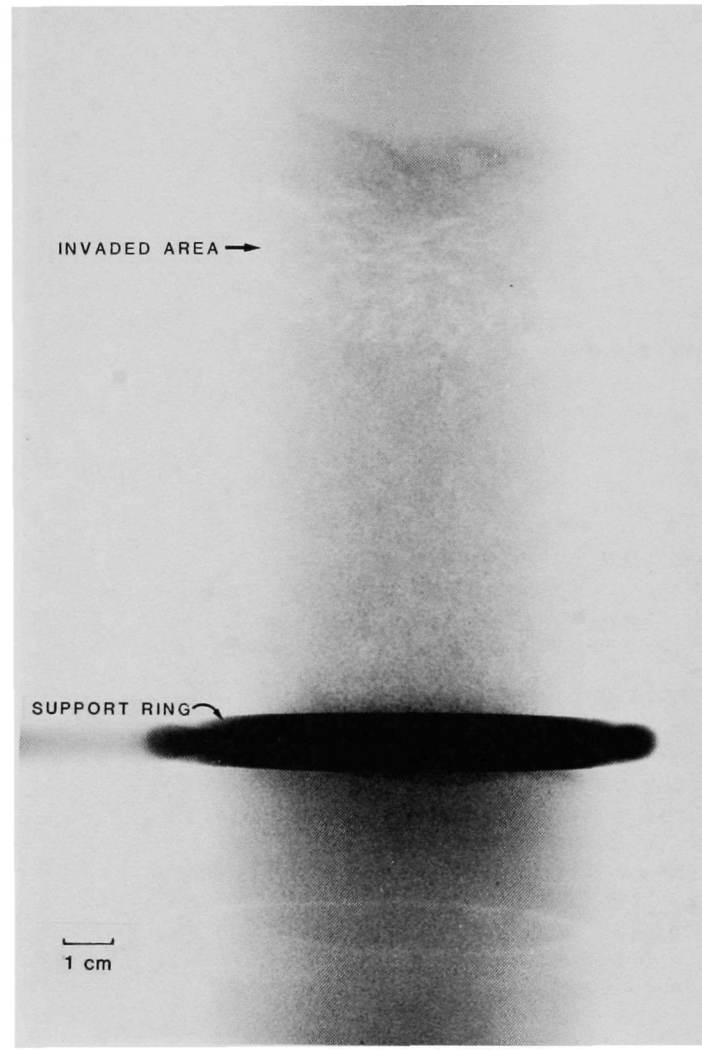

Figure 3
Print of Radiograph of Simulated Liner One Day after Application of Acidic Lead Nitrate Solution

X-ray radiographs were made of the test cell at one to five day intervals using a Norelco MG 3000 X-ray system equipped with a tungsten target tube. Kodak Industrial M film was used with a 1 to 2 min exposure. The X-ray unit was operated at 290 kV with 11 mA current.

Figure 2 shows the liner prior to testing. Breakthrough of the simulated waste was noted after 16 days. Figures 3 and 4 show the progressive failure of the liner after a one-day and after a 25-day exposure to the simulated waste. When the test cell was opened, the presence of voids in the simulated liner easily could be observed (Fig. 5). The X-ray radiographs had detected shrinkage cracks forming in the simulated liner and had accurately indicated the mode of failure in the simulated liner. Lead nitrate, a radio-opaque solution, was used initially in the tests to assure that any invasion of the liner could be observed. The formation of the voids in the clay reduced the usefulness of the lead solution because the lead salts lowered the contrast between the fluid-filled voids and the surrounding soil. Where flocculation and void formation are the expected modes of failure, there is no benefit in using radio-opaque permeants.

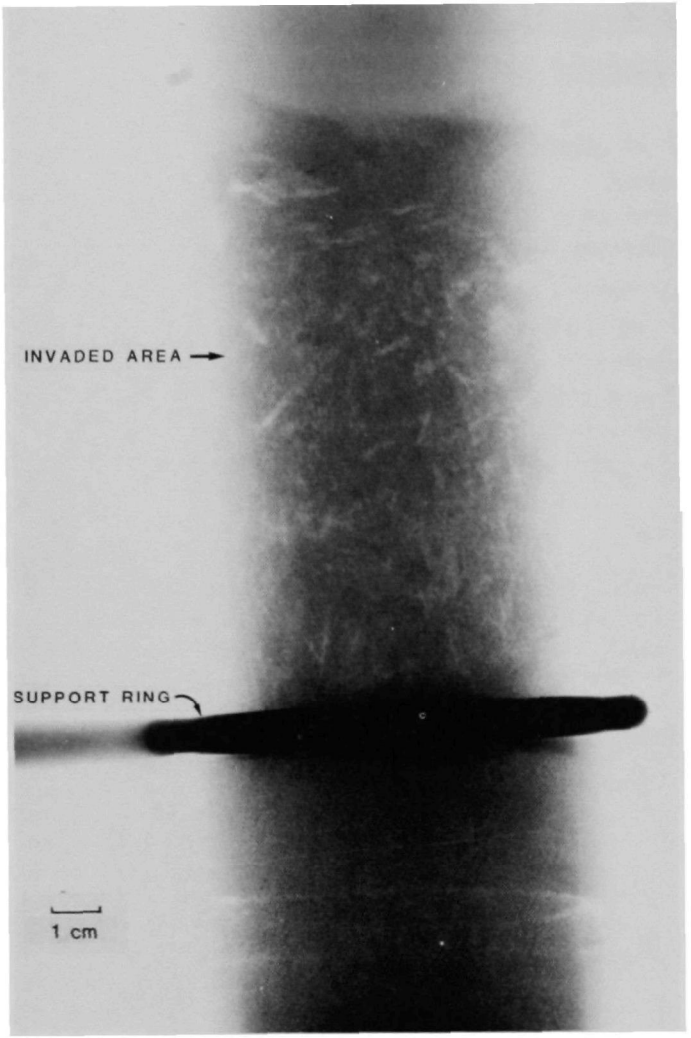

Figure 4
Print of Radiograph of Simulated Liner 25 Days after Application of Acidic Lead Nitrate

X-RAY RADIOGRAPHIC STUDY OF PERMEAMETER SAMPLES

The evaluation of the interaction of soil liners and simulated or actual industrial wastes generally has been performed by forcing samples of selected permeants (wastes) through packed soil columns in a fixed wall or flexible wall permeameter.[4] Interactions are evaluated by determining if the permeability of the packed soil is changed by the permeant. The type of interaction that has occurred between the soil and the permeant cannot be determined without examining the soil. For example, the hydraulic conductivity of the liner may decrease, but the reason for the decrease (for example, swelling of the soil or the formation of precipitates) cannot be determined without measuring the change in sample volume (for swelling) or looking for the formation of new compounds in the clay (for precipitation). X-ray radiographs can detect both volume changes and increased liner density due to the formation of precipitates. More than 60 soil samples from permeameter tests were examined to evaluate the ability of radiographic data to assist in the interpretation of permeability changes.[5] The major effects observed have included the breakdown of the clay structure (causing an increase in sample permeability) and the formation of precipitates (with a decrease in permeability).

Figure 5
Photo of Bentonite and Sand Mixture after Permeation with Acidic Lead Nitrate Solution

Samples of permeated soils were prepared using techniques proposed for testing potential landfill liner materials.[4] In the examples discussed here, six samples of the Lufkin soil (a non-calcareous smectite) from Brazos County, Texas, were packed into standard-design fixed wall permeameters (Fig. 6). Each sample was compacted in three equal lifts using 25 blows per lift from a 2.41-kg hammer falling 300 mm. One set of three samples was permeated with a 60% (by weight) lead acetate solution; the other set was permeated with a 50% (by weight) lead nitrate solution in 0.1% HNO_3.

After a sufficient volume of permeant had passed through the sample to establish a trend in changes in hydraulic conductivity, the permeameters were opened and checked for swelling. The samples permeated with lead acetate had increased in height by

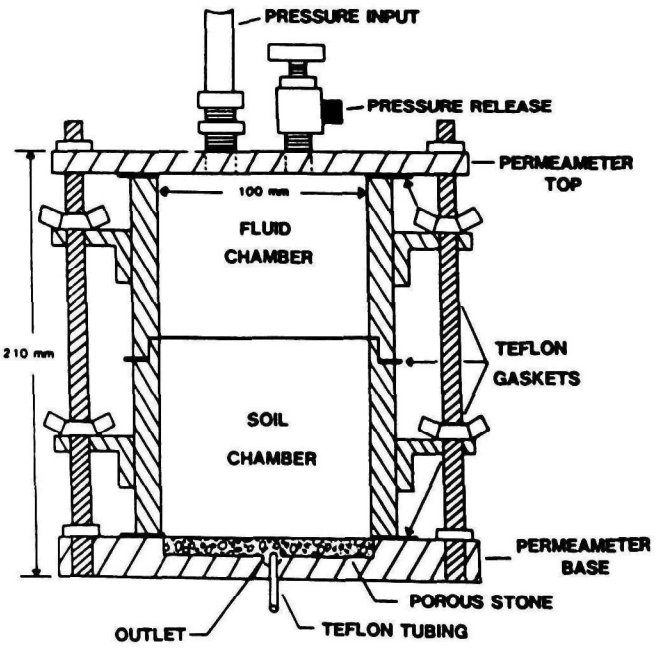

Figure 6
Cross-Section of Permeameter Used in the Study of Soil-Waste Interaction

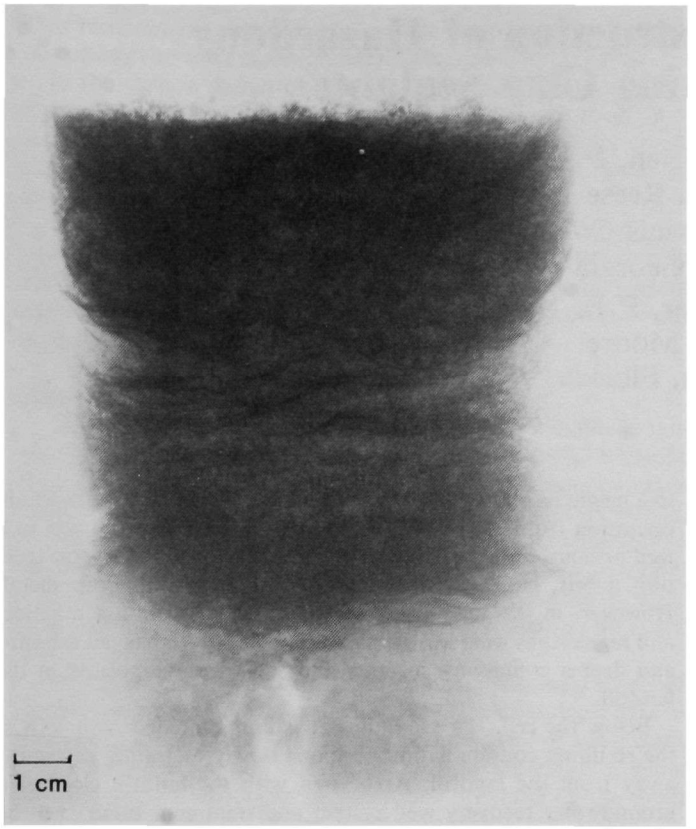

Figure 7
Print of Radiograph of Non-Calcareous Smectite Soil Permeated with Lead Acetate Solution

maximum of 2.7%. Maximum swelling in the samples permeated with lead nitrate was 1.6%. The samples were extruded and wrapped in foil. X-ray radiographs were prepared using a Norelco MG 300 Industrial X-ray System. The unit was operated at 290 kV at 10-12 mA. Exposure times varied from 1 to 3 min using Kodak Industrial M film.

Permeameter testing established that the lead acetate caused a decrease in hydraulic conductivity by a minimum of 50%. X-ray radiographs showed lead compounds were precipitating in the soil (Fig. 7).

The lead nitrate solution caused an increase in hydraulic conductivity by a minimum of over 100%. The X-ray radiographs showed irregular connecting voids suggesting the clay had developed a flocculated or blocky structure similar to that observed in the real-time failure study (Fig. 8).

CONCLUSIONS

X-ray radiographic techniques, previously applied to the study of soils, can be employed usefully in the investigation of the interaction of wastes and clay (or clay soil) liners. Using suitable test cells, real-time effects of waste (or simulated wastes) on sections of liner can be observed. Soil samples that have been permeated by simulated wastes can be X-rayed to examine the soils for density or structure changes that indicate occurring liner-waste interaction.

Field techniques for sampling soils to obtain undisturbed samples are available, and it should be possible to use X-ray radiographic methods along with standard soil description techniques to examine the condition of liners at landfills or waste storage areas. X-ray examination of soil cores is completely non-destructive, and altered sections observed in the X-ray radiographs can be documented by sampling and examining anomalous soil intervals.

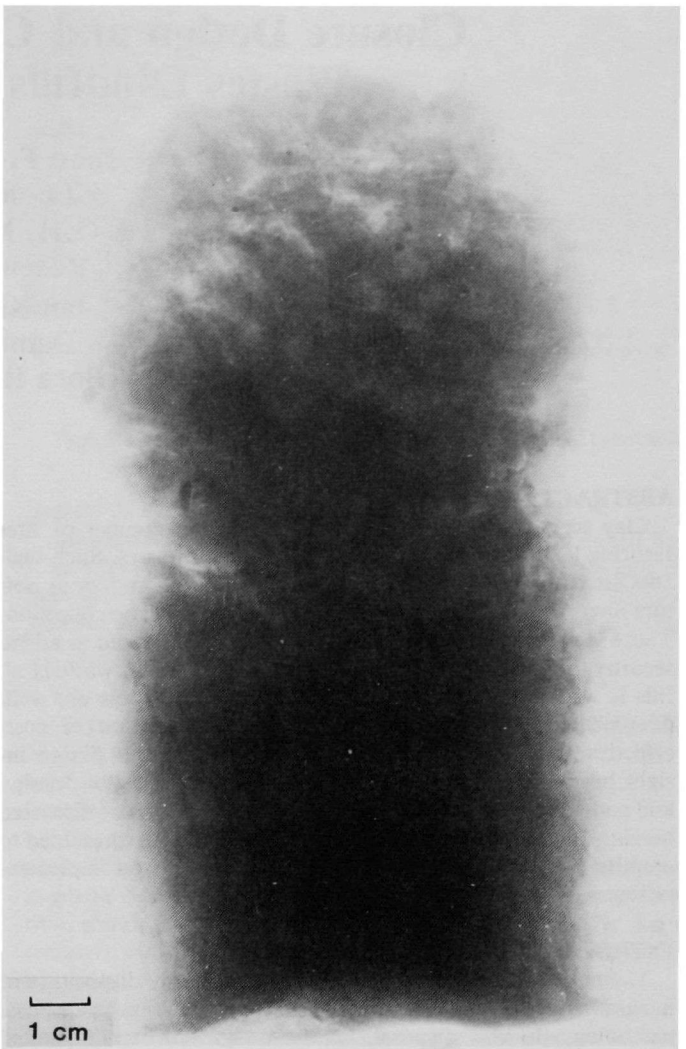

Figure 8
Print of Radiograph of Non-Calcareous Smectite Soil Permeated with Lead Nitrate Solution

ACKNOWLEDGEMENTS

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Independent Laboratory Initiated Research Program, Project No. 4A161102A91D Task Area 02 Work Unit 154, of the United States Army Corps of Engineers by the USAE Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish this information.

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Closure Design and Construction of Hazardous Wastes Landfills Using Clay Sealants

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ABSTRACT

Clay sealants are employed at an increasing number of sites securing land disposal of hazardous industrial wastes. Such sealants are employed as topliners to limit infiltration and/or as bottom liners to limit exfiltration and provide for leachate collection. These sealants are employed both as primary liners and as added security to synthetic liners. Liner design for hazardous waste landfills is well-regulated and quantitative analytical tools are well-documented. However, the practical implementation of cost-effective, buildable and reliable clay liners requires design insight beyond the obvious. Key elements in the selection, design and construction of landfill liners using clay sealants are discussed herein. The case histories of two landfill closures are presented to amplify the impact of the designers' assumptions on implementation.

INTRODUCTION

The national concern for environmentally secure disposition of hazardous wastes has led to increased sophistication in disposal technology. In land disposal, landfill design has been expedited not only by expansive regulatory requirements, but also by analytical modeling which allows cost- and time-effective evaluation of design alternatives.

Ideally, landfills securing hazardous materials are designed prior to disposal of the materials. Such planning includes design to limit the development of leachate and preclude exfiltration of leachate to the groundwater. However, as a result of years of unregulated and unenforced disposal, thousands of small to large "out back" sites at industrial facilities exist across the nation. It is the closure of these existing facilities which is the subject of this paper. These existing facilities include several distinguishing characteristics which impact closure design and construction:

- The waste material often is poorly defined
- Stabilized or unstabilized, wastes are left in-place and closure includes emplacement of a top liner only
- Construction of the design groundform often includes substantial regrading of unknown materials, placing a premium on planning equipment, selection and safety.

Two case histories will amplify this discussion.

- "Site A, Southern Florida": closure of a hazardous waste landfill using an imported bentonitic clay as a topliner
- "Site B, South Carolina": closure of a solvent contaminated landfill using locally available clays

Site A, South Florida

The landfill at Site A is located within an industrial facility in South Florida. It consists of one 4-acre cell that was constructed to a height of about 35 ft above existing grade. The landfill was in operation from 1958 until the middle of 1984. The cell was utilized primarily for the disposal of paper cartons, boxes, construction debris, cafeteria waste, yard trimmings and scrap metal. However, in the early years of filling when operating practices and regulations were less stringent than today, unbagged asbestos and drums containing solvents and fuels were deposited in the landfill.

Below the cell, the groundwater is contaminated with VOCs; the resulting contamination plume is slowly migrating eastward, away from the landfill. Associated with the landfill closure, a groundwater recovery well system and treatment plant will be constructed around the perimeter of the landfill.

The landfill is bounded closely on three sides by water. Uncontrolled filling over the years left a very irregular groundform with slopes as steep as 1:1.

Site B, South Carolina

Site B is located within an industrial facility in South Carolina. Over at least 10 years of operation, the site was used as a dump for solvents and drums. At the time of closure, the drums had been removed and closure involved capping solvent contaminated soils on the 5-acre site. The contaminated soils were encountered largely in depressions in the land surface on this site.

MODELING LANDFILL PERFORMANCE

Closure design of industrial and hazardous waste landfills usually involves the following generic evaluations:

- Determine the waste composition and characteristics at the closure sites
- Determine regulatory and design dictated materials and groundform requirements
- Determine liner materials alternatives based on compatibility with the waste, availability, constructability and performance
- Complete analytical evaluations to determine optimum landfill design based on cost and performance

Regulatory

The regulatory requirements for design of hazardous waste landfills are well-documented by the U.S. EPA under RCRA, published July 26, 1982. The Interim Final Rule on "Hazardous Waste Management System: Permitting Requirements for Land Disposal Facilities" became effective Jan. 26, 1983.[1] These federal criteria do not dictate either liner parameter, but do include the criteria for bottom liners for new (not existing) landfills.

> ...The liner must be constructed of materials that prevent wastes from passing into the liner during the active life of the facility.[2]

This requirement virtually requires the use of geomembranes in lieu of any clay liner as the primary sealant of a new landfill.

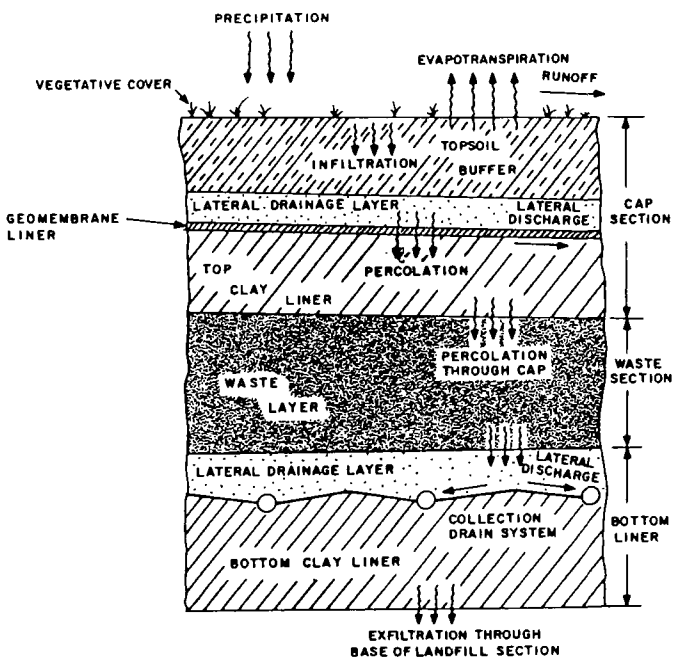
In the closure design of existing facilities, closure requires a cap to limit infiltration as well as groundwater monitoring. In the usual case, closure of an existing hazardous site allows the designer some latitude in the selection of a landfill cap, either employing geomembranes or clay liners.

The regulatory environment of closure design requires consideration. To this end, it is imperative the owner and engineer develop communication with the appropriate regulatory agency early in the design process to assure compatibility of the design with the regulatory expectations.

Analytical

The hydrologic processes within landfills were originally modeled using water balance techniques developed by Thornwaite.[3] The U.S. EPA developed the first widely used landfill model, Hydrologic Simulation on Solid Waste Disposal Sites (HSSWDS), in 1980. Since that time, the U.S. EPA has developed Hydrologic Evaluation of Landfill Potential (HELP), the most sophisticated analytical model now available for landfill systems. HELP was developed specifically for hazardous waste landfill evaluations as required by RCRA.[4]

HELP provides a quasi-two-dimensional hydrologic model of a landfill section, applying section geometry, climatologic data and material parameters to account for the movement of water across, into, through and out of landfills. Figure 1 presents a generic landfill section indicating the solutions provided by the model. The model allows the use of geomembranes in the section, both enhancing lateral drainage and limiting percolation. Despite the claims of some suppliers, geomembranes (synthetic liners) should not be considered impervious. Hydrologic modeling of a landfill performance may be completed using any of the above techniques: Thornwaite, HSSWDS or HELP. Of these models, HELP certainly represents the most sophisticated modeling alternative. Regardless of the approach used, some quantitative evaluation of landfill performance should be undertaken.



(after Schroeder, et al)

Figure 1
Modeling a Landfill Section Using HELP

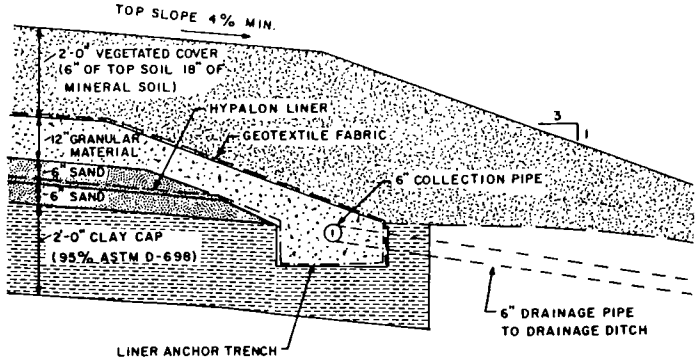


Figure 2
Typical Landfill Cap Employing Clay, Geomembrane and Geotextile

Sealant Alternatives

Clay sealants may be used as, or as a part of, a landfill liner. Figure 2 shows the implementation of a geomembrane and clay liner as a cap following stabilization of a sludge pond. Whatever the case, the designer will have two alternatives in clay selection:

- Naturally occurring and locally available clays
- Locally available soils improved by admixtures

Clays are chosen as sealants for their low degree of perviousness. In the design of topliners, a clay barrier with a coefficient of permeability of 10^{-7} cm/sec or less normally will be required to limit infiltration.

Many naturally occurring clays can readily achieve this low permeability. However, the designer should not presume that any available clay may be placed to this permeability. Design assumptions should be correlated with careful laboratory testing. Representative samples of the available clay should be compacted in laboratory molds and tested to determine permeability.

In most topliners used in the closure of existing hazardous waste sites, the permeant will be rainwater. However, if this is not the case, a permeant representative of that which will infiltrate the liner should be used to test the compatibility of the permeant with the clay minerology.

Permeability of clays will vary with relative compaction. The most commonly used compaction standard is the standard Proctor, ASTM D-698. Laboratory molds compacted to varying degrees of relative compaction and thereafter tested to determine permeability generally will show substantial variation. Clays compacted to 95% of the maximum dry density achieved in the standard Proctor test may show an order of magnitude decrease in permeability over a sample of the same soil compacted to 90% of standard Proctor. Similarly, a clay compacted from wet material of the optimum moisture content generally will have a lower permeability than the same soil at the same relative compaction, but compacted from dry material. Thorough testing to determine the mechanical properties of clays considered for use as liners is important not only to determine the suitability of a material, but also to determine the range of performance to be expected from field variations in installation.

In many areas, the naturally occurring soils will not provide the low permeability required for liner design. In this event, soil admixes may be used to lower permeability. Cement, as well as industrial wastes such as fly ash and kiln dust, may be added to soils to lower permeability. However, the brittle behavior makes these materials undesirable to seal structures as prone to irregular settlement as landfills.

The most common soil admix is sodium bentonite. Not commonly encountered in nature, sodium bentonite is mined largely in the North Central United States. As a soil admixture, sodium

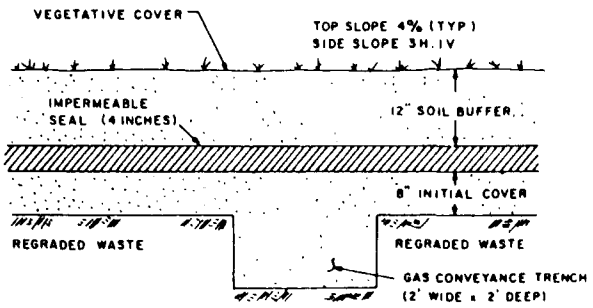


Figure 3
Typical Section, Florida Site, Including Gas Conveyance

bentonite is attractive for its expansive characteristics. The addition of 5-15% (by weight) sodium bentonite to soils will lead to a coefficient of permeability of 10^{-7} cm/sec or less. As with natural clays, the selection of sodium bentonite as a soil admix should include careful testing of representative materials.

Figure 3 presents a section of the top liner used at Site A, South Florida. Clayey soils are almost totally absent in South Florida. Economic evaluations of geomembranes and admix improved local soils led to the selection of the sodium bentonite and local sand section. Laboratory testing indicated that the sandy local soils mixed with 13% by weight sodium bentonite and compacted to 95% of standard Proctor (ASTM D-698) would achieve a permeability of 10^{-7} cm/sec or less.

Figure 4 presents the topliner section used at Site B, South Carolina. At this site, the Owner's property included an area of thick clayey residual soil about 0.5 miles from the landfill. Laboratory testing demonstrated a permeability of 10^{-7} cm/sec for these clays compacted to 95% of standard Proctor.

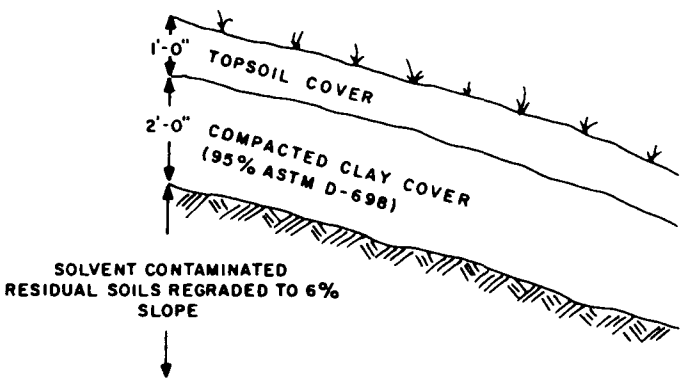


Figure 4
Typical Section, South Carolina Site B

Buffer and Cover Protection

Protection of clay liners from environmental damages is an important design consideration. Clay liners should, at a minimum, include a top soil buffer to protect the material from erosion. The buffer also should be of sufficient thickness to preclude breaking by roots and burrowing animals. A vegetated soil cover of about 1 ft is sufficient in most cases to adequately protect the clay.

Specifications and Quality Control

Certainly the best closure planning and design is impotent without carefully developed specifications and good field quality control.

The designer should be responsible for the technical specifications. In the writers' experience, many landfill closure specifications include exacting criteria for material type, degree of compaction and permeability. Such tightly constructed specifications open the owner to substantial costs in change orders.

If the material to be used has been pre-determined by laboratory testing, specifications for liner construction should be limited to degree of compaction and material type. Additionally, to assure good field control, a minimum compactive effort and soil moisture may be specified (for example, "three passes of a kneading-type compactor weighing a minimum of 8 tons, compacting soils within 3% of their optimum moisture content").

If the specific clay material has not been predetermined, specifications should be limited to general material type and permeability requirements.

Installation of clay liners should be under the full-time surveillance of a representative of the designer's office. At a minimum, this surveillance should be supplemented by testing for soil parameters detailed in the drawings and specifications to include material type, thickness, degree of compaction, moisture and permeability.

State regulated closure criteria for Site A in South Florida (Fig. 3) dictated permeability requirements (10^{-7} cm/sec), but left materials selection to the contractor. Quality control testing for the liner installation included thickness, moisture, relative compaction and laboratory permeability of field samples. Additionally, the contractor was required to submit his sodium bentonite-local sand mix design, which was monitored in the field. The average permeability determined from field samples was 10^{-8} cm/sec.

At Site B, South Carolina, liner construction specifications detailed the borrow source and compaction requirements only. Pretesting of these soils had well-established the density and permeability relationships of these soils. A full-time representative from the designer's office monitored compaction and liner thickness. Additionally, it was required that this 2-ft thick liner be placed and compacted in increments no greater than 6 in.

CONSTRUCTION CONCERNS IN CLOSURE

Closure construction of hazardous waste landfills requires considerable skill, equipment and experience. Such work should be undertaken only by a contractor experienced in the field.

Construction planning for closure involves the following generic process:

- Equipment scoping, based on materials, earthwork and productivity requirements
- Project safety planning
- Decontamination planning
- Contingency planning

The contractor views the closure of a hazardous waste landfill differently than does the engineer. The good design engineer best serves his client, the owner, if designs and specifications consider the constructability questions the contractor faces.

Equipment Scoping

Both sites A and B present good examples of the constructor's response in equipment and approach to particular site requirements. Site A, in South Florida, was characterized by constrained work space and relatively steep side slopes. Site B, in South Carolina, required effective hauling of a large quantity of clay cover to the site.

The constrained (bounded closely on three sides by water) site conditions at Site A, South Florida, required the landfill groundform to be constructed with a side slope as steep as practical. The

designer selected 3 horizontal to 1 vertical (3:1). Construction of the topliner section required the importation of about 16,000 yd^3 of soil. Permit requirements required construction to be complete in an 8-week period. The physical constraints not only dictated the landfill groundform, but also limited the area available for materials staging.

The steep side slopes and moderate materials requirements complicated earthwork at Site A. All soils were placed using 12-yd^3 scrapers pushed by a dozer up the sides of the landfill and depositing soils as they glided down-slope. Materials deliveries were carefully coordinated with placement productivity because of the limited staging area.

The sodium bentonite-local sand liner was mixed on-site using a pugmill to effect thorough mixing. About half-way through the clay liner construction, mechanical problems forced abandonment of this mixing technique. Thereafter, the clay and sand were mixed using bulldozers to place the materials together in a controlled area. The scrappers then picked up and placed the mix.

The 4-in. thick clay liner was difficult to place on the steep side slopes. Measured thickness of the liner varied from 3.5 to 7 in., averaging about 5 in.

A self-propelled, rubber tired vibratory compactor was used to compact the sand-clay topliner at Site A. Again, because of the steep side slopes, the compactor was pushed up-slope, then glided and compacted moving down-slope. The thin liner section limited equipment alternatives. The contractor, concerned that a dozer-towed vibratory compactor would damage the 4-in. liner with its tread, elected to use the rubber tired compactor. Adequate compaction was achieved in a single pass, which alleviated the awkwardness of compaction,

Experience at Site A indicated that 3:1 slopes are about the steepest which may be practically constructed, limiting equipment and earthwork control. Indeed, flatter slopes are more desirable from a construction standpoint.

At Site B, South Carolina, emplacement of the clay liner required moving about 30,000 yd^3 of clay from the borrow source 1 mile (by road) from the site. To optimize placement, a high productivity earthwork program was established, moving 3,000 yd^3 per day. Self-loading 12-yd^3 scrapers were used to pick up, transfer and place the clay. Kneading compactors ("sheepsfoot" compactors) towed behind bulldozers were used to compact the clay to specifications.

Project Safety Planning

Safety should be given the highest priority during any work with hazardous wastes. Personnel involved in cleanups at both Sites A and B were participants in comprehensive medical monitoring programs—both that on-going by the contractor and project specific medical monitoring.

No closure of a hazardous waste landfill should be completed without a Site Safety Plan (SSP) developed by a Certified Industrial Hygienist (CIH). This document not only advises personnel of hazards and potential hazards caused by exposure to the landfill materials, but also establishes site safety protocol. At a minimum, this protocol includes definitions of levels of protection required for different areas of the site as well as site monitoring procedures and emergency equipment and procedures.

Both Sites A and B required personnel to wear full face air-purifying respirators and skin protection afforded by disposal suits and gloves. Working in this wear (particularly in summer) is quite fatiguing and should be associated with increased breaks and liquid intake. Project planning should consider the associated loss in productivity.

Both Sites A and B were attended by a full-time health and safety officer. A portable decontamination trailer, including showers, and contingency decontamination equipment was utilized on each site. Daily "tailgate" safety sessions were conducted throughout the projects to address safety concerns for each day's planned work.

Equipment and Personnel Decontamination

Equipment and personnel decontamination is required following any exposure to hazardous materials. The best decontamination program is, of course, one which minimizes the contact of equipment and personnel with the hazardous wastes. However, as this exposure is not always avoidable, equipment and personnel decontamination should be provided for.

Equipment decontamination procedures should be such that no decontamination is trafficked off-site. Equipment decontamination normally is undertaken on a specially constructed pad designed to collect and store any wash water.

A convenient personnel decontamination area should be provided. At this station, workers should have easy access to all safety equipment required for work on the site. It is here that workers remove street clothes and put on protective clothing before entering the site.

CONCLUSIONS

Landfill design has progressed to the point where a number of liner alternatives may be evaluated quickly and cost effectively. While quantitative methods to model landfill performance are available, practical implementation of cost-effective and buildable liners requires design insight beyond the obvious. Closure of existing hazardous waste facilities should be completed by contractors experienced in the field. Experience not only in the work but also in the associated personnel protection and decontamination concerns, should be closure imperatives.

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Soil Liners for Hazardous Waste Disposal Facilities

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ABSTRACT

The Hazardous and Solid Waste Amendments of 1984 contained a requirement for double liners containing both a flexible membrane liner and compacted soil liner. The soil component can be used either as the sole secondary liner or as the lower component in a composite secondary liner. In either case, soil liners must be at least 3 ft thick with a demonstrated field permeability of less than or equal to 1 x 10^{-7} cm/sec. Factors affecting field permeability of soil liners include soil characteristics and liner construction methodology. Some soil characteristics which can yield low permeability liners (e.g., high plasticity) also can give rise to the potential for shrinkage and permeability increases.

One of the most important considerations in the selection of methods for soil liner construction is the destruction of clod structure during compaction. After the selection of a specific construction methodology, the best way to achieve design specifications is by implementating a sound construction quality assurance program.

INTRODUCTION

Soil liners are a required component of double liner systems for hazardous waste disposal facilities (Fig. 1). This requirement was established in the Hazardous and Solid Waste Amendments of 1984 and further defined in the Minimum Technology Guidance (MTG) on Double Liner Systems.[1] In this paper, the author discusses ways to incorporate soil liners into these liner systems and factors most greatly affecting the field permeability of these liners.

All double liner systems are required to have primary flexible membrane liners (FML). The MTG provides two options for the design of secondary liner systems, both of which include soil liners. Following is a discussion of the soil liner components to these liner systems.

Soil Liner Component to Secondary Composite Liners

One of the designs suggested in the MTG incorporates a secondary composite liner composed of an upper FML and a lower compacted soil liner (Fig. 1A). In the configuration suggested in the MTG, the FML and soil liner are sandwiched together to minimize the potential for lateral flow between the liners. It has been suggested that this configuration would limit leakage through defects in the FML to the rate at which leachate could flow into the area of soil liner directly under the FML defect. If this theory is correct, composite liners should be able to reduce leakage from disposal facilities to a much greater extent than either an FML or soil liner alone.

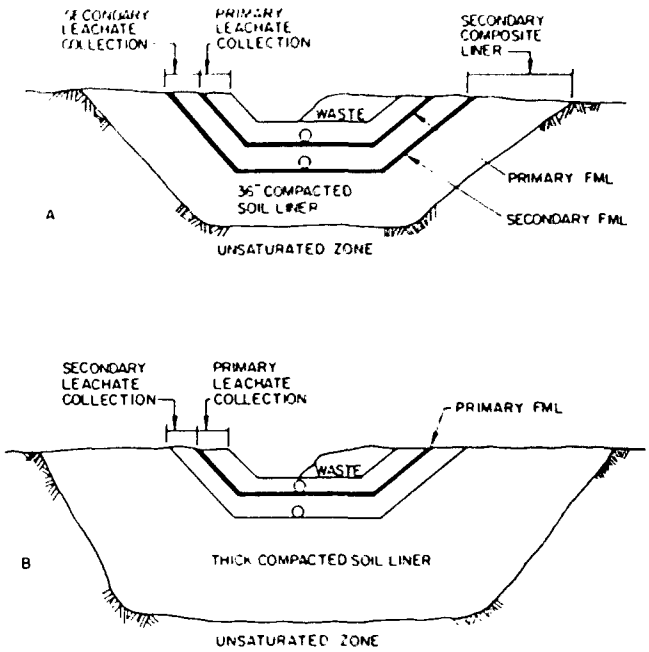

Figure 1
Double Liners for Hazardous Waste Landfills Must Have a Primary FML and Either an (A) Composite, or (B) Thick Compacted Soil Secondary Liner

Requirements for the soil component to secondary composite liners are given in Table 1. The traditional requirement for a permeability of less than or equal to 1 x 10^{-7} cm/sec must be verified in the field.[1] Laboratory permeability tests are no longer considered adequate to verify actual field performance.

Secondary Soil Liners

The other secondary liner design given in the MTG is that of a thick compacted soil liner (Fig. 1B). The liner must be thick enough and have a sufficiently low permeability to prevent the release of waste constituents prior to the end of the post-closure period or greater than 30 years.[1] There is a considerable amount of uncertainty in the regulatory community as to whether such a liner is feasible. A currently available model for evaluating the time to breakthrough of moisture through unsaturated soil liners indicates that such a liner would need to be very thick.[2] For instance, the model indicates that a 5-ft thick soil liner with a

Table 1
Requirements for the Soil Component to Secondary Composite Liners

- Total compacted thickness of ≥ 36 in.
- Chemically resistant to the waste and leachate
- Permeability of ≤ 1×10^{-7} cm/sec
- Permeability verified in field tests
- Compacted lifts of ≤ 6 in.
- Scarification between lifts
- Uniform moisture distribution
- Protection from desiccation/freezing
- Protection from damage due to traffic
- Adequate thickness to prevent failure from hydraulic pressures
- Minimization of clod size
- Removal of rocks, roots and rubbish
- No structural nonuniformities which might increase the field permeability
- A comprehensive construction quality assurance plan

permeability of approximately 4.7×1.0^{-9} cm/sec and only a 1-ft head of leachate would allow initial breakthrough in only 11 years (Fig. 2).

The U.S. EPA has several reservations concerning the use of a secondary soil liner, including the following:[1]

- There is no standard method for measuring breakthrough in soil liners
- It is questionable as to whether a soil liner of sufficient thickness would be economically feasible
- There is a great deal of uncertainty concerning the feasibility of constructing soil liners with sufficiently low permeability to prevent constituent breakthrough during the operational life of the facility

While use of a secondary soil liner is not ruled out by the U.S. EPA, it may be very difficult to prove that a particular design can meet the no breakthrough requirement. Consequently, the course of least regulatory resistance and best economic feasibility would appear to be the composite secondary liner.

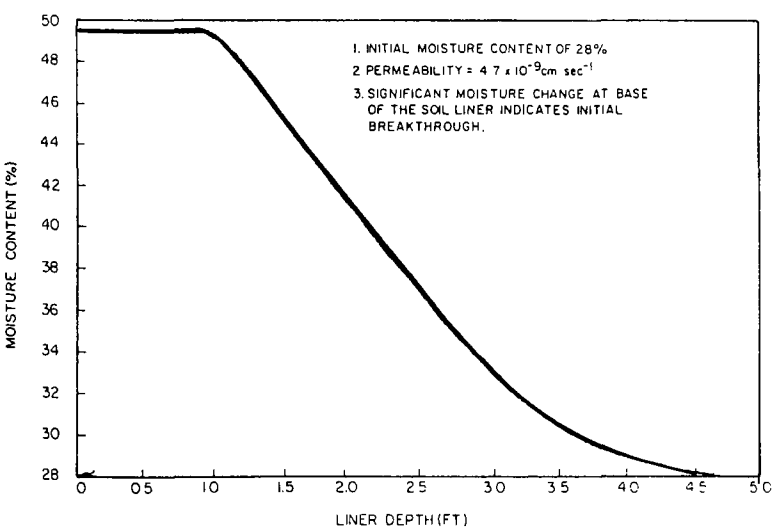

Figure 2
Moisture Content as a Function of Depth in a 5-Foot Thick Liner Beneath a Landfill After 11 Years of Exposure to a 1-Foot Head of Leachate (Modified from Reference 3)

FACTORS AFFECTING FIELD PERMEABILITY OF SOIL LINERS

While there are additional requirements in certain cases, all soil liners must be at least 3 ft thick and have a permeability of less than or equal to 1×10^{-7} cm/sec. The U.S. EPA believes that field permeability tests are needed to verify that the permeability requirement can be met using the soil material, equipment and compaction procedures proposed for use in the construction of the soil liner.[1]

Recent studies have indicated that laboratory tests tend to underestimate the actual permeability obtained in the field.[4-7] Several of these studies discuss cases where very low permeabilities were obtained in laboratory tests but much higher permeabilities were detected in the field. It has become increasingly apparent that a thorough understanding of factors that affect permeability is necessary to construct a soil liner which meets the field permeability requirement. Following is a discussion of several of these factors.

Soil Characteristics

Characteristics of a soil which affect permeability include clay content, plasticity, water content and density. Fine-grained and high plasticity soils can be compacted to obtain low permeability liners. However, high plasticity soils tend to be susceptible to large permeability increases in the field due to desiccation cracking. Highly plastic clay soils are widely used in the construction of soil liners for hazardous waste facilities along the Gulf Coast. During the hot, dry summer months, clay liners constructed from these soils can undergo significant desiccation in a matter of hours. In a few days, desiccation cracks can extend downward through much of a standard 3-ft thick soil liner. To prevent desiccation, a protective cover, such as an FML, should be placed immediately following the completion of a soil liner.

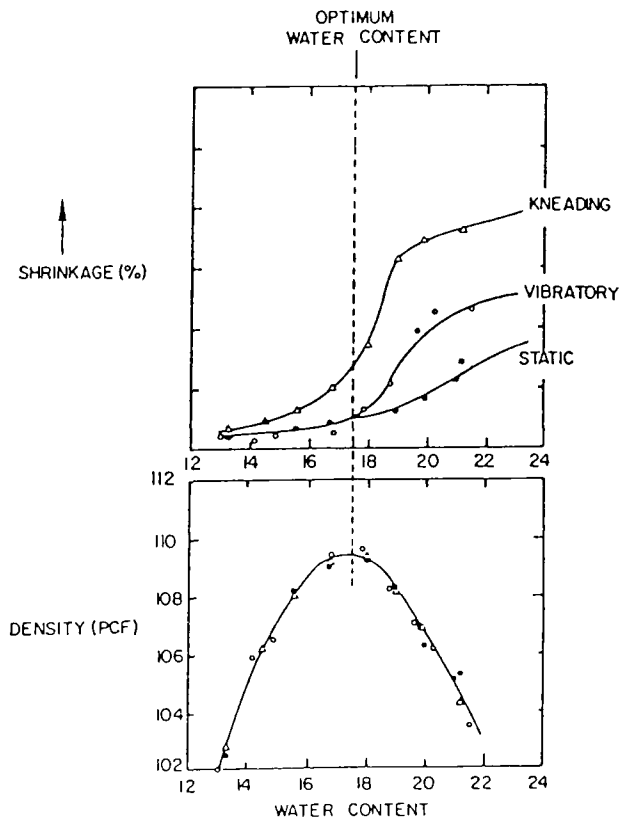

Figure 3
Shrinkage as a Function of Water Content and Type of Compaction (From Reference 9)

Low permeabilities can be obtained by compaction of soils at water contents a few percent above optimum.[8] However, soils compacted wet of optimum generally have a greater potential for shrinkage (Fig. 3). An increase in shrinkage potential may well coincide with an increased potential for cracking if a soil liner is allowed to desiccate.

Permeability generally decreases with increases in the density of a soil. There can, however, be orders of magnitude differences in the permeability of soil samples compacted to the same density.[8] This possibility is especially important to note due to the widespread reliance on density tests for construction quality control testing of soil liners. In addition to testing the density, water content, particle size distribution and plasticity of a soil liner, a construction quality control program should include laboratory and field permeability tests.

Liner Construction Methodology

A wide variety of equipment and procedures are used to construct soil liners.[10,11] Few studies have been conducted, however, to evaluate how these construction factors affect field permeability. Examples of these factors include precompaction processing of soil, characteristics of compaction and construction quality assurance.

Precompaction processing of soil includes such activities as the removal of off-specification materials, reduction in the size of clods and the adjustment of the moisture content of soil. Removal of off-specification materials is important because their presence can result in zones of high permeability due to either interference in the compaction process (e.g., rocks, gravel, indurated soil) or formation of channels through the liner (e.g., roots, trash, sand lenses). It is also important to minimize clod size because clods can both prevent the uniform distribution of moisture and result in the occurrence of large pores between clod remnants. One study found that increases in maximum clod size caused increases in the resulting permeability of a compacted soil.[6] The ultimate solution, however, is to use compaction equipment and procedures which destroy all clod structure in the soil liner.

The compaction equipment used will greatly affect the permeability of a soil liner. If, for instance, a smooth wheeled roller, tracked vehicle or rubber tired roller is used, there may not be sufficient shearing stress and remolding at depth in a lift to destroy clod structure. Even padfoot rollers with short feet may not completely remove clod remnants. Sheepsfoot rollers with feet at least as long as the loose lift thickness are the best units in widespread use. Such a compactor, if sufficiently ballasted, can effectively remove clod structure and the associated large interclod pores throughout the thickness of a lift.

Procedures for compaction which can reduce field permeability include the use of thinner lifts, more compactor passes and immediately covering the liner after compaction. Thinner lifts assure effective compaction throughout the lift thickness. When thin lifts are installed with sheepsfoot rollers, clod remnants are removed and the occurrence of high horizontal permeability zones between lifts can be minimized. More compactor passes (i.e., the application of a greater compactive effort) generally results in a lower permeability liner.[8] Finally, the immediate coverage of a soil liner after compaction can preserve the low permeability by preventing either the heaving and ice lense formation associated with freezing or the cracking associated with desiccation.

One of the most underrated factors affecting field permeability of soil liners is construction quality assurance (CQA). A properly conceived and implemented CQA program will ensure that a soil liner is constructed in a way that meets the design specifications (e.g., 3 ft thick and field permeability of less than or equal to 1×10^{-7} cm/sec). The U.S. EPA[11] has developed guidance which recommends that CQA programs be implemented in three phases

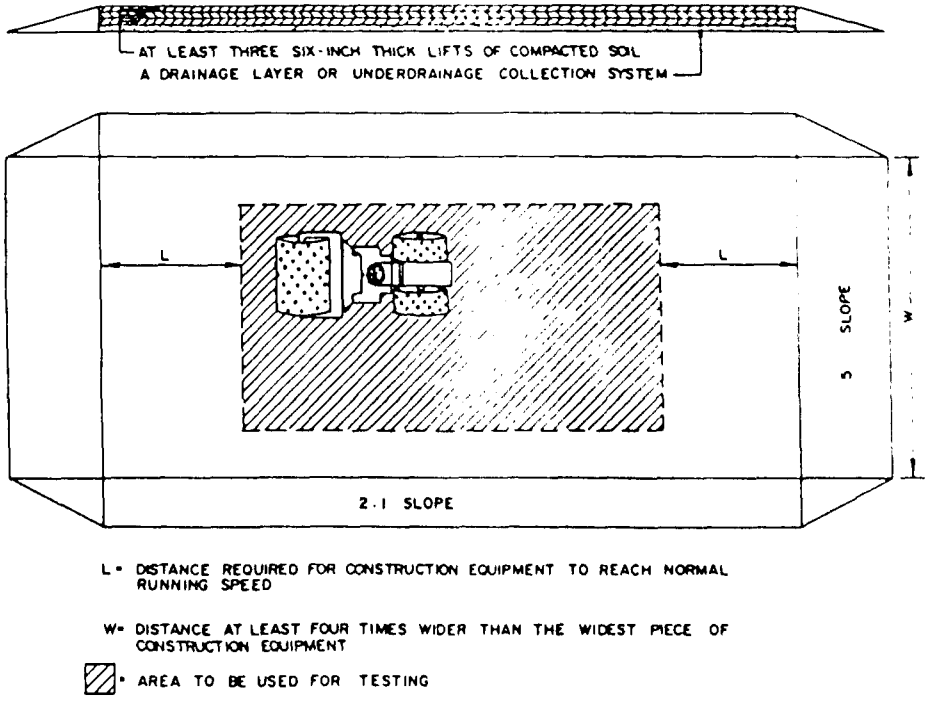

Figure 4
Schematic of a Test Fill
(From Reference 13)

(i.e., pre-construction, construction and post-construction). Pre-construction activities associated with soil liners include inspection of the soil and construction of a test fill (Fig. 4). The test fill should be designed to validate the materials, equipment and procedures planned for use in the construction of the soil liner. While a number of index property tests should be conducted on the test fill,[13] the most important of these is field permeability. An infiltrometer capable of measuring field permeabilities of less than 1×10^{-7} cm/sec has been described by Anderson, *et al.*[14]

After completion of the pre-construction phase of the CQA program for soil liner construction, there should be few remaining uncertainties as to how to achieve the design specifications. The construction phase CQA activities simply should be directed toward assuring that the soil liner is constructed with the materials, equipment and procedures validated in the pre-construction activities. The post-constructive CQA activities should include a final inspection of the soil liner followed by immediate placement of a cover sufficient to protect the soil liner from desiccation, freezing and other types of damage.

CONCLUSIONS

All double liner systems to hazardous waste disposal facilities must have a compacted low permeability soil component. The most important design specification for soil liners is the requirement for a demonstrated field permeability less than or equal to 1×10^{-7} cm/sec.

Factors impacting the field permeability of soil liners include characteristics of the soil and methods used in the construction of the liner. Soil characteristics which can result in a low permeability liner (e.g., water content above optimum, high clay content and high plasticity) may also yield a liner which has a high shrinkage potential. If such a soil liner is allowed to desiccate, shrinkage cracks may form, resulting in large permeability increases. Methods of construction which can result in a low permeability liner include removal of off-specification materials from the soil, reduction in clod size, minimization of lift thickness, use of sheepsfoot rollers with feet as long as the loose lift thickness and implementation of a properly conceived CQA program.

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Slurry Wall Economical in Dewatering of Sydney Mine Disposal Site

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ABSTRACT

The Hillsborough County, Florida, Department of Solid Waste used the Sydney Mine site for disposal of septage tank and grease trap wastes and waste oil products. When hazardous constituents were found in the ponds and groundwater, remedial action was begun to remove and incinerate the pond contents. Conventional dewatering techniques would have resulted in excessive incineration quantities and costs. A temporary slurry wall used for dewatering during site cleanup resulted in substantial cost savings.

INTRODUCTION

The Hillsborough County, Florida, Department of Solid Waste deposited septage tank and grease trap wastes and waste oil products in two shallow ponds excavated in tailing sands left from phosphate mining operations at Sydney Mine. The tailing sands, approximately 10 to 25 ft thick, are underlain by very soft plastic clay slimes, also a byproduct of mining operations. A perched groundwater table occurs in the tailing sands near the ground surface.

When hazardous constituents were found in the ponds and groundwater, a remedial action was begun to remove and incinerate the pond contents. If groundwater flowed into the ponds during removal of the pond contents, then excessive incineration quantities and costs would have resulted. Conventional dewatering using well points could have required the treatment of approximately 36 million gallons of groundwater at an estimated cost of $1.8 million, assuming treatment costs of approximately $0.05/gal.

This paper relates how a temporary slurry wall was used to facilitate dewatering during site cleanup, thus resulting in substantial cost savings. By installing a slurry wall to isolate the ponds, the groundwater could be lowered at a slower rate using fewer well points.

Traditionally, slurry walls have been used to facilitate dewatering of excavations. Since the early 1980s, they have been used for containment of hazardous wastes and contaminated groundwater and for decreasing recovery volumes for groundwater restoration. The slurry wall constructed at the Sydney Mine site combined these various applications for a cost-effective site cleanup. Unique site conditions made possible additional cost savings in wall construction and dewatering.

SITE HISTORY

The Sydney Mine Waste Disposal site is located east of Tampa in Hillsborough County, Florida (Fig. 1). The land was strip-mined for removal of phosphate ore during the 1930s and 1950s and then abandoned. Hillsborough County leased the 9.5-acre site in 1973 for disposal of grease trap waste, septic waste and waste oil; the county utilized the site for waste disposal activities until November 1981.

The primary disposal facilities on-site consisted of two surface impoundments, a 1.5-acre septage pond and a 0.6-acre oil pond. Each impoundment is about 4 to 6 ft deep. A review of initial site investigations[1,2,3] and additional intensive sampling[4] indicated the presence of toxic organics in the disposal ponds and in the perched groundwater beneath the ponds.

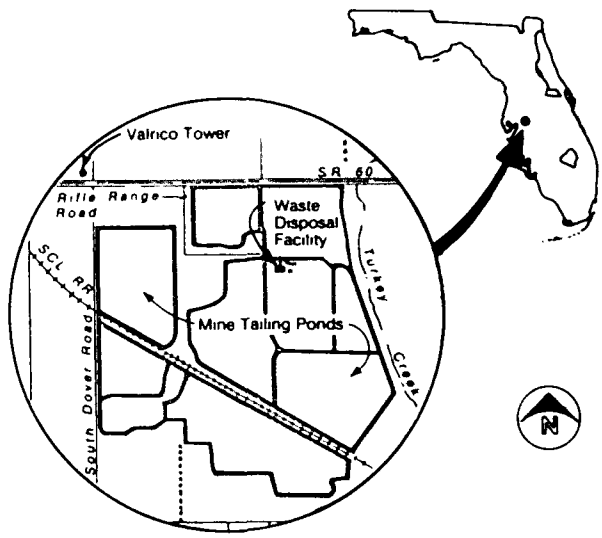

Figure 1
Sydney Mine Waste Disposal Site Location

Feasibility Study

Using data obtained during the site investigations, a feasibility study was conducted to identify and evaluate site closure alternatives.[5] This study addressed both cleanup of the waste ponds and restoration of the contaminated groundwater. The general approach was to select technologies for source removal or control that were technically feasible, environmentally sound and cost-effective. Following source removal or control, the selected groundwater restoration technologies would be implemented. Groundwater cleanup therefore would be undertaken only after the source of the contamination was removed. This approach would provide effective implementation of the remedial program as County funding became available.

Twenty-two alternatives were evaluated for the closure of the waste ponds, with three categories of alternatives recommended for further consideration by the County:

- *On-site Containment.* Waste materials would be left at the site, and features to impede off-site migration of contaminants from the source materials would be constructed. This solution would have involved construction of a permanent slurry containment wall all around the ponds and a clay or synthetic cap over the ponds.
- *Off-site Disposal.* All contaminated liquids and solids would be removed from the ponds and transported to an approved out-of-state facility for disposal. No licensed facilities for disposal of such wastes currently are located in Florida.
- *On-site Destruction.* All contaminated wastes would be removed from the ponds and incinerated on-site to destroy the organic contaminants.

County officials studies each option to determine which would be the most environmentally responsible and yet cost-effective. On-site containment was eliminated because the potential future migration of contaminants from the site remained an undesirable risk. Also, leaving contaminated material at the site would limit future use of the site.

Because either of the remaining options was acceptable, the County retained CH2M HILL as prime contractor to conduct a detailed comparison of off-site disposal and on-site destruction and to implement the site restoration. Proposals were solicited from potential subcontractors for surface cleanup and closure of the site. The responsible proposals showed that on-site destruction was less expensive than off-site disposal because of high costs associated with transporting the wastes out-of-state. The County therefore selected on-site destruction for implementation.

A mobile waste incinerator was found to be the least-cost alternative for on-site destruction of organic contaminants within the pond liquids, sludges and bottom sands. The mobile incinerator would be transported to the site, set up, operated and then removed when all the on-site waste materials had been incinerated. Environmental Services Company (ENSCO, Inc.) of Little Rock, Arkansas, in a joint venture with Tyger Construction Company of Spartanburg, South Carolina, was selected to remove and incinerate the wastes. ENSCO manufactured the modular incineration unit at its Pyrotech Systems, Inc. facility located in White Bluff, Tennessee.

SURFACE CLEANUP

The method of excavation of pond wastes and underlying contaminated soil was not detailed in the surface cleanup proposal. ENSCO-Tyger proposed to pump out impounded liquids for incineration, then excavate using bulldozers or backhoes to remove sludges and soils.

Upon closer examination of the cleanup proposal, the feasibility and cost of removing materials in the ponds became a source of concern. The groundwater table was at approximately the same level as the liquid level in the ponds. A thin layer of grease and oil covered the bottom of the ponds and provided an impediment to vertical seepage from the ponds. However, if the liquid levels in the ponds were to be lowered, this thin layer would not provide a barrier to groundwater flow in the reverse direction.

The volume of groundwater seepage into the ponds would depend on actual groundwater levels, rate of waste removal inside the ponds and the permeability and thickness of the tailing sands. An estimate of the groundwater flow suggested that more than 200,000 gal/day of groundwater might seep into the ponds during source removal. Without groundwater recovery or control concurrent with source removal, this would have resulted in costs of approximately $60,000/day to incinerate the groundwater. In reality, the incineration facility would not have been able to handle or treat that volume of flow; ultimately, the pond contents could not have been removed.

Dredging to remove solids and contaminated soils seemed to be a viable alternative since the majority of the contaminated wastes (having the highest BTU value) could have been excavated and incinerated without altering groundwater levels. The remaining impounded liquids would have been somewhat dilute and could have been treated using a separate groundwater recovery and treatment system; only a limited volume of liquid would be incinerated. However, the cleanup permit negotiated with the State of Florida stipulated that contaminated soils were to be excavated to remove all "visible contamination." Dredging below the water level in the impoundments would not permit visible inspection of the pond bottom following removal of the contaminated soils and solids. Furthermore, dredging raised the possibility that soils without visible contamination could become contaminated during excavation by coming into contact with pond liquids. Therefore, it would not have been feasible to demonstrate removal of the contaminated soil.

Installation of a dewatering scheme using a series of well points around the ponds to lower groundwater levels prior to waste excavation was an acceptable possibility. A groundwater treatment system would have had to be constructed to treat the groundwater from this dewatering system. Groundwater treatment using air stripping and carbon adsorption would have been substantially cheaper than incineration. At a treatment cost of approximately $0.05/gal, treatment of the groundwater from dewatering would have cost approximately $10,000/day. If the surface cleanup lasted for 6 months, the treatment costs would have amounted to more than $1,800,000. Although the groundwater treatment system would be implemented ahead of schedule, it could be used during final groundwater restoration following source removal.

Dewatering would have resulted in the removal of approximately 200,000 gal/day of groundwater. This rate of groundwater removal was substantially reduced by installing a temporary slurry wall upgradient of the dewatering well point system. Traditionally, slurry walls used in dewatering applications have been useful where the required groundwater removal rates are so large that drawdown cannot effectively be achieved. The Sydney Mine site, having shallow, fine sand deposits and less than 8 ft of drawdown to achieve suitable dewatering, would not normally warrant the use of a slurry wall for temporary dewatering. However, high costs of groundwater treatment associated with the dewatering system made the relatively high capital costs of a slurry wall economical, even for short-term dewatering use.

Estimates of probable construction costs indicated a slurry wall would cost on the order of $250,000 and would reduce total groundwater treatment costs to approximately $300,000 for a 6-month surface cleanup period. This represented a total potential savings of more than $1,250,000. If surface cleanup continued for a longer period of time, even greater savings could be realized. Therefore, it was recommended that a contaminated slurry containment wall be used in conjunction with a temporary well point dewatering system and associated groundwater treatment system for the Sydney Mine site.

DEWATERING DESIGN DEVELOPMENT

Slurry walls have been used successfully in several hazardous waste remediation applications. These applications have included physical waste containment as well as a hydraulic barrier to reduce groundwater extraction quantities. Most of these applications are permanent or long-term installations where waste compatibility and wall integrity are critical to the reliability of the total remedial action.

At the Sydney Mine waste disposal site, however, the slurry wall represented a short-term means of reducing groundwater recovery volumes. Contaminant concentrations in the upgradient groundwater were relatively low; therefore, the effect of possible contaminant degradation of wall backfill materials was not considered a serious threat to wall performance. In addition, because the wall was not intended to serve as a sole method of containment or groundwater barrier, a loss of integrity of the wall resulting in the presence of "windows," seams or gaps would not represent an imminent threat to contaminant migration.

Previous subsurface explorations and investigations at the Sydney Mine waste disposal site provided information on site hydrogeologic conditions and groundwater quality.[2,3] However, detailed soil characteristics and geotechnical information, such as grain size, density, strength, permeability and variations in conditions across the site, were not available. Because of the strict time constraints, design and construction of the groundwater containment had to be completed prior to the start of waste incineration. Therefore, the existing information was supplemented by conducting a program of soil test borings and laboratory testing during construction of the slurry wall.

Hydrogeological Setting

A general understanding of the hydrogeological conditions beneath the site was developed by evaluating well logs. These logs revealed a unique combination of natural and man-made conditions.

Natural soil conditions in the area typically consist of approximately 30 ft of silty sands overlying stiff phosphatic clays of the Bone Valley and Hawthorn formations. These formations provide an effective upper confining layer for the porous limestones which comprise the Floridan aquifer, an artesian aquifer and principal source of drinking water in the area. A perched groundwater table is present in the overburden material above the phosphatic clays.

Strip-mining of the phosphate-rich deposits significantly altered these natural conditions, as shown in Fig. 2. The phosphatic clays were mined to a depth of approximately 60 ft; the former strip mine area was eventually reclaimed by backfilling with clay wastes from phosphate processing. These wastes, called clay slimes, are very soft unconsolidated clays having a relatively low permeability.

Settling ponds were constructed for the disposal of the clay slimes by forming perimeter dikes using mine overburden material. The dike itself, therefore, consists of moderately permeable silty and clayey sand deposits. The Sydney Mine waste disposal site is located at the southern edge of a former dike separating two settling ponds.

The clay slimes were subsequently covered with a thin layer of tailing sands. These tailing sands are fine-grained, uniformly-graded, washed sands also obtained as a byproduct of phosphate processing. The thickness of the tailing sands varies, but is generally thickest at the perimeter dikes and thinnest in the center of the settling ponds. The tailing sands reach a maximum thickness of approximately 25 ft near the settling pond dike.

Consolidation and settlement of the soft clay slimes underlying the tailing sands has not been uniform. Next to the dike where the thickness of the clay slimes decreases because the dike slopes, the surface of the clay slimes has developed a pronounced "lip" which effectively separates the tailing sands from the dike deposits. The elevation of this "lip" is near the former water level within the settling ponds.

A perched water table, recharged by rainfall, has developed in the tailing sands. This perched water table is not used for water supply and varies in thickness. North of the dike, the perched

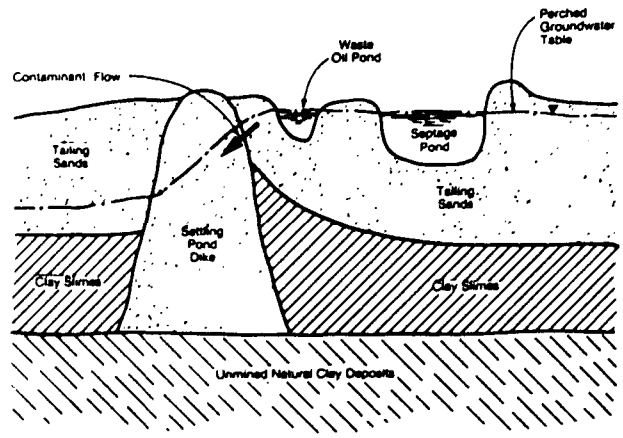

Figure 2
Hydrogeologic Cross Section of the Sydney Mine Disposal Site

groundwater table is present at a level of approximately 20 ft. South of the settling pond dike, the perched water table has a limited outlet for groundwater flow; the "lip" of clay slimes acts as a weir, trapping the perched groundwater within the tailing sands. During rainy periods, a rising water table allows groundwater to flow over this clay weir into the separate perched groundwater within the dike. The groundwater table south of the dike is generally near the ground surface, approximate elevation 90 to 100 ft. The groundwater table within the dike deposits is present at a level which is about 20 ft lower than the perched groundwater within the tailing sands.

Wall Design

These unique geologic conditions substantially influenced the design of the groundwater containment system for cleanup of the Sydney Mine waste disposal site. Because the perched groundwater within the dike was well below the level of the ponds, it did not serve as a source of recharge or groundwater flow to the area of the ponds. Therefore, both the slurry wall and the dewatering well point system were constructed around only three sides of the existing waste impoundments, as shown in Fig. 3. In this way, the slurry wall containment system would serve its intended function as an effective temporary means of dewatering the ponds, but would not function as a reliable long-term containment system. The depth and length of the wall were therefore much less than would have been needed for site containment, providing further cost savings.

Design of the slurry wall specified a minimum width of 2 ft and a minimum embedment into the clay slimes of 2 ft. The backfill was to consist of a mixture of bentonite and the excavated tailing sands and clay slimes. Conventional Wyoming bentonite (high-swelling sodium montmorillonite) was to be added to the backfill mixture in dry powder form to comprise a minimum of 6% by weight of the completed backfill. The mixture could then be sluiced with bentonite slurry from the trench to produce a backfill having a slump between 3 and 6 in. and a permeability less than 1×10^{-7}) cm/sec. Compatibility testing of the specified mix was not performed because: (1) the contaminant concentrations in the area of the wall were generally low, (2) the wall was not intended to serve as a long-term containment barrier and (3) only limited time was available for testing prior to construction.

The dewatering system to be installed inside the enclosed area between the ponds and the slurry wall consisted of a series of well points about 75 ft apart for a total of 20 wells. Each well point was to consist of a 2-in. diameter PVC standpipe with a 2-ft slotted tip.

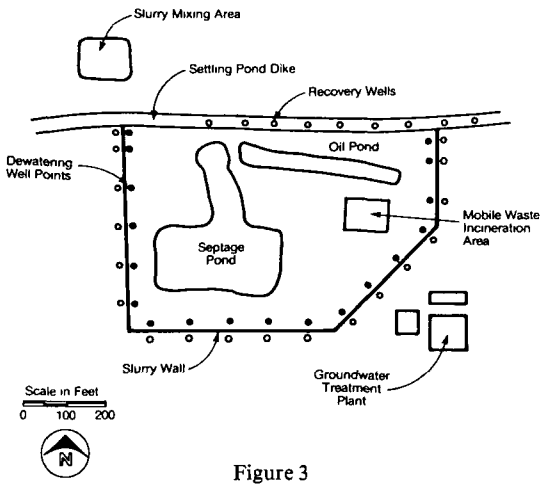

Figure 3
Plan of Slurry Wall and Dewatering System

The well points, which were to be connected to a vacuum header pipe, were to be installed by jetting to a depth just above the top of the clay slimes. Specifications called for the completed dewatering system to be capable of delivering a minimum discharge rate of 150 gal/min at a discharge pressure of at least 20 lb/in.^{2}.

Contract documents for the groundwater containment system, including the slurry wall and well point dewatering system, were prepared and distributed to four potential subcontractors for bid in early September 1984. The successful bidder was Riverside Construction Company of Tampa, a subsidiary of Moretrench American Company of Rockaway, New Jersey.

A groundwater treatment system was installed under a separate subcontract and is only briefly described here. The treatment system consisted of a 100,000-gal flow equalization tank followed by air stripping, iron removal and carbon adsorption. Treated groundwater effluent was stored temporarily in a second 300,000-gal holding tank prior to spraying the effluent on the tailing sands south of the site.

SLURRY WALL CONSTRUCTION

Initial site preparation was begun on schedule in October 1984. A 65-ft wide level pad was constructed around the perimeter of the site to accommodate trenching and backfill mixing equipment. The pad was constructed initially using tailing sands available on-site; however, the tailing sands were found to be excessively uniform and non-cohesive. An imported silty material was therefore brought in to provide a stable working surface in a portion of the trench area.

Soil borings were drilled along the slurry wall alignment at a spacing of approximately 100 ft. The borings were to be drilled to a depth of 4 ft below the top of the clay slimes, although the subcontractor elected to drill even deeper to verify a minimum thickness of the clay slime stratum. Split spoon samples were taken continuously at the anticipated level of the clay slimes.

The soil borings indicated that the level of the clay slimes was higher than interpreted from earlier hydrogeologic studies. The decreased depth to the clay slimes reduced the overall surface area of the slurry wall, resulting in minor construction cost savings. The clay slimes were found to be present to a depth more than 2 ft below the bottom of the slurry trench, thereby assuring that the clay slimes stratum would not be penetrated during well construction.

Laboratory testing specified in the Contract Documents included grain-size analyses of the tailing sands for selection of appropriate well point screen slot size. A minimum of four trial mixes of the proposed backfill mixture was to be tested using a triaxial cell apparatus with nominal confining pressure and driving head of 5 to 7 lb/in^2.

After reviewing the initial soil boring results, the subcontractor proposed an alternative to the specified soil-bentonite backfill mixture. The clay slimes were found to be very soft and malleable and could be mixed relatively easily with the tailing sands to produce a homogenous mixture. The resulting material required little added slurry to achieve the specified slump. The principal benefit, however, was that additional dry bentonite did not need to be added to the mixture to obtain the required degree of impermeability.

A series of permeability tests was conducted on various backfill mixtures to identify an acceptable ratio of clay slimes to tailing sands. Results showed that a mixture of approximately 35% clay slimes and 65% tailing sands could achieve a permeability less than 1×10^{-7} cm/sec. Consequently, the depth of the wall was increased nearly 50%; the total depth of the wall was 1.55 times the depth to the top of the clay slimes. In two small sections of the wall where insufficient clay slimes were available, the specified dry-mixed bentonite backfill was used.

The modified wall backfill material resulted in a cost savings of $12,200, or 8.5% of the wall installation cost. The unit price for the wall was reduced from $4.96/ft^2 to $4.54/ft^2. Measurement of the wall area for payment purposes was determined based on actual soundings of the depth to the top of the wall and based on a theoretical depth of the wall below the clay slimes of 2 ft, as specified.

Construction activities began in early November 1984. A temporary holding pond was constructed for mixing a 5.65% bentonite slurry. The slurry was pumped continuously from the holding pond to the portion of the trench being excavated. Trench excavation was accomplished using a backhoe with a 2-ft wide bucket. Mixing the clay slimes and tailing sands for backfill of the trench was accomplished using a D-7 bulldozer. Mixing was continued until a visually homogenous mixture was obtained. Fig. 4 shows the slurry trench excavation and backfilling operations in progress during construction of the cutoff wall.

The tailing sands, being very loose and non-cohesive, were sensitive to variations in the slurry level within the trench. Occasional caving of the trench sidewalls occurred when slurry levels dropped more than 2 ft below the level of the construction pad.

A geotechnical engineer was present while the slurry wall was constructed to ensure that the backfill mixture was homogenous and that no sand inclusions were present because sand inclusions could impair the integrity of the wall. Health and safety procedures were strictly adhered to during trench excavation. At several locations along the trench alignment, construction workers were required to use respiratory protection because of high levels of organic vapors detected in the breathing zone.

After the slurry wall was backfilled, the top of the trench was covered with a geotextile fabric and soil mat to support occasional or inadvertent pick-up truck traffic across the completed trench. The geotextile fabric consisted of a 12-ft wide woven polypropylene fabric. Native tailing sands were then placed to a depth of 12 in. over the geotextile, and the surface was hydroseeded.

The proposed well point dewatering system also was modified based on suggestions offered by the subcontractor. Because the top of the clay slime stratum was irregular and varied up to 10 ft in elevation, operation of the dewatering system could have been complicated by the need to continuously monitor throttling of the well points to avoid cavitation or loss of vacuum in shallower wells as the groundwater table dropped.

The accepted alternative well point detail shown in Fig. 5 consisted of jetting a 6-in. diameter temporary casing to a uniform depth of 25 ft, which was typically below the level of the clay

Figure 4
Photographs Showing the Slurry Wall Construction

slimes. A 2-in. diameter PVC well point with 5-ft slotted screen section at the level of the clay slimes was then inserted inside the temporary casing. Coarse filter sand backfill was added slowly around the well point while the temporary casing was withdrawn. Finally, a 1.25-in. diameter open-ended PVC drawdown tube was inserted into the well point to a depth of 25 ft. Vacuum was applied to the drawdown tube; cavitation was avoided by setting the tip of the drawdown tube below the maximum depth of drawdown possible using vacuum pressure. The completed well point therefore acted like a sump-type of installation.

Construction, which began in early November, remained on schedule and was substantially completed prior to the Christmas holidays. Waste removal and incineration could therefore proceed without delay.

PERFORMANCE

Quality control testing included a series of slump tests, grain size tests and triaxial permeability tests on the completed backfill mixture. Results of this testing verified that the required permeability of 1×10^{-7} was obtained using the clay slimes-tailing sands mixture.

Startup testing of the well point dewatering system verified that the 20 wells were capable of delivering the specified 150 gal/min at 20 lb/in². As the groundwater table within the contained area dropped, recovery from the dewatering system declined substantially. Therefore, flows to the groundwater treatment facility were supplemented by installing 20 additional well points outside of the wall. This increase in number of wells allowed recovery of the contaminated groundwater within the tailing sands outside the containment area to proceed ahead of schedule.

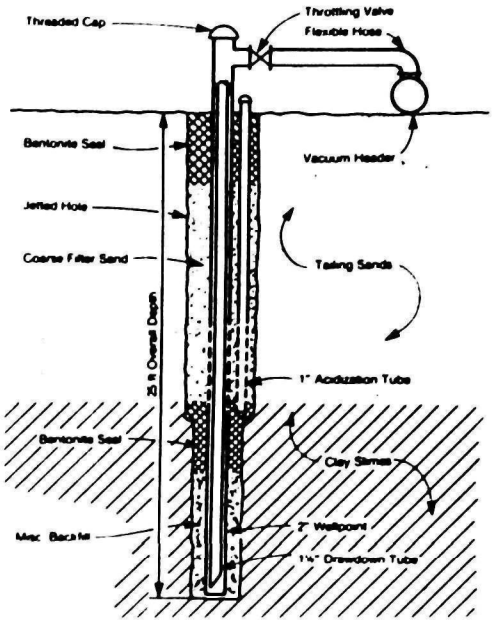

Figure 5
Typical Dewatering Well Point Detail

Water levels in the containment area dropped at a fairly uniform rate for 3 to 4 months before leveling off, as shown in Fig. 6. Heavy rains, such as those associated with hurricane Elena in September 1985, resulted in a sudden rise in groundwater levels but did not jeopardize waste excavation.

Waste excavation from the impoundments proceeded rapidly in early March 1985. Most of the septage pond, including underlying visibly contaminated soils, was excavated and placed in a temporary, lined holding basin. The excavation was dry and stable and backfilled immediately.

Difficulties in the incineration process resulted in a series of unavoidable delays. As of Dec. 1, 1985, however, most of the waste material has been removed and incinerated, and the former impoundments have been backfilled to match surrounding grade. The extended waste removal period will therefore be approximately 12 months. The slurry wall containment system provided a vital means of controlling groundwater levels throughout this period. Dewatering using the slurry wall represents a substantial savings in treatment costs over dewatering without use of the wall, particularly in view of unpredictable delays in site remediation.

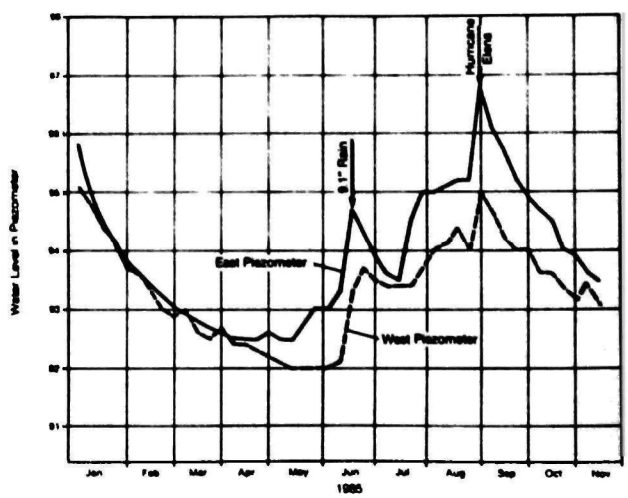

Figure 6
Groundwater Level Measurements at the Sydney Mine Disposal Site

CONCLUSIONS

Slurry wall containment systems can be an economical solution in waste disposal site remediation when used for temporary construction dewatering on small sites, even if not economical for long-term containment (encapsulation).

Advantages afforded by unique site conditions can be incorporated into slurry wall design to earn additional cost savings. At the Sydney Mine waste disposal site, these conditions permitted a three-sided wall layout for containment and offered an economical alternative in backfill materials using native clay slimes.

Flexibility in design and construction can result in savings in both time and cost. Site remediation is non-traditional construction with unforeseen conditions and imposed constraints; cooperation between contractors, designers and owners can identify economical alternatives during construction.

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Utility of Soil Barrier Permeability Data

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ABSTRACT

This report discusses the limitations of singular expressions of permeability data for soil barriers designed to restrict the migration of chemical contaminants from landfills or contaminated soil sites into surrounding groundwater. Also described are the additional quantitative data needed for more accurate interpretation of stated permeability values. These supplementary data include: (1) results of soil blend analyses, (2) results for additional tests of soil characteristics, (3) information about sample preparation before laboratory tests, (4) data on soil physical state as tested, (5) descriptions of test time periods and test termination criteria, (7) information on statistical data treatment and (8) observations about test post-mortems.

INTRODUCTION

Engineered soil structures are accepted by design engineers and regulatory agencies as viable means of controlling liquid movement in hazardous waste treatment, storage and disposal facilities and in uncontrolled hazardous chemical waste sites. Compacted clay soils are being used both as part of landfill liner systems and as an infiltration barrier in cover designs for both landfills and uncontrolled dump sites cleaned up under Superfund authority. Engineered soils also form vertical groundwater barriers constructed by slurry trench techniques. The primary design and construction specification used to characterize soil-based hydraulic barriers is hydraulic conductivity. The soil barrier's degree of hydraulic conductivity is commonly referred to as the permeability, since the factor K in D'Arcy's equation usually is expressed in the same units as hydraulic conductivity (volume cubed per volume squared per unit of time).

The hydraulic conductivity (or corresponding coefficient of permeability) usually is cited as a numerical criterion that describes the liquid migration barrier properties of these engineered soil structures. This report discusses the limitations of such singular expressions of permeability data, and it describes the additional quantitative information that will permit more accurate interpretation of stated permeability values. These supplementary data are as follows:

- Results of soil blend analyses
- Results from additional tests of soil characteristics
- Information about sample preparation before laboratory tests
- Data on soil physical state as tested
- Descriptions of test cell features and techniques
- Specification of test time periods and test termination criteria
- Information on statistical data treatment
- Observations about test post-mortems

Documentation of these parameters provides a basis for comparing permeability test results from different laboratories, investigators and soil and permeant liquid combinations. Such information also strengthens the credibility of hydraulic conductivity data by quantifying parameters that significantly affect the accuracy and practical applicability of permeability test results.

BACKGROUND

In the late 1970s, the U.S. EPA proposed technical performance specifications for landfill construction that would require compacted clay liners for hazardous waste treatment, storage or disposal facilities (TSDFs) to have hydraulic conductivities that did not exceed 1×10^{-7} cm/sec.[1] Since that proposal, regulatory approaches have changed somewhat,[2] but strong support continues for low hydraulic conductivity. Since compacted clay soils also are used for cover systems at hazardous waste storage facilities or at uncontrolled chemical dumps, the hydraulic conductivity of the clay cap has been used as a design and performance criterion for the completed structure.

Permeability Test Methods

The permeability of compacted clay soils can be tested in the laboratory using any of four general types of apparatus: A rigid wall cell, a triaxial cell, a consolidation cell or a constant flow rate cell. The permeability of clay compacted in the field can be measured using: (1) lysimeter pans installed underneath an area of the compacted clay, (2) ring infiltrometer systems installed on the surface of the compacted clay or (3) shallow well slug tests in cylindrical excavations into the compacted clay.

Slurry Trench Cut-Off Walls

CERCLA has specified the application of available engineering technologies to reduce the adverse environmental impact of uncontrolled hazardous chemical dump sites. Both regulatory agencies and engineering companies have accepted the slurry trench cut-off wall as a structure that can restrict the lateral groundwater flow into and out of a subsurface land mass contaminated by hazardous chemical wastes.[1]

A slurry trench cut-off wall is built by constructing a vertical trench that is kept open by clay suspensions during excavation. A barrier material then is backfilled into the trench excavation. The material may be a mixture of soils formulated by design engineers, a soil-cement-bentonite mixture, synthetic plastic sheets or metal sheet pilings.

For a backfill barrier made of soil, permeability is a primary characteristic for describing the lateral movement of groundwater

through it. Design specifications for slurry trench cut-off walls at uncontrolled hazardous chemical waste sites usually require that the backfill hydraulic conductivity not exceed 1×10^{-7} cm/sec, as is the case with compacted clay soil liners and surface caps.

The permeability of slurry trench backfill mixtures can be tested in the laboratory using any of the apparatus applied to compacted clay soils, but sample preparation techniques differ. The permeability of an installed backfill can be evaluated by installing monitoring well systems on both sides of the barrier or by extracting samples of backfill materials from the barrier and subjecting them to laboratory permeability tests. No simple field tests have been reported to measure the actual hydraulic performance of a slurry trench cut-off wall after installation.

Although both native soils and those amended with clays, fly-ash, cements or other materials are characterized by other laboratory tests (grain-size distribution, plasticity, color, exchange capacity, pH, etc.), the hydraulic property of the soil after construction is the main parameter of interest to a regulatory agency and thus to a design engineer.

Existing Data Base on Soil Permeability

Numerous studies have been conducted in the past 6 or 7 years to determine how hydraulic conductivity tests in soil are affected by variables such as soil type, liquid type and test technique. The results of these studies have been reported in technical journal publications, agency reports and proceedings of environmental research conferences and symposia.[4,5,6,7] Briefly, this research has documented the effects of various organic liquids on the permeability of many different soil types when the organic liquid is substituted for water in a laboratory permeability test. Similar studies have included both dilute and highly saline inorganic liquids such as those from mining, metal plating or drilling mud waste disposal. In addition, numerous tests using compaction mold, triaxial cell and consolidation cell permeameters have been conducted (including various operating technique modifications of each) to quantify and improve test precision. Ultimately, a report is developed stating that the soil has a hydraulic conductivity of some stated numerical value (typically near or lower than 1×10^{-7} cm/sec) when it is tested with the permeant liquid specified. Thus, a large data base that declares the permeability of individual soil materials to individual liquid systems exists.

Soil/Pollutant Compatibility

A geotechnical testing laboratory should state clearly whether the soil permeability test has been conducted with laboratory water, relatively uncontaminated groundwater from the site or a liquid containing known pollutants. If a test is being conducted to document the stability of an engineered soil barrier after exposure to a leachate, contaminated groundwater or other liquid, the permeability test should be clearly defined as a measure of compatibility. This step is necessary because testing procedures, as referred to later in this paper, require particular selection and operational techniques when the primary goal of the tests is to determine soil and pollutant compatibility.

The U.S. EPA has published a procedure[8] for determining clay liner compatibility using a rigid-wall permeameter. Further studies are under way to develop reliable procedures using triaxial cell and consolidation cell apparatus.[9] Another device, the high-pressure, constant flowrate cell, is being used to determine the water permeability of clays,[10] but it has not been extensively used to determine soil and liquid compatibility. Since there has been little experience with the constant flowrate cell and chemically aggressive liquids, and since reported uses of this type of apparatus have involved relatively small sample volumes, the cell will not be discussed further in this paper.

SUPPLEMENTARY DATA NEEDED FOR INTERPRETING PERMEABILITY VALUES

To objectively evaluate permeability data, it is necessary to have information about soil properties and test procedures that goes beyond the expression of the coefficient of permeability.

Soil Blend and Other Characteristics

Although compacted clay liner and surface cap components have essentially common design, construction and testing characteristics, soils prepared to serve as a slurry trench barrier are usually a fluid mass that contains a much higher initial water content than a compactable clay soil. However, each of these applications usually requires a certain specified minimum clay or fines content so that a minimum of pore space is present in the completed structure. Thus, soil engineering tests of candidate soil barrier materials routinely include particle size distribution data. A noticeable shortcoming in these data is the usual omission of proportions of gravel or other coarse fractions in the borrow (i.e., the content to which materials coarser than a prescribed maximum are removed before actual barrier construction). The presence of rock fragments more than an inch in dimension may become a significant inclusion in soils compacted to form clay liners or caps. Thus, the largest allowable soil or rock particle sizes in barrier materials must be specified in the standard particle size classification reported for candidate barrier soils.

Before soil is characterized by laboratory tests for barrier construction, the representativeness of soil sample(s) must be determined. Most clay borrow areas vary in properties, so the engineer who is characterizing the clay source must measure and report on the variability of the total candidate soil resource. Both research reports and actual RCRA Part B Permit Application information indicate that soil areal and volumetric variability are unaccounted for parameters. Sometimes these sources do state that the total soil supply is uniform within the limits of variability accepted by ASTM for particle size or engineering index test results.

A design engineer also should insist on a valid statistical sampling of the total soil volume to be used for barrier construction. Such methods as are standardized for coal stockpile or limestone stockpile sampling easily could be adapted to clay reserves. For in-situ soil sources, guidelines adopted by agricultural testing laboratories for field sampling could be scaled to the soil source site.

Any of these suggested approaches or even more detailed site-specific sampling schemes should be appended to permeability data to assure clients of conscientious protocols applied preceding laboratory tests.

Sample Preparation Before Laboratory Tests

Sample preparation before the permeability test has a profound effect on the actual results obtained. Daniel[11] has published data from a small laboratory experiment that describes the effect of soil clod size on permeability tests in the laboratory. These data have been widely cited to proclaim the importance of clod size as a controlling factor in clay liner permeability. These data are more significant as an indicator of the effects of laboratory sample preparation. Rarely would a clay liner or cap be installed with clay soil in which all the clods were reduced to tiny fractions of an inch in dimension; nevertheless, it is prudent to expect that an extrapolation of Daniel's data to larger clod sizes will result in correspondingly greater permeability values.

Many laboratory permeability data have been published for soil that has been ground to pass a 40 mesh sieve. Such sample treatment drastically improves the precision of replicate laboratory permeability tests conducted on the same soil. One must be alert for such reports of careful sample pulverization and mixing, since the resulting data are good documentation of technician compe-

tence rather than the acceptability of a proposed soil material as a pollutant barrier.

Other aspects of sample preparation should be documented as part of a report of permeability tests. Particle sizes excluded from the laboratory sample but present in the sample obtained in the field should be reported in detail, even if departures are made from standard ASTM procedures. Terms such as "moisturization" and "equilibration to wet of optimum moisture" have appeared in permeability test reports. The degree to which all of the soil sample to be tested has been brought to a uniform moisture content before assembly in the permeability test cell may have a significant effect on both actual values and precision of replicate permeability results. Uniformity certainly is greater where the soil has been pulverized to uniform small fragments and mixed thoroughly. Many testing laboratories do not take proper care in size reduction and mixing because of economic pressures.

If a client is to understand the potential limitations of the data he receives, he must insist that sample preparation details be included within the permeability report. A client also needs to be provided with a thoroughly documented moisture/density curve that includes numerous data points. Where soil material is proposed to be amended with additives such as additional clay material, flyash, cement, various industrial process wastes, etc., curves should be provided for the actual amended soil.

Soil Physical State as Tested

The soil physical state as tested for permeability in the laboratory depends upon both sample preparation and subsequent handling. Application of standard or modified Proctor compaction procedures to cell sizes other than those accepted by ASTM methods should be documented by statements describing the actual apparatus used. After compaction, a density measurement calculated from cell volume and weight is the only parameter presented to indicate attainment of the desired compaction. Geotechnical engineers accept the fact that soil structural units must be molded to achieve the most impervious material after compaction. No one has shown how impact compaction using standard or modified Proctor procedures achieves remolding in clayey soils. Compaction "wet of optimum" has been reported to decrease permeability in many laboratory studies. Of these reports, many fail to describe the sample compaction procedure applied.

Some commercially available laboratory machines are designed to apply "kneading compaction," but few reports of clay liner permeability have included the use of this apparatus. Where kneading compaction might be advantageous, studies have not clearly documented what minimum cell size is needed in relation to the compaction foot size and soil particle or clod size to achieve expected or acceptable kneading compaction. This also leads one to question the utility of some of the smaller sizes of laboratory permeability cells—for example, those only 1 to 2 in. in size. Where the soil sample has been compacted and later extruded into a test cell (such as for triaxial confinement) the apparatus used should be clearly described.

Smearing or polishing the sample end surfaces has been shown to lower clay permeability. Side polish or smearing caused by extrusion may not have any significant effect, but it may mask observations of actual small clod structure on the sample surface. The client needs to be aware of the potential for such results, particularly so he will not be surprised if later tests by a different laboratory yield different results showing that the liner candidate soil does not meet specifications.

Several procedures have been published[8,12,13] detailing laboratory sample preparation and introduction of prepared samples into permeability apparatus. These may provide guidelines, but since each laboratory is likely to have different apparatus and in-house procedures, deviations from published techniques should be documented as part of the permeability test result.

Test Cell Features and Techniques

The particular features of laboratory test cells and the mode of conducting a test need to be described. A report that permeability was determined with a falling head test should not be accepted. The inflow and/or outflow permeant liquid level may have been determined by two different readings on a burette or graduated sight tube. But where hydraulic gradients of several tens or more are imposed to reduce testing time, it is likely that the liquid level change in the burette represents an insignificant head change compared to the actual gradient imposed during the test. Thus it is imperative to include actual apparatus dimensions and operating parameters within a test report.

Statements of sensitivity, resolution and readability of all gauges, burettes and digital or analog readout devices should be available to the data recipient. Raw data parameters may include such items as examples of actual burette reading at actual time and volume increments obtained during testing of samples reported. Examples cited should consist of actual raw data, because laboratory notebook pages may have to be reproduced for data quality assurance audit. This information provides both the client and the permit reviewer with confidence that indeed the laboratory test was carried out in a professional manner consistent with the best known practice of such tests. Confidence in test results needs to exceed the norm for structural engineering tests because of the unique social, political and environmental sensitivity of data characterizing pollutant barriers.

Test Time Periods and Test Termination Criteria

Time required for obtaining a soil permeability test result is commonly included in graphic reports of the test results. The hydraulic conductivity is plotted as time passes during the test. Time required to perform a permeability test of compacted soil materials that are expected to be only slightly pervious is a function of several operational parameters that can be controlled by the test technician to perform tests at an economical rate. Thus the question of when to terminate a test because acceptable values have been obtained also needs to be clearly answered. A widely accepted standard for a permeant liquid other than water (e.g., a known chemical liquid, solvent or waste stream) is that several pore volumes of the permeant liquid should be passed through the sample to ensure adequate exposure of the soil sample to the liquid to cause an observable effect. A minimum of two pore volumes has been used as a criterion by numerous laboratories. Such tests as this may be more accurately called liner/leachate compatibility tests, although hydraulic conductivity is the primary indicator of compatibility. This case simplifies the question of minimum testing time.

A related question concerns the frequency (either on a real time scale or in terms of permeant liquid inflow and/or outflow volume) with which appropriate hydraulic flow rate measurements may be validly calculated to indicate an accurate hydraulic conductivity of the sample being tested. Clearly, the closer the apparatus readings, the greater the chance of obtaining readings that consecutively agree, thus indicating achievement of a stable hydraulic flow and therefore indicating that the calculated permeability accurately depicts the sample properties! The frequency of acquiring the time and volume of data also must be considered with respect to sample size, hydraulic gradient applied and other factors. These factors should be included as part of the test procedure, as suggested in this paper. The procedure should describe the criteria applied to determine the time and volume frequency

of data collection as well as the criteria used for ending the laboratory test. This information should be included with test results even if decisions were unique to individual samples and not based on standardized methods. Where a published procedure has been applied, any deviations from the published method should be noted.

Statistical Data Treatment

Soil permeability data for materials proposed as clay liners, clay claps or slurry wall backfills normally are reported as a few distinct data points. Where a slurry trench cut-off wall is under construction, data may originate from daily sample determinations. This is likely to result from batch mixing of trench backfill soils. In the case of clay soils proposed for liner or cover use, individual datum statements are more common than summaries of numerous tests. Thus, the application of statistically valid and accepted designs of soil borrow or clay liner test schemes is at an early stage of development. Some private firms appear more supportive of statistical approaches than others. The client who buys permeability tests for pollutant barrier materials would be served best by a clearly described statistical scheme for sampling soil, conducting tests and reporting results. Such an array of information would allow the client to provide this information to reviewing agencies with a high degree of confidence that he has taken the best known approach to documenting the validity of test results for barrier material characterization.

Agricultural literature abounds with statistical approaches to soil testing. Engineering approaches to assuring that soil structures are competently designed and constructed should be taken as the minimum requirement with respect to statistical sampling and data interpretation. A recent Draft Quality Assurance document issues by the U.S. EPA[14] treats statistical considerations at some length and should be noted as directed toward pollutant containment structures.

Irrespective of the site-specific statistical approach applied to permeability testing, the methods used should be included with data reports. Data reports, either graphic or tabular, should use parameter units that are standard or well recognized in ASTM, ASCE or similar publications. Authors should carefully assure that all significant digits in reported data are actually meaningful. Where local terms (e.g., tap water, energy gradient, effective confining stress, etc.) are used to test descriptions, they should be defined so that they are understandable to a broad range of technical reviewer audiences. Citation of published authorities can easily account for standardized use of terms for common parameters.

Observations About Test Post-Mortems

Where the hydraulic conductivity of a compacted clay soil or a slurry trench backfill mixture is determined specifically as a compatibility test using a site-specific leachate or other liquid as permeant, it is usually fruitful to carefully examine the soil mass after removal from the laboratory permeability cell. Although specific procedures for such examinations or evaluations of observable features are not standardized, many geotechnical engineers apply their own experience and that of consultants to note any significant sample changes. The testing laboratory should be encouraged to examine permeated soil samples and report the post-mortem observations. Where index tests on the permeated soil have been applied, these data should be reported. Some engineers have examined the soil fabric and noticed clear changes induced by non-aqueous permeant liquids.

Some laboratories routinely collect periodic samples of outflowing permeant liquid and publish (from chemical analyses) changes in permeant liquid composition as solute breakthrough curves. Such data provide useful documentation of the barrier soil's attenuation capacity for potential pollutant compounds. Where slurry wall backfills are being tested for permeability, the actual slump and moisture content after completion of sample consolidation and hydraulic testing would be useful to properly interpret the permeability results. Whatever post-mortem approach is applied, the testing laboratory should be encouraged to conduct these examinations and report observations for inclusion with permeability data reports.

CONCLUSIONS

Inclusion of supplementary data with singular expressions of the hydraulic conductivity of a clay soil liner, clay cap or slurry wall backfill can only improve the credibility of permeability data. In addition, any data reviewer is provided with a better opportunity to compare data from among sites, soils, laboratories or test methods. Since nearly all soil-based pollutant barriers represent unique site-specific installations, it is essential that a maximum degree of barrier performance comparability be available to both owners of multiple sites and agency staffs responsible for reviewing data. Some of the specific examples mentioned are not directly usable in every site-specific case, and it is likely that practicing design engineers, geotechnical testing laboratory staffs and researchers may have additional factors and parameters that need to be considered. This paper is intended to highlight shortcomings in present data reporting and encourage the geotechnical laboratory testing industry to incorporate the results of supportive soil tests into permeability test reports.

ACKNOWLEDGEMENT

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

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Quality Assurance and Quality Control Procedures for Installation of Flexible Membrane Liners

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ABSTRACT

The significant number of strengthening regulatory requirements governing the design, construction and operation of waste management facilities has brought about a rapid growth in the technology employed in the industry. Among these advancements in technology is the use of flexible membrane liners (FMLs) for lagoon and landfill lining systems. However, the rapidly growing popularity of FMLs has resulted in a situation where FMLs are being specified or used by owners, contractors and engineers with little or no previous FML installation experience. The purpose of this paper is to present the fundamental procedures relevant to controlling the installation of an FML.

INTRODUCTION

During the past decade our experience inspecting the installation of flexible membrane liners has led us to conclude that there are four primary aspects of FML installation control. As outlined below, two of these primary aspects should be performed prior to the commencement of any actual installation and preferably prior to arrival of the material at the construction site. The four primary aspects of controlling FML installations and the appropriate times to implement such aspects are as follows:

- Prior to Commencement of Installation
  - -Material Assurance
  - -Installation Planning
- During Installation
  - -Constant Observation
  - -Seam Testing

MATERIAL ASSURANCE

Among the FMLs commercially available and commonly used for lining waste management facilities are high density polyethylene (HDPE), chlorosulfonated polyethylene (CSPE), polyvinyl chloride (PVC) and chlorinated polyethylene (CPE). The selection of the proper material for a given application is considered a design function and will not be discussed in this paper. This paper will, however, recommend procedures for attaining a maximum quality installation of the specified material.

One of the most fundamental aspects of providing control over an FML installation is making certain the material delivered to the site complies with the specifications. Most FMLs suitable for consideration as liners in waste management facilities are not comprised of a single polymer; rather, FMLs consist of a combination of two or more materials that are produced independently and shipped to a common manufacturing plant for production of the specified FML.

Among materials that may be added to the basic raw material (polymer) are: reinforcement fabrics (such as nylon or polyester scrims) to improve tear strength; pigments (such as carbon black) to provide ultraviolet radiation resistance; and plasticizers to increase flexibility and additives (such as calcium carbonate) to improve surface smoothness characteristics. To further complicate efforts aimed at assuring proper FML manufacturing, the basic raw materials often are specified via a generic name (such as polyethylene) which could include specific polymers (resins) unable to yield a specification complying product. For this reason, a proper FML specification always should include a listing of one or more specific manufactured raw products (i.e., resin number and manufacturer) that would be acceptable for the project. In addition, the specification should include similar details for any materials that are to be added to the basic raw product to comprise the final FML. Finally, the specification should include a list of minimum physical property criteria for the manufactured FML.

As stated above, an FML is manufactured from one or more raw materials that are shipped to a manufacturing plant. The first step in providing control over an installation should be to determine where the material is going to be manufactured and the specific raw products intended for use.

Just as there are many FMLs to choose from, there are many FML suppliers and installation contractors in the industry. Many firms in the business of installing FMLs are also in the business of manufacturing FMLs. Other installers and/or suppliers purchase the raw products and subcontract with manufacturing plans for production of the sheeting. Aside from the fact that the former case has some advantage in providing a greater certainty of warranty, both of the above procedures can and have been used with success. In any case, the plant identified for manufacturing the FML should be qualified by verifying its experience in producing the specific FML specified for the project.

In addition, the manufacturer of each raw product used in the production of the FML should be similarly identified and qualified. For each material component used during the manufacture of the FML, it is recommended that a quality control certificate be obtained from the manufacturer of the raw product. In addition, the transport of the approved material to the manufacturing plant should be verified to make certain the approved materials are used in the manufacture of the project.

Upon completion of the manufacture, random samples of the FML material should be tested both by the party providing the quality control over the installation and by the manufacturer. The manufacturer's results should be submitted to the former party for comparison and verification. The specifications for the pro-

ject should contain a list of minimum physical properties to be verified. We recommend, as a minimum, that elongation, tensile strength and thickness always be verified. The frequency of random sampling would depend upon the method of production and the volume of FML produced. Samples should be obtained from each representative mode of production. For example, should the FML be manufactured over a several day period with shutdown during the evenings, samples from each day's production should be tested. Conversely, if the material is manufactured continuously over a multi-day period, samples should be obtained from each shift of production workers.

INSTALLATION PLANNING

Perhaps the most crucial component for controlling the installation of FMLs is the planning which is necessary before the material arrives on the site. Just as there are numerous manufacturers who provide a varied degree of control, there are numerous installers in the business. The qualifications, experience and knowledge of the firm selected to install the FML must be verified. As will be explained in detail below, there are many seaming and testing techniques available and each of these techniques is highly dependent upon the skills of those using them.

It is necessary to look beyond the firm itself and determine which individual people will be performing the installation. All seamers should have adequate experience in the type of seam to be used. A foreman should be identified as a liaison between the person providing the control and the production crews. The number of crews, the number of people in each crew and the minimum skills of each person in each crew should be identified. A panel diagram should be provided by the installer indicating the intended alignment of the panels. The following items should be discussed with the installer:

- Panel Alignment and Seam Location: Seams should be minimized and situated at least 5 ft from toes of embankment slopes. Panel width should be optimized.
- Treatment of Project Irregularities: Penetrations, sumps, embankment abutments, etc., must be addressed. Patching techniques should be identified on this diagram. Compensation folds for temperature fluctuations should also be discussed and agreed upon.
- Operational Procedures: The direction of installation operation giving consideration to slope of subgrade and prevailing winds should be agreed upon. Specific techniques to protect against wind uplift and rainwater intrusion between the FML and subgrade should be identified and agreed upon. The shift hours and number of crews should be determined to establish manpower needs for quality assurance and quality control.
- Treatment of Anchor Trench: A detail should be provided for the location and cross-section of the trench itself. The contractor should agree to excavate the trench daily in sufficient length for the day's scheduled installation. The trench should be backfilled in sections immediately upon installing each panel of the FML in the trench to protect against wind uplift.

In addition, before approving the installer for the project, a set of protocols should be established. This agreement should include an area set aside outside of the work area for smoking. It should be understood that no smoking will take place during the act of installing the membrane or upon sections of completed membrane. Coordination, respective responsibilities and communication protocol with other on-site contractors should be thoroughly reviewed to avoid costly installation delays and conflicts of interest between contractors. This agreement should include addressing responsibility for subgrade preparation and maintenance of subgrade from the time of acceptance to FML installation.

The specific seaming technique should be reviewed as well as any proposed non-destructive testing to be implemented by the installer himself. If the party charged with controlling the installation is not totally familiar with either the seaming technique or the non-destructive testing method, an arrangement should be made—prior to approving the installer for the project—for test seaming and demonstrations.

The contractor should be made aware of the quality control requirements that will be implemented during the installation and agree to cooperate, be bound by the determinations of the quality control effort and perform all patching or test seaming that may be required. Other aspects of the project which should be reviewed prior to any material arriving on the site include on-site storage of the material, the equipment that will be used and cleaning and overlapping requirements at seams.

CONSTANT OBSERVATION

The most crucial part of the quality control process is constant observation of the installation by a qualified inspector. The initial responsibility of the inspector is to verify that the material delivered to the site is the same material which was previously approved for use under the material assurance aspect of the quality control program. This assurance is made by comparing the identification slips accompanying the material with the identification appearing on the submitted quality control certificate.

The inspector should be responsible for approving the subgrade preparations in conjunction with the installer. We recommend that both the installer and the inspector certify the acceptability of the subgrade in terms of firmness and texture regularity (smooth and free from sharp objects such as stones).

The inspector should carefully observe the handling of the material, noting if any mechanical grips are used and subsequently checking for any damage caused by such mechanical grips. He should watch during the unfolding or unrolling of the material to note any material irregularities or concentrated stressing during the handling operation. He also should carefully observe the placement of the material to confirm that the specified overlap is attained and satisfactory cleaning of the FML (or an existing FML in the case of an extension) is accomplished.

All seaming should be done only upon the performance and acceptance of a test seam at the beginning of each crew shift and immediately following any stoppage of work for lunch, etc. The test seam should be performed outside of the limits of the work, but in conditions representative of the work area. Test seams should be carefully observed by the inspector and then be checked by hand or mechanical stressing in tension and in peel. Should the test seams prove inferior, no seaming operations should commence until the cause of the inferiority is determined, corrective action is implemented and acceptable test seaming is conducted.

SEAM TESTING

All seaming should be observed by the inspector and tested using a non-destructive technique by the installer under the constant observation of the inspector. Literally every inch of seam should be inspected using one or more non-destructive techniques.

There are numerous non-destructive techniques available and suitable depending upon the type and thickness of the specific FML. Among the test methods available are: ultrasonic pulse echo which utilizes a principle similar to sonar; air lancing which involves detecting unbonded areas via air jets; vacuum chambers which utilize a vacuum pump to detect leaks; mechanical point stressing which involves blunt instrument probing of the seam to detect unbonded areas; and dual-seam pressurization which is limited to specific seams that result in a twin bond. Information is available in the literature with regard to which non-destructive

techniques are appropriate for specific FMLs of a given thickness and material type.

As discussed above, proper installation planning would have resulted in a prior agreement with the contractor regarding the specific nature of the non-destructive technique or techniques to be employed. The inspector should observe every inch of non-destructive seam testing and document the testing. Any areas of failure should be identified and patched in accordance with the previously agreed upon patching technique. Any suspect areas should be patched, cap-stripped (is appropriate for the specific FML) or identified for subsequent destructive sampling.

Despite the most rigorous field observation and non-destructive testing effort, our experience has shown that destructive sampling is imperative. Field seaming is a labor-intensive/dependent operation and, despite the most conscientious efforts on behalf of the installer and the inspector, destructive sampling sometimes reveals unknown and unexpected occurrences that potentially could impact the quality of the installation.

Destructive sampling involves obtaining a sample along the length approximately 18 in. square (centered on the seam) and cutting out test specimens for laboratory testing in accordance with the appropriate ASTM Standards for the specific FML material. We recommend that a field test be done from each destructive sample cut in the field to determine whether it is possible for a seam to pass the field test and not the laboratory test. Minimum laboratory testing should be peel adhesion testing and tensile testing to determine elongation and tensile strength.

Since all sampling must result in a patch in the completed product, destruction sampling should be minimized in cases where destructive sampling has not revealed unexpected causes for concern. We recommend that the location of destructive sampling be prioritized as follows:

- At all areas identified as suspect, but not otherwise remediated, during the non-destructive sampling.
- A minimum of one sample from each seamer (both personnel and equipment).
- A minimum of one sample from each different seaming condition (for example, relatively "flat" floor areas, toe areas, grade steps, slopes, etc.).
- A minimum of one sample from each representative working conditions (for example, extremely hot or cold days, seams during or following precipitation events, etc.).

Should samples representative of all of the conditions outlined above be obtained and tested yielding satisfactory results, no further destructive testing would be warranted. However, should the test results be unsatisfactory or otherwise reveal unexpected occurrences, further destructive testing might be warranted to identify the problem and determine the appropriate remedial measure. The quantity of destructive sampling should be the minimum necessary to provide a representative cross-section of the various types and locations of seams.

CONCLUSIONS

If the installation is properly planned and adequate measures are taken to assure the proper material is provided, full-time construction observation and seam testing can assure an environmentally sound FML installation.

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Illinois Plan for On-Site Incineration of Hazardous Waste

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ABSTRACT

The Illinois Environmental Protection Agency (IEPA) has been a leader in promoting the use of alternative treatment technologies for hazardous waste treatment and disposal. One of these technologies is the Transportable Thermal Destruction Unit (TTDU) or mobile incinerator. IEPA has prequalified a list of companies and put a request for proposal out for bids on the cleanup of two state-funded hazardous waste sites utilizing a TTDU. IEPA also has worked with U.S. EPA in the creation of a task force to study ways to make mobile incineration more attractive at NPL sites. The House of Representatives has adopted an amendment in its version of CERCLA that will make it easier for Illinois and other states to use mobile incineration at non-NPL sites under State statutes.

THE ILLINOIS HAZARDOUS WASTE PROBLEM AND PROGRAM

Illinois generates 526,227,923 gal of hazardous waste annually. This amount is second only to the state of New Jersey. Due to the state's long industrial history, there are hundreds of hazardous waste sites within its borders. There are nearly 1,000 known or suspected hazardous waste sites in Illinois. IEPA has evaluated in a preliminary manner 750 of these sites. The remaining 250 sites will be evaluated in 1986. It is anticipated that a total of at least 50 of these sites will be placed on the federal Superfund list during the next 5 years. There are currently 22 sites on or proposed for the federal list. Another 50 sites will be placed on the state cleanup list over the next 5 years including the 19 which are currently on the list or proposed. In addition, the state is currently conducting cleanups classified as immediate removals at 18 sites per year. The agency is currently involved in the oversight of 20 voluntary cleanups being financed by responsible parties.

IEPA is currently involved in approximately 80 hazardous waste studies, oversight or cleanup activities. Over the next 5 years the agency may be involved in as many as 290 such cleanup activities. The primary focus of the state-funded Clean Illinois program in its first 2 years has been to remove the source of contamination from the sites and secure waste on-site so that it no longer migrates into the groundwater or leaves the site. This program has resulted in the excavation and removal from the sites of 6,510 tons, 10,730 yd^3, 16,077 55-gal drums and 194,815 gal of hazardous waste from state-funded cleanups. These wastes typically were contaminated with PCBs, volatile organic solvents and heavy metals. It is estimated the combined federal, state, local and responsible party costs to support the cleanup program in Illinois may exceed $1 billion between now and the year 2000.

IS THERE A BETTER WAY?

As states go, Illinois is blessed with hazardous waste treatment facilities including three hazardous waste landfills, two commercial stationary hazardous waste incinerators and numerous aqueous waste treaters, solvent recovery operations and recyclers. However, from the spring of 1984 through the spring of 1985, IEPA began to realize the tremendous amount of hazardous waste that was being landfilled as the result of State-funded cleanups. The potential problems of future state liability at these sites really become evident when manifests signed by agency employees as generators are returned to the agency and appear in computerized monthly and annual reports. To make this problem more acute, some of the cleanup contractors were proposing in the lowest cost bids to dispose of the waste in out-of-state landfills. These developments caused the agency to take the following steps.

The agency would begin paying a premium for cleanup plans that land disposed the least amount of hazardous waste and incinerated, recycled or treated the greatest amount of hazardous waste. The Illinois General Assembly already had passed a law prohibiting the disposal of liquid hazardous waste in landfills as of July 1, 1984 and prohibiting the land disposal of all hazardous waste by Jan. 1, 1987, unless there is no other alternative to landfilling. By these actions, the state was trying to place less dependence on landfilling of hazardous waste and more reliance on alternative treatment technologies such as incineration.

Even though the state has two fixed incinerators, IEPA found it difficult to obtain cleanup plans with serious incineration alternatives for thousands of cubic yards of contaminated soils. Cleanup contractors found it difficult to obtain firm incineration prices over time. In addition, the incinerators did not want to accept large volumes of soils, and if they did accept soils they had to be packed in 15-gal fiber drums. These drums had to be hand-filled and sometimes posed leakage problems in transportation. In addition, Illinois has a hazardous waste treatment and disposal siting law which allows local governmental jurisdiction to veto new facilities that are to accept waste outside of their political jurisdiction. For these reasons the agency began looking at mobile incineration options.

DOES ANYBODY HAVE A MOBILE INCINERATOR FOR SALE?

In March 1984, IEPA created an in-house work group which included representatives from its various organizational divisions including Air Pollution Control, Land Pollution Control and the Office of Chemical Safety; legal staff were included. IEPA also

obtained assistance from the U.S. EPA Region 7 and the Cincinnati based ORD incineration research group. This panel of nine people reviewed the equipment of six companies that claimed they had or soon would have mobile incineration capabilities. The work group was sufficiently encouraged by this review to identify more interested companies that had or could build a mobile incineration system for IEPA's use. By the summer of 1984, the IEPA had, through the placement of advertisements and direct mailings, developed a list of 78 persons or companies interested in providing TTDU services to IEPA. The IEPA hosted a meeting in Springfield in June which 35 companies attended to discuss a future Request for Statement of Qualifications (RFQ). In September 1985, IEPA put out an RFQ which had the preamble given in Table 1.

Table 1
Preamble to the IEPA RFQ on a Mobile Incinerator

Request for Statement of Qualifications for Cleanup Services Using a Transportable Thermal Destruction Unit

It is the intention of Illinois Environmental Protection Agency, Division of Land Pollution Control ("IEPA/DLPC" or "agency"), to utilize Transportable Thermal Destruction Unit (TTDU) technology at a hazardous waste site that is now on the State Remedial Action Priority List (SRAPL) or National Priority List (NPL).

IEPA/DLPC is seeking qualified firms who will agree to own and operate a TTDU in conjunction with their hazardous waste cleanup services on an Illinois hazardous waste site to be designated by IEPA/DLPC. Typical contaminants and wastes found at the site will be PCBs at levels above 50 ppm volatile organic solvents, non-volatile organics, halogenated organics, pesticides, oils and other petroleum products. These contaminants will be in several different forms, including liquid wastes, in soils or in various objects (for example, 55-gal metal drums).

IEPA/DLPC desires proposing firms to provide the following services:

1. Own and operate a TTDU at the specified cleanup site.
2. Design and build a feed system that will handle contaminated soil, liquids, sludges and various sized metal or fiber drums.
3. Perform all acts necessary for a hazardous waste cleanup, including excavating, staging, processing and feeding waste material to the TTDU.
4. Remove treated wastes from the TTDU for appropriate management and/or disposal.
5. Test air emissions and obtain necessary permits.
6. Prepare the delisting petition for treated wastes.
7. Provide all necessary equipment and appurtenances to make system functional.
8. Provide all necessary personnel to operate all systems.

The purpose of this Request for Statement of Qualifications (RFQ) is to select from the universe of prospective bidders those bidders who can best demonstrate to the agency that they possess the financial strength and resources, state-of-the-art technology, management strength, relevant experience and satisfactory plan for financing the program's capital expenditures to successfully implement all of the services previously described.

Twelve firms responded to the RFQ. One was considered nonresponsive due to incomplete information. In December 1985, IEPA put out a Request for Proposal (RFP) covering two sites; the Beardstown PCB site and the Ability Drum site. Responses on these two sites are due by Jan. 27, 1986. The IEPA has been informed that two of the 11 companies do not wish to bid. That leaves nine firms on the pre-qualified bidders list for these two sites. Those firms from whom we anticipate bids are:

1. Ensco
   Pyrotech Division
   Franklin, Tennessee
2. Sitex Corporation
   Clayton, Missouri
3. Rollins Environmental Services
   Wilmington, Delaware
4. John Zink Co.
   Tulsa, Oklahoma
5. IT Corp.
   Knoxville, Tennessee
6. Roy F. Weston, Inc.
   West Chester, Pennsylvania
7. G.A. Technologies
   San Diego, California
8. Detoxco Inc.
   Walnut Creek, California
9. Mid-America Environment Services, Inc.
   Riverdale, Illinois

BEARDSTOWN PCB SITE

The Beardstown site was a metal salvage yard occupying 10 acres located 3 miles west of the Illinois River at Beardstown, Illinois in Mason County. The site, located on very fine sandy soil, had taken in transformers from local utilities and salvaged the copper from them. The PCB-contaminated oil from several hundred transformers was dumped on the ground over the years. The sandy soil was contaminated to a depth of 10 ft, with the majority of contamination occurring in the top 2 ft. An initial cleanup of the site resulted in the removal of 4,125 yd^3 of clean scrap metal, 320 transformer cases, 96 capacitors and 120 yd^3 of contaminated soil. The second phase of the cleanup identified 4,900 yd^3 of soil contaminated at levels exceeding 5 ppm PCBs, the established cleanup objective. The third phase of the cleanup will use the TTDU to incinerate the 4,900 yd^3 of contaminated soil and treat to a level of 5 ppm or less. The treated material will be placed back on the site and will not be capped.

ABILITY DRUM SITE

Ability Drum, located in Tazewell County near Washington, Illinois, operated from 1964 to 1984 as a metal drum cleaner and reconditioner. As a byproduct of treating thousands of drums from the heavily industrialized Peoria area, hazardous waste was generated. This material was spilled and dumped on the plant property and placed in metal separation tanks and in a 1 acre lagoon. The lagoon was drained later and the soil berm was pushed in on top of several feet of contaminated sludge. IEPA removed over 100 drums of hazardous waste from the site. Also discovered at the site were 70 buried drums filled with hazardous waste. These were secured in a building at the site. What remains to be handled by the TTDU is 12,000 yd^3 of contaminated sludge and soil and 70 metal drums and their contents.

SELECTING THE BEST EQUIPMENT AND COMPANY

IEPA has created a review panel to assist in the selection of the best qualified company to provide mobile incineration services along with waste excavation services. In addition to in-house reviewers, the IEPA has contracted with CH2M Hill to provide expert engineering, advice and technical assistance in the evaluation and selection of a contractor. IEPA intends to award a contract to construct, mobilize, own and operate a TTDU at both the Beardstown and Ability sites. In deciding which company to select, IEPA intends to look at the stage of development of their

unit, permitting status, mobilization time frames, prior operating experience, financial strength and cost of treatment. The pay items in the contract will be tons of soil and sludge treated measured as dry treated tons after processing and drums and gallons as inputted to treatment. IEPA hopes to have started treatment at one site by the end of 1986.

CAN WE USE A TTDU AT A NATIONAL PRIORITY LIST (NPL) SITE?

If Illinois is to fully accomplish its goal of the use of TTDUs at private and NPL sites, there is a lot more work to be done. IEPA has taken several actions to gain acceptance of mobile incineration technology at NPL sites.

In April of 1985, IEPA asked Region 5 U.S. EPA to adopt in a Federal Record of Decision that the Acme Solvent site use on-site incineration as the means to detoxify thousands of yards of soil, sludges and drums. In October 1985, the Regional Administrator signed a Record of Decision which included incineration. Since then the consultant retained by the potentially responsible parties (PRPs) at Acme has estimated that on-site incineration of approximately 12,000 yd^3 of Acme waste will cost approximately $10 million and off-site incineration will cost approximately $30 million. While IEPA does not agree with these on-site cost figures, the ratio is instructive of the cost effectiveness of on-site incineration.

On Sept. 12, 1985 the Director of IEPA, Richard Carlson, wrote to Lee Thomas, Administrator of U.S. EPA, to request that a task force on the use of TTDUs at hazardous waste sites be formed. Mr. Carlson's letter reads in part:

...''Over the past few years Illinois EPA has been a vigorous proponent of alternative treatment technologies. I know you share our concern for reducing dependence on the landfilling of hazardous waste. Over the past year we have been evaluating the procurement of Transportable Thermal Destruction Unit (TTDU) that could be utilized at National Priority List (NPL) sites as well as sites in our State clean-up program....My staff and several incinerator manufacturers have been in contact with U.S. EPA employees in various regional offices and at headquarters attempting to identify what federal requirements must be met to operate a TTDU at a hazardous waste site. Due to the newness of this issue and the plethora of programs and regulations that are involved, it has been difficult to obtain consistent, clear answers to questions about relevant regulatory requirements. The regulations at issue involve RCRA, TSCA, CERCLA and the Clean Air Act. Therefore, I am requesting that a task force be formed by U.S. EPA to establish a uniform regulatory policy regarding the use of TTDUs at cleanup sites....I believe it would be very helpful in reaching our mutual goal of decontaminating soils and destroying hazardous waste at NPL sites if there was a clear understanding of a reasonable regulatory structure that could be articulated to prospective users. I look forward to your reply.''

In November 1985, Winston Porter, U.S. EPA Assistant Administrator, responded to Mr. Carlson's letter by informing him that a TTDU task force had been formed and inviting Mr. Carlson to participate. Since that time, staff of IEPA and U.S. EPA have conversed about the objectives of the task force. An initial meeting of U.S. EPA members to the task force was held in December 1985. IEPA is hopeful and optimistic that this task force can evaluate the many federal programs and regulations that impinge on the technology of mobile incineration and develop a simple but effective regulatory structure to speed the use of this technology at hazardous waste sites.

On Nov. 20, 1985, final publication of the National Contingency Plan goes part of the way in demonstrating U.S. EPA's willingness to consider on-site mobile incineration as an innovative technology that may be applicable at some NPL sites. Several wording changes from the original NCP show change in attitude and policy on U.S. EPA's part. The NCP amendment also included exemptions from having to obtain federal and state permits at NPL sites.

The State of Illinois supports this provision and similar language in the House and Senate versions of the CERCLA amendment, as long as the substantive state standards are considered and the state is consulted prior to a final remedy being selected. In fact, IEPA thought this permit exemption at NPL sites was such a good idea that we proposed an amendment to the House Superfund Reauthorization bill that accomplishes the same thing for states that have done certain things in relationship to non-NPL sites. At Section 121, (J) (13) (M) Permits For On-Site Cleanups Under State Authority, the House CERCLA version would exempt State-operated mobile incinerators from obtaining a RCRA Subtitle C permit, if certain conditions are met by the State. We believe by reducing the time normally required to obtain an RCRA Subtitle C permit, mobile incinerators will become most cost-effective because they can be kept in more constant service. The State of Illinois intends to meet all applicable state and federal regulations while operating its TTDUs when exercising the permit waiver.

TTDU USE AT FUTURE NPL SITES

IEPA is considering the use of a TTDU at a portion of the Waukegan Harbor NPL site. This proposal would involve on-site dredging, dewatering and incineration of 12,000 yd^3 of PCB-contaminated silt and sand. The treated material would be landfilled off-site.

IEPA is the state lead on the LaSalle Electric Utilities site. This site manufactured and reconditioned transformers for approximately 40 years in LaSalle, Illinois. As part of its operations, it sprayed waste oils containing PCBs on adjacent parking lots, soils, on city streets and alleys; some PCBs reached residential lawns. IEPA is considering proposing the use of a TTDU on the plant property to decontaminate tens of thousands of yards of PCB-contaminated soils.

PRIVATE USE OF TTDUs

A great many of the hazardous waste sites on and off the NPL are going to be remediated by responsible parties. IEPA has been encouraged that PRPs at the Acme Solvents site have put out a bid request to incinerate 12,000 yd^3 of sludge, soil and contaminated drums on-site. The IEPA also has been encouraged that Monsanto has chosen to exhume and incinerate 5,000 drums of hazardous waste buried on its property. This waste is being incinerated off-site by Rollins Environmental Services. In addition, the IEPA has been encouraged by the dozens of inquiries from potential TTDU vendors, PRPs and other prospective users in the private and governmental sector including various agencies of the Federal government and other states.

CONCLUSIONS

The handling of contaminated soil at hazardous waste sites is one of the most vexing problems to be dealt with in site cleanups. There is a tendency to cap, cover or contain on-site with a slurry wall or transport off-site for disposal in an RCRA approved landfill. IEPA believes that in many situations this is a short-term approach which will not permanently solve the problem. Under CERCLA, the state assumes the responsibility for long-term operation and maintenance. Under the uniform manifest system,

the state ends up signing as generator at many state cleanups and at all state-led NPL sites. This is a very disconcerting situation which the state is attempting to remedy. IEPA believes the availability of mobile incineration technology is one way to really cleanup sites more permanently—not merely postpone the problem until later.

IEPA is proud of its accomplishments in serving as a catalyst in promoting the use of mobile incineration as an alternative treatment technology whose time has come. IEPA has been willing to match its conviction with substantial amounts of state monies. We do not mind being the "guinea pig" if it serves the public purpose of furthering a promising technology. Our goal is to have this technology provided by many different companies in a competitive market place situation. This will allow the State of Illinois to have its choice among many qualified providers so that we are able to landfill less hazardous waste and incinerate more hazardous waste as the IEPA strives to achieve more permanent environmental solutions in our hazardous waste management program.

An Introduction to EPA's New Trial Burn Data Book

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ABSTRACT

A trial burn data book has been prepared by the U.S. EPA's Center for Environmental Research Information, Technology Transfer Staff, for use in the permitting and testing of hazardous waste incinerators regulated under RCRA. Test results from 23 hazardous waste trial burns conducted in the United States at various types of full-scale stationary incinerators are summarized. In addition to the incinerator trial burn data, the book also contains results of U.S. EPA Hazardous Waste Engineering Research Laboratory tests at 11 U.S. lime, cement and aggregate kilns and nine industrial boilers. This paper discusses only the data derived specifically from trial burns at incinerators.

INTRODUCTION

RCRA requires that hazardous waste incinerators adequately destroy hazardous organic compounds while maintaining acceptable levels of particulate and chloride (HCl) emissions. Owners and operators of these incinerators must demonstrate the acceptable performance of the facility by means of a trial burn. Consequently, industry and control agency personnel have become involved in planning for, conducting and interpreting the results from trial burns as an integral part of the RCRA permitting process.

In an effort to assist the RCRA permitting process, the U. S. EPA has prepared a trial burn data book as a reference document for use in the permitting and testing of hazardous waste incinerators and other thermal treatment devices that are now or soon may be regulated under RCRA. The trial burn data book summarizes the test results from hazardous waste trial burns conducted at 23 full-scale stationary incinerators in the United States. Eight of these trial burns were designed and conducted by the U.S. EPA and its contractors as part of the U.S. EPA's Regulatory Impact Analysis of the RCRA incinerator regulations. The other 15 were conducted separately and individually by private industrial concerns and their contractors as part of their Part B application requirements for obtaining full operating permits under RCRA.

This paper discusses incinerator performance only; however, the report also contains data from hazardous waste test burns at 11 lime, cement and aggregate kilns and nine industrial boilers in the United States. The U.S. EPA conducted these tests as part of an overall research program aimed at determining the efficiency of these thermal units for cofiring (and thereby destroying) hazardous wastes as fuel supplements or replacements. The practice of substituting hazardous wastes for fossil fuels in kilns and boilers is currently exempt from RCRA regulation, but this situation may change as more is learned about the overall effect of typical kiln and boiler operating conditions on various waste-oriented performance parameters, such as waste destruction and removal efficiencies, chloride and particulate emissions and the formation of unwanted byproducts of combustion.

This is the first time that a trial burn data book containing results from a wide variety of combustion tests has been assembled. The authors sincerely hope the document will be a beneficial source of information for those involved in the planning, execution and evalulation of hazardous waste trial/test burns. This data book is intended to be used in conjunction with other U.S. EPA guidance documents on hazardous waste incineration.

DATA BOOK CONTENT

The trial burn data book gives introductory material on the purpose, scope and intended use of the document. Major types of incinerators, boilers and process kilns now in use in the United States are discussed, and the names and addresses of incinerator manufacturers/vendors are identified. Schematic diagrams are included to help the reader visualize each type of unit. The design information presented herein is meant to give the reader a technical overview of these processes.

The results of the trial and test burns conducted at incinerators, boilers and kilns are presented and analyzed. The discussion includes specifics of the types of units tested, operating conditions during the tests, emission test results and any notable trends in the data. Basic data derived from the trial and test burn reports at each incinerator, boiler or kiln are presented on summary forms similar to that shown in Figure 1.

ANALYSIS OF INCINERATOR PERFORMANCE DATA

As noted earlier, this book contains avai'able trial burn test data from 23 separate incinerators located throughout the United States. These test data were taken from 15 trial burn reports[1] submitted by private concerns to the U.S. EPA over the past several years as part of their RCRA permitting requirements and from the U.S. EPA's most recent R&D performance study of eight operating units.[2] Most of the trial burns consisted of multiple tests or runs in which one or more POHCs were monitored under varying operating conditions (e.g., varying feed concentrations or rates, temperatures or residence times). As a result, the trial burn data discussed and analyzed in this report include a total of 534 POCH/test combinations. Table 1 presents a broad overview of the test results.

INCINERATOR TRIAL BURN SUMMARY

Date of Trial Burn. _____

Run No. _____

Incinerator information:

Type of unit: _____

Capacity: _____

Pollution control system: _____

_____

Waste feed system _____

_____

Residence time: _____

Commercial. ☐ Private/industrial ☐

Trial Burn Conditions.

Waste feed data

Type of waste(s) burned _____

_____

_____

Length of burn: _____

Total amount of waste burned _____

Waste feed rate: _____

POHC's selected and concentration in waste feed

Name Concentration

_____

_____

_____

_____

_____

Btu content: _____ Chlorine content. _____

Ash content: _____ Moisture content. _____

Operating Conditions

Temperature Range _____ Average _____

Auxiliary fuel used: _____

_____

_____

Excess air: _____

Other: _____

_____

Monitoring Methods:

POHC's: _____

Cl: _____

Particulate: _____

Other: _____

_____

_____

Emission and DRE Results

POHC's _____

_____

_____

_____

_____

Cl: _____

Particulate: _____

THC: _____

CO: _____

Other: _____

PIC's: _____

_____

_____

Reference(s)

_____

_____

Comments: _____

_____

_____

Figure 1
Example Data Summary Form

Table 1
Overview of Incinerator Test Results

Item	No. Tested	No. of failures		
		DRE	Particulate	HCl
Sites	23	9[a]	10	3
Individual POHC's	57	22[b]		
POHC/test combinations	534	119		-

[a] All of these sites also had at least some POCH DREs greater than 99.99%.

[b] Almost all of these POHCs also had at least some successful (greater than 99.99% DRE) test runs. Exceptions were diethyl phthalate, hexachlorobutadiene, m-dichlorobenzene and 1,2,4-trichlorobenzene.

DRE

Tables 2 and 3 show more detailed summaries of the POHC-DRE test data. Table 2 lists the test data by site, giving information on the type of incinerator, type of wastes, temperature, POHCs and DRE results. The table shows that seven of the eight units tested by the U.S. EPA experienced periodic DRE failures (as well as successes), whereas only one of the 15 privately sponsored study units (Site 4) reported a DRE value of less than 99.99%. One would expect the trial burn data submitted to the U.S. EPA in support of a permit application to indicate DREs of 99.99% or greater, but the operating incinerators tested by the U.S. EPA also should perform consistently at this level. One conclusion that can be drawn from this data pattern is that the DRE is obtained during "tweeked" conditions (i.e., when operating parameters are adjusted to their optimum performance levels) during trial burns often does not exist during extended day-to-day operations.

The relationship between incinerator type and performance as measured by DRE successes and failures can be studied by examining Table 2. The data show that four of seven rotary kilns tested experienced DRE failures. None of the single-chambered liquid or liquid-gas incinerators had DRE failures, whereas three of the five double- or triple-chambered liquid-solid incinerators did. Although no configuration emerges from the data as a clearly superior system, those which burn liquids or gases (not solids) tend to get consistently better DRE performance results. This is consistent with acknowledged difficulties in achieving complete combustion efficiency when burning solids.

Table 3 shows POHC statistics in terms of DRE successes and failures. Some POHCs such as carbon tetrachloride, tetrachloroethylene, trichloroethylene, chlorobenzene, toluene, chloroform, trichloroethane and a few others have been tested more frequently. Most tests have been successful, but there also have been a significant number of failures. On average, better than one of every five POHC tests has failed. The table clearly demonstrates that no POHC is guaranteed to get 4-9's (i.e., 99.99%) DRE. POHCs which have been more extensively tested tend to experience a 10 to 30% failure rate. For those POHCs for which only three or four test results are available, the true failure rate probably not known.

Particulate and Hydrogen Chloride Emissions

Emissions of particulate matter and HCl are limited by 40 CFR 264.343 as follows:

Particulate matter — 0.08 gr/dscf* corrected to 7% O_2

HCl — 4 lb/hr, or an HCl removal efficiency equal to or greater than 99%

*gr/dscf = grains/dry standard cubic foot of gas

Table 2
Average DREs by POHC and Test Site

Site No.	Sponsor	Type of Incinerator	Type of Waste	Approximate Temperature, °F	POHC	Average DRE, % (No. Values)	No. of DRE Values Less Than 99.99%
1	Private	Rotary kiln with secondary chamber	Solid, liquid	1880-2030	1,1,2-Trichloroethane	99.9973 (10)	0
					Carbon tetrachloride	99.9988 (10)	0
2	Private	Vertical cylinder	Solid, liquid	1620-1830	Formaldehyde	99.993777 (9)	0
3	EPA	Single-chamber	Liquid	1160-1240	Aniline	99.999918 (4)	0
					Diphenylamine	99.999133 (3)	0
					m-Dinitrobenzene	99.99 (1)	0
					Mononitrobenzene	99.99991 (1)	0
					Phenylene diamine	99.9984 (3)	0
4	Private	Rotary kiln with secondary chamber	Liquid, solid	1800	Chlorobenzene	99.99916 (5)	0
					Hexachloroethane	99.9958 (5)	0
					Methylbenzene	99.99856 (5)	0
					Tetrachloroethene	99.992 (5)	1
5	EPA	Rotary kiln and cyclonic furnace			Bromodichloromethane	99.98 (2)	1
					Carbon tetrachloride	99.966 (5)	2
					Chloroform	99.99 (5)	0
					Dichlorobenzene	99.99 (3)	0
					Hexachlorobenzene	99.99 (6)	0
					Hexachloroethane	99.99 (3)	0
					Hexachloroethene	99.99 (6)	0
					Hexachlorocyclopentadiene	99.981666 (6)	2
					Pentachloroethane	99.99 (3)	0
					Tetrachloroethane	99.99 (2)	0
					Tetrachloroethene	99.986 (5)	1
					Trichloroethane	99.99 (1)	0
					Trichloroethylene	99.99 (1)	0
6	Private	Acid regeneration furnace	Liquid	1830	1,1,1-Trichloroethane	99.999979 (4)	0
					Benzene	99.999995 (4)	0
					Carbon tetrachloride	99.999979 (4)	
7	Private	Rotary kiln with secondary chamber	Solid, liquid	1800-1860	1,1,1-Trichloroethane	99.997 (2)	0
					Carbon tetrachloride	99.9975 (2)	0
					Trichlorobenzenes	99.9935 (2)	0
8	Private	Vertical-cylinder	Solid, liquid	1830-1910	Carbon tetrachloride	99.999851 (7)	0
					Dichloromethane	99.999642 (7)	0
9	EPA	Rotary kiln with secondary chamber	Solid, liquid	2640	1,1,1-Trichloroethane	99.932 (1)	1
					Benzyl chloride	99.999533 (3)	0
					Carbon tetrachloride	99.99985 (3)	0
					Chloroform	99.990733 (3)	1
					Cis-dichlorobutene	99.999953 (3)	0
					Dichloromethane	99.999103 (3)	0
					Hexachloroethane	99.99 (3)	0
					Naphthalene	98.166666 (3)	3
					Tetrachloroethylene	99.999486 (3)	0
					Toluene	99.999883 (3)	0
					Trans-dichlorobutene	99.999906 (3)	0
					Trichloroethylene	99.99798 (3)	0
10	Private	Single-chamber	Liquid, gas	1700-1730	Formaldehyde	99.996666 (3)	0
11	Private	Fluidized-bed	Sludge, liquid	1310	Naphthalene	99.998 (3)	0
					Phenol	99.993333 (3)	0
12	Private	Double-chamber	Solid, liquid	1800	1,1,1-Trichloroethane	99.999992 (4)	0
					Carbon tetrachloride	99.999957 (4)	0
					Tetrachloroethylene	99.997555 (4)	0
					Trichloroethylene	99.999855 (4)	0
13	EPA	Double-chamber	Liquid	1930-2050	Benzene	99.903 (2)	2
					Bis(ethylhexyl)phthalate	99.995833 (2)	0
					Butyl benzyl phthalate	99.986666 (3)	1
					Carbon tetrachloride	99.994375 (4)	1
					Methyl ethyl ketone	99.991675 (4)	2
					Naphthalene	99.975333 (3)	3
					Phenol	99.998153 (3)	0
					Tetrachloroethylene	99.9929 (1)	0
					Toluene	99.96075 (4)	4
					Trichloroethylene	99.988975 (4)	2
14	EPA	Single-chamber	Liquid, gas	2090	Dichlorodifluoromethane	99.99 (2)	0
					Trichlorofluoromethane	99.99985 (2)	0
15	Private	Single-chamber	Liquid, gas	2350	Dichlorofluoroethane	99.998142 (7)	0
16	EPA	Unknown	Unknown	Unknown	Butyl benzyl phthalate	99.9687 (3)	1
					Carbon tetrachloride	99.90636 (5)	4
					Chloroform	99.362 (5)	5
					Diethyl phthalate	99.959666 (3)	3
					Naphthalene	99.862333 (3)	3
					Phenol	99.981333 (3)	3
					Tetrachloroethylene	99.975516 (5)	2
					Toluene	99.991306 (5)	2
					Trichloroethylene	99.9026 (5)	5
17	EPA	Rotary kiln	Solid, liquid	2040-2110	1,1,1-Trichloroethane	99.999173 (3)	0
					1,1,2-Trichloroethane	99.999994 (3)	0
					2,4-Dimethylphenol	99.9992 (3)	0
					Aniline	99.998 (3)	0
					Butyl benzyl phthalate	99.998866 (3)	0
					Carbon tetrachloride	99.996133 (3)	0
					Cresol(s)	99.999133 (3)	0
					Dichloromethane	99.978333 (3)	3
					Methyl ethyl ketone	99.99943 (3)	0
					Methyl pyridine	99.998 (3)	0
					N,N-dimethylacetamide	99.999866 (3)	0
					Naphthalene	99.993 (3)	0
					Phenol	99.994 (3)	0
					Phthalic anhydride	99.99 (3)	0
					Tetrachloroethylene	99.998473 (3)	0
					Toluene	99.998513 (3)	0
					Trichloroethylene	99.997676 (3)	0

(Continued)

Table 2 (continued)

Site No.	Sponsor	Type of Incinerator	Type of Waste	Approximate Temperature, °F	POHC	Average DRE, % (No. Values)	No. of POHC Values Less Than 99.99
18	Private	Rotary kiln with secondary chamber	Solid, liquid	2220	PCB	99.999762 (4)	0
19	Private	Single-chamber	Liquid	1620-1710	Chloroform	99.99999 (3)	0
					Methylbenzene	99.998243 (3)	0
					Tetrachloroethene	99.999983 (3)	
20	EPA	Double-chamber	Solid, liquid	1810-2080	1,1,1-Trichloroethane	99.8145 (8)	8
					Benzene	99.992951 (8)	3
					Bis(ethylhexyl)phthalate	99.93275 (4)	4
					Carbon tetrachloride	99.997178 (8)	0
					Chlordane	99.999866 (3)	0
					Chlorobenzene	99.861237 (8)	7
					Chloroform	99.4555 (8)	8
					Dibromomethane	99.983503 (8)	4
					Dichloromethane	99.7385 (8)	8
					Hexachlorobutadiene	99.98 (1)	1
					Hexachlorocyclopentadiene	99.9924(4)	0
					Naphthalene	99.996(1)	0
					Tetrachloroethylene	99.860428 (7)	7
					Toluene	99.996716 (8)	0
					Trichloroethylene	99.995168 (8)	1
21	Private	Three-chamber	Solid, liquid	1600-1800	1,2-Dichlorobenzene	99.999705 (12)	0
					Chlorobenzene	99.999366 (12)	0
					Hexachloroethane	99.999906 (12)	0
					Tetrachloroethylene	99.99979 (12)	0
22	EPA	Horizontal cylinder	Liquid, gas	2040	1,2,4-Trichlorobenzene	99.333333 (3)	3
					Aniline	99.992866 (3)	1
					Bis(ethylhexyl)phthalate	99.97 (3)	3
					Carbon tetrachloride	99.994166 (3)	0
					Chlorobenzene	99.9025 (2)	1
					Chloromethane	99.9971 (3)	0
					Chlorophenyl isocyanate	99.9991 (1)	0
					m-Dichlorobenzene	99.919666 (3)	3
					o-Dichlorobenzene	99.997 (3)	0
					p-Dichlorobenzene	99.997666 (3)	0
					Phenyl isocyanate	99.999913 (3)	0
					Phosgene	99.99575 (2)	0
					Trichloroethylene	99.99892 (3)	0
23	EPA	Double-chamber	Liquid	1550-1660	Carbon tetrachloride	99.993327 (4)	1
					Chlorobenzene	99.99665 (4)	0
					Dichloromethane	99.906 (1)	1
					Toluene	99.98305 (4)	1
					Trichloroethylene	99.9925 (4)	1

Although these emissions are generally a function of the ash and chloride contents of the waste, the outlet concentration also depends on the exhaust gas control system. Because control systems varied from site to site, correlating the particulate and HCl emissions with input concentrations is impossible. Although the available data do not permit the development of such a relationship, they do indicate that, in general, the emission limits are achievable.

Not all of the reports were complete enough to determine with certainty whether both the HCl emission limits were met, but the data indicate that HCl emissions exceeded 4 lb/hr at only two sites (Sites 5 and 13). One site (No. 21) reported HCl removal efficiencies of less than 99%, but the information was insufficient to determine whether emissions from this site were within the quantitative limit of 4 lb/hr.

Ten sites (representing both the privately sponsored trial burn group and the U.S. EPA's recent eight-plant study) experienced periodic problems in limiting particulate emissions to the 0.08 gr/dscf required by Federal Regulation 40 CFR 264.343. Six of the sites in the eight-plant U.S. EPA study exceeded the 0.08 gr/dscf (corrected to 7% O_2) during one or more of the test runs. Four sites (Sites 4, 5, 13 and 16) were particularly deficient in control of particulate matter.

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Table 3
DRE Successes and Failures Arranged Alphabetically by POHC

POHC	No. of Tests	No. of Successes (≥99.99%)	No. of Failures (<99.99%)
Aniline	10	9	1
Benzene	14	9	5
Benzyl chloride	3	3	0
Bis(ethylhexyl)phthalate	10	3	7
Bromodichloromethane	2	1	1
Butyl benzyl phthalate	9	7	2
Carbon tetrachloride	62	54	8
Chlordane	3	3	0
Chlorobenzene	31	22	9
Chloroform	24	10	14
Chloromethane	3	3	0
Chlorophenyl isocyanate	1	1	0
Cis-dichlorobutene	3	3	0
Cresol(s)	3	3	0
Dibromomethane	8	4	4
Dichlorodifluoromethane	2	2	0
Dichlorobenzene	3	3	0
1,2-Dichlorobenzene	12	12	0
Dichlorofluoroethane	7	7	0
Dichloromethane	22	10	12
Diethyl phthalate	3	0	3
2,4-Dimethylphenol	3	3	0
Diphenylamine	3	3	0
Formaldehyde	12	12	0
Hexachlorobenzene	6	6	0
Hexachlorobutadiene	1	0	1
Hexachloroethane	23	23	0
Hexachloroethene	6	6	0
Hexachlorocyclopentadiene	10	8	2
m-Dichlorobenzene	3	0	3
m-Dinitrobenzene	1	1	0
Methyl ethyl ketone	7	5	2
Methyl pyridine	3	3	0
Methyl benzene	8	8	0
Mononitrobenzene	1	1	0
N,N-Dimethylacetamide	3	3	0
Naphthalene	16	13	3
o-Dichlorobenzene	3	3	0
p-Dichlorobenzene	3	3	0
PCB	4	4	0
Pentachloroethane	3	3	0
Phenol	12	9	3
Phenol isocyanate	3	3	0
Phenylene diamine	3	3	0
Phosgene	2	2	0
Phthalic anhydride	2	2	0
Tetrachloroethane	2	2	0
Tetrachloroethylene	48	37	11
Toluene	27	20	7
Trans-dichlorobutene	3	3	0
Trichlorofluoromethane	2	2	0
1,2,4-Trichlorobenzene	3	0	3
Trichlorobenzenes	2	2	0
Trichloroethane	1	1	0
1,1,1-Trichloroethane	22	13	9
1,1,2-Trichloroethane	13	13	0
Trichloroethylene	35	26	9
Totals	534	415	119

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Low Temperature Thermal Stripping of Volatile Compounds

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ABSTRACT

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), located in the Edgewood area of Aberdeen Proving Ground, Maryland, has Army responsibility for installation, restoration and demilitarization of unserviceable or obsolete chemical agent munitions. It also serves as the lead agency within the U.S. Army Materiel Command (AMC) for pollution abatement and environmental control technology development. In this role, USATHAMA routinely conducts generic research and development (R&D) studies with wide application to current U.S. Army environmental problems. The low temperature thermal stripping of volatile organic compounds from soil is an example of one of the many successful R&D efforts USATHAMA has conducted.

INTRODUCTION

Contamination of soils from past operations involving volatile organic compounds (VOCs) has become one of the predominant environmental concerns at several U.S. Army installations. Trichloroethylene (TCE) is the most frequently found contaminant; however, other VOCs such as dichloroethylene, tetrachloroethylene and xylene also have been found. If allowed to remain in the soil, these compounds can migrate to contaminate underlying groundwaters.

The U.S. Army Toxic and Hazardous Materials Agency currently is developing a number of technologies to treat VOC-contaminated soils. One technology is low temperature thermal stripping. This innovative process utilizes a heated screw conveyor to volatilize the organics from the soil and an afterburner for thermal destruction of the volatilized organics. Bench-scale studies of the thermal stripping concept identified the method as a feasible treatment process. A pilot-scale field demonstration of the process, using actual VOC-contaminated soils, became the next phase in the development of the technology.

In May 1985, USATHAMA contracted Roy F. Weston, Inc. to conduct a pilot test of the low temperature thermal stripping technology using soils from an actual VOC-contaminated site. Weston's responsibilities fro the project included:

- Design of the pilot system
- Preparation of test and safety plans
- Environmental permitting
- Equipment selection
- Equipment installation and startup
- Performance of the test program
- Demobilization and site closure
- Preparation of a technical report

OBJECTIVES

The primary objective of the pilot investigation was to determine the feasibility of low temperature thermal stripping as a remedial action technology for VOC-contaminated soils. Secondary objectives included:

- Determination of the impact on system performance of varying design parameters (e.g., operating temperature, residence time, air temperature, etc.)
- Determination of the optimum range of operational parameters for the pilot system
- Identifiçation of full-scale design criteria
- Evaluation of the off-gas pollutant levels to determine air pollution control devices required for full-scale implementation of the process
- Preparation of engineering cost estimates for application of the technology
- Identification of any future research needs for system optimization

PROJECT DESCRIPTION

The pilot-scale thermal processing equipment (Fig. 1) was transportable and was delivered to the site on a single flatbed truck. The entire system was installed and fully operational within 10 days after delivery.

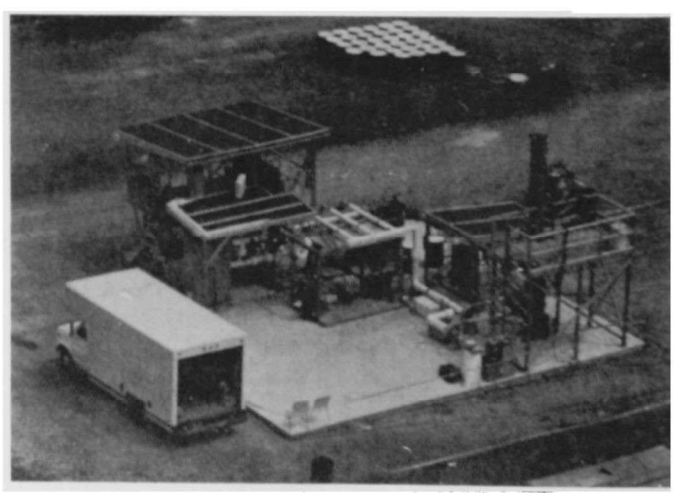


Figure 1
Installed Pilot Thermal Processing System

During the 28 days of rigorous testing, more than 15,000 lb of soil were processed. The four primary elements of the testing program were excavation and materials handling, thermal processing, sampling and analysis.

Excavation and Materials Handling

The VOC-contaminated soil was excavated by backhoe from a site near the processing area (Fig. 2). Excavation operations began early each morning of the testing period. As excavation progressed, a portable gas chromatograph was used to identify contaminated soils for the test. VOC levels in the soils were as high as 20,000 ppm. Soils chosen for processing were placed in closed containers to minimize release of contaminants prior to processing. The soils typically were processed within several hours of excavation.

Thermal Processing

The heart of the treatment system is the thermal processor which heats the soils sufficiently to volatilize the organics (Fig. 3). Once volatilized, the organics are destroyed in the afterburner.

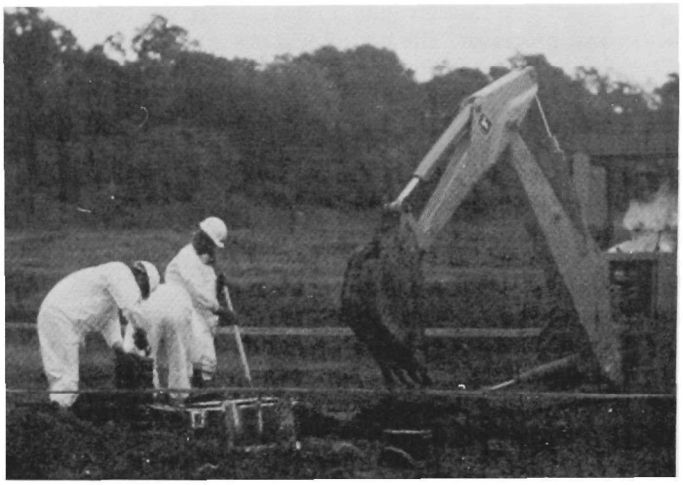


Figure 2
Typical Excavation Operations of VOC-Contaminated Soil

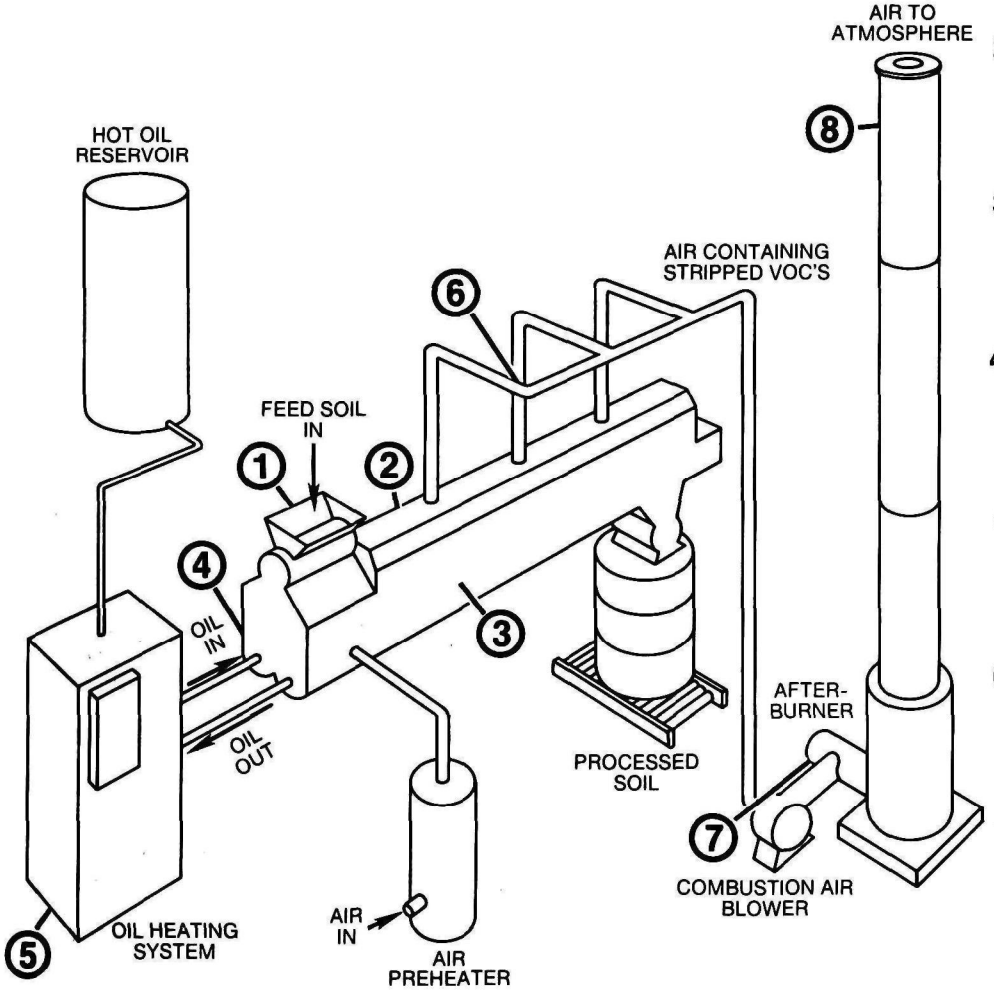
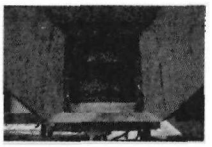
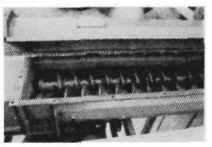


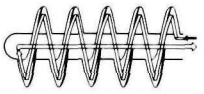
Figure 3
Schematic Illustration of the Low Temperature Thermal Stripping System



1 ***Soil feed hopper.*** *Rotary valve design provided positive feed control and ensured air-tight operation.*

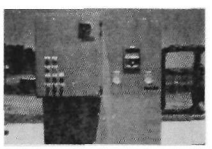


2 ***Thermal Processor.*** *Internal view of Holo-Flite® Processor leased from the Joy Manufacturing Company.*



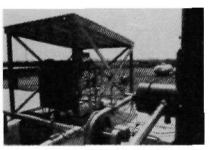
3 ***Holo-Flite® Screw.*** *Hot oil entered the first flight of each screw conveyor, traveled the full length of each screw, then returned back through the center of each shaft continuously throughout system operation.*

4 ***Trough jacket.*** *Trough walls provided additional heat transfer surfaces. The hot oil moved down and back the length of the jacketed trough.*



5 ***Oil heating system.*** *Electric resistance oil heater provided infinite control of oil inlet temperature up to 300°C.*

6 ***Off-gas emission monitoring.*** *Continuous emission monitoring of VOC concentrations was conducted for each of the three off-gas lines.*



7 ***Afterburner.*** *The air containing stripped VOC's was combusted in an afterburner which provided a residence time of greater than two seconds at a temperature of 1000°C to ensure complete destruction of the organics.*

8 ***Stack testing.*** *Stack testing was conducted to determine atmospheric emission rate, if any, of VOC's, particulates, and HCl.*

An indirect heat transfer fluid, in this case oil, was used to heat the thermal processor. The hot oil was not contaminated by the soil and was recycled to obtain maximum thermal efficiency.

The soil was conveyed from the feed end of the thermal processor to the discharge end by the twin screws. Both the screws and the screw conveyor trough were heated by the circulating hot oil.

The continuous movement of the screws conveyed and thoroughly mixed the VOC-contaminated soils. This intermixing action caused break-up of soil lumps and allowed soil particles to come into frequent contact with the surfaces containing the circulating hot oil, providing good heat transfer and soil/air interface.

For the pilot-scale system, the processed soil discharged into a 55-gal drum for containment and storage.

The air entering the thermal processor was either ambient or heated, depending on test conditions. The air containing the volatilized organics was sent to the afterburner.

The afterburner provided a residence time of greater than 2 sec at a temperature of 1,000 °C to ensure complete destruction of the organics. The VOC-contaminated air served as the combustion air for the burner flame. Therefore, the VOCs were exposed to the high temperatures and turbulence within the flame vortex, which ensured complete thermal destruction of the organics.

Sampling

The field demonstration program determined the VOC contaminant removal efficiency under several varied operating conditions, including:

- Soil discharge temperatures (50 °C to 150 °C)
- Soil residence times (30 to 90 min)
- Air inlet temperatures (ambient to 90 °C)
- Heating oil conditions (100 °C to 300 °C)

Samples were collected for analysis from soil and air. Figure 4 provides a thermal processor instrumentation and sampling/analysis diagram.

Soil Sampling—Composite soil samples were collected for each test run at these locations:

- The excavation site
- Prior to feed into the thermal processor
- After discharge from the thermal processor

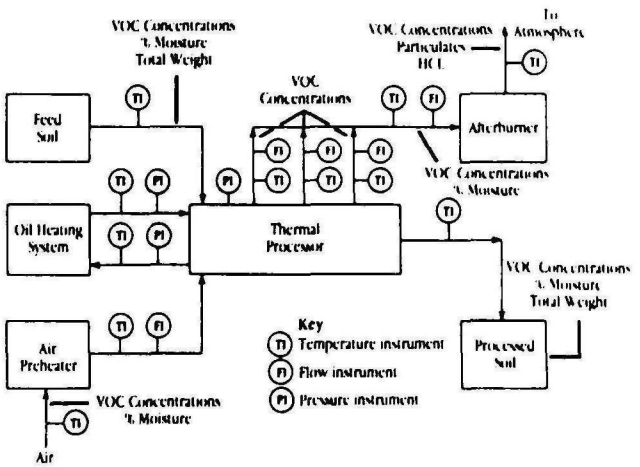


Figure 4
Thermal Processor Instrumentation and Sampling/Analysis Diagram

This procedure allowed: (1) the estimation of contaminants violated during soil excavation and handling operations; and (2) determination of the VOC removal efficiency of the thermal processor.

Air Sampling—Air VOC concentrations and corresponding removal efficiencies were determined at three separate locations: ambient air entering the thermal processor; off-gas leaving the thermal processor; and stack gas downstream of the afterburner.

In addition, particulate and HCl emissions were sampled in the afterburner stack to determine air pollution control devices required for full-scale implementation of the process.

Analysis

A portable field gas chromatograph (GC) was used to provide continuous real-time total VOC emission monitoring in each of the three air discharge lines from the thermal processor during actual testing. A mobile gas chromatograph/mass spectrometer (GC/MS) also was utilized at the site during 1 week of testing to provide additional qualitative and quantitative VOC data at the same locations. All soil and air samples collected during testing were analyzed using a GC/MS (Fig. 5). These analyses provided complete and accurate identification of all VOCs present in the samples.

The testing program consisted of 28 test runs in a matrix format designed to facilitate statistical analysis of the results. Analysis of the test data provided important information regarding optimization of system performance and development of full-scale design criteria.

Figure 5
GC/MS Analyses of Samples

RESULTS

Eighteen days of formal testing were completed within 22 consecutive calendar days. During this period, more than 10,000 lb of contaminated soils were processed.

Upon completion of formal testing, 10 additional days of testing were conducted to optimize system performance. During this period, more than 5,000 lb of contaminated soils were processed.

A comparison of the VOCs measured in the feed soil to VOCs measured in the processed soil and stack gas yielded the following destruction and removal efficiencies (Table 1):

Table 1
Summary of Soil VOC Concentrations and Maximum VOC Removal Efficiencies

Summary of Soil VOC Concentrations and Maximum VOC Removal Efficiencies

VOC	Feed Soil Concentrations Average (ppm)	Feed Soil Concentrations Maximum (ppm)	Maximum Removal Efficiency
Dichloroethylene	83	470	100%
Trichloroethylene	1,673	19,000	100%
Tetrachloroethylene	429	2,500	100%
Xylene*	64	380	100%
Other VOC's	14	88	100%
Total VOC's	2,263	22,438	> 99.99%

*Xylene is not classified as a VOC since its boiling point is approximately 140°C. However, it was included in this study to evaluate the effectiveness of this technology on higher boiling point semi-volatile compounds.

- Greater than 99.99% removal of VOCs from the soil was attained
- No VOCs were detected in the stack gas, indicating a destruction and removal efficiency (DRE) for the overall system of 100%

Stack emissions were in compliance with all Federal and state regulations (including VOCs, HCl, CO and particulates).

After regulatory approval, the processed soils were disposed of on-site as backfill.

CONCLUSIONS

Based on the unqualified success of this field demonstration program, USATHAMA will proceed with the following phases of low temperature thermal processing technology development:

- Develop optimized design and performance criteria for full-scale implementation of the low temperature thermal stripping process
- Develop life-cycle costs for comparison of the thermal stripping process to alternative treatment/disposal options applicable to VOC-contaminated soils
- Prepare detailed thermal processing equipment bid specifications for full-scale applications of the technology

Comparisons Between Fluidized Bed and Rotary Kiln Incinerators for Decontamination of PCB Soils/Sediments at CERCLA Sites

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ABSTRACT

Currently, there is a tremendous number of sites at which contaminated soils will need to be detoxified by on-site incineration or taken for off-site disposal in a secure landfill.

A total of 787 hazardous waste sites are currently on the U.S. EPA National Priorities List, designated and proposed. On Mar. 26, 1985, 26 new sites were recommended for addition to the list.[1]

In October 1984, the U.S. EPA estimated that, nationwide, there were 54,644 landfills and 180,000 industrial park lagoons containing potentially dangerous amounts of hazardous waste. Some 18,000 of these sites presently are listed as posing potential health risks to the surrounding populations.[1]

The U.S. Congress, Office of Technology Assessment, estimates that at least 10,000 hazardous waste sites nwill have to be cleaned up over the next 50 years, involving over $100 billion in Federal funding.[1]

Since 1950, possibly 6 billion tons of toxic waste have been disposed of in or on the land, creating a tremendous residual backlog in waste management. Incremental tons of contaminated soil, which have leached contaminants from hazardous landfills, have been created over the years.

Presently, the Corps of Engineers and the U.S. EPA are very interested in on-site incineration for the detoxification of contaminated soil, so that the decontaminated material can be used for site reclamation. Since landfill costs range from $200 to $400/ton and incineration costs for on-site cleanup may range from $400 to $600/ton, incineration may appear more expensive.[2,3] However, considering the liability involved with landfilling and any possible leakage, costs may exceed $1,000/ton over a period of 10-20 years. Considering the liability situation, on-site incineration may look more attractive. In addition, costs for transportation are reduced, and the costs of fill materials for

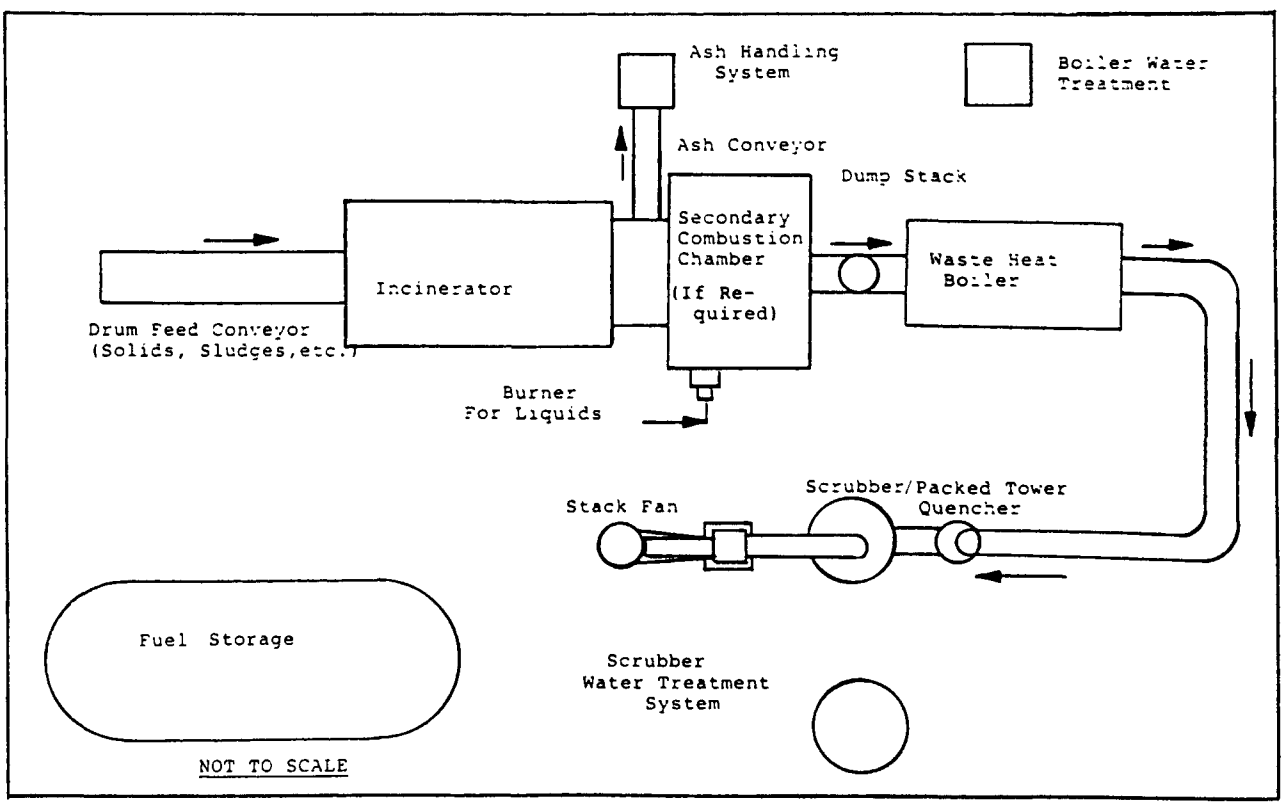

Figure 1
Integrated Hazardous Waste Incineration System

reclamation are practically eliminated since incinerated soils may be available for reclamation.

More importantly, under U.S. EPA regulations, release of PCB-contaminated material into the environment at concentrations of or exceeding 500 ppm is considered improper PCB disposal. The U.S. EPA requires that PCBs in these concentrations be cleaned up and disposed of properly. Thus, this requirement eliminates landfilling as an ultimate disposal option and limits cleanup to decontamination by incineration.

INTRODUCTION

Traditionally, rotary kiln incinerators have been used at commercial facilities for the destruction of hazardous wastes. The once emerging technology of fluidized bed incineration is now a demonstrated technology and is being considered for the destruction of hazardous wastes and the decontamination of soils/sediments at industrial and CERCLA sites.

For either type of incinerator system, a systematic approach should be followed and an integrated system should be developed for the excavation, storage, mixing, combustion and ash disposal as shown in the schematic in Figure 1.

Assuming that the system basically would be the same for any given site, the focus of this paper should be on the combustion unit (Fluidized Bed Incinerator and Rotary Kiln Incinerator).

ROTARY KILN UNIT

The Rotary Kiln Unit has the potential for handling a wide variety of solid wastes including sludges, soils and slurries. The system also can handle liquid and gaseous wastes if required.

The Rotary Kiln Unit consists of a horizontal cylinder which is lined with refractory; this cylinder rotates about its horizontal axis with its angle to the horizontal being normally less than 2 or 3%. As the kiln shown in Figure 2 rotates, it continually exposes the waste material surfaces to the heat and oxygen in the flowing gas. The speed of rotation is variable, normally being in the range of 0.25-1.5 revs/min. The peripheral speed of the kiln (outer surface) normally is within the range of 1 to 5 ft/min.

Another unique property of the Rotary Kiln Unit is the difference in retention time between solid materials within the kiln and combustion gases traversing the kiln. The retention time of the solids within the kiln is a function of the kiln speed, the rake and the physical parameters of the unit; the combustion gas retention time is based on temperature, excess air utilization and kiln diameter.

In the system shown in Figure 2, the material is ram fed into the kiln. As the kiln rotates, the waste burns to ash which is discharged to an ash bin. Burners can be mounted in either end of the kiln to provide wither startup or supplementary heat as required.

Both liquids which will burn in suspension and gases can be injected into the kiln from the front or rear face, although these nozzles normally are placed at the kiln entrance. Liquid and gaseous waste also can be injected into the afterburner for their destruction.

Sludges, slurries and solids are dropped on the kiln hearth. For some materials, the rake is set at zero or at a negative value to increase retention time.

The main advantages and disadvantages of the Rotary Kiln Unit are summarized below.

Advantages of Rotary Kilns

- Incinerates a wide variety of liquid and solid wastes
- Incinerates materials passing through a melt phase
- Capable of receiving liquids and solids independently or in combination
- Capable of accepting drums and bulk containers
- Adaptable to a wide variety of feed mechanism designs
- Characterized by high turbulence and air exposure of solid wastes
- Has continuous ash removal which does not interfere with the waste oxidation
- Has no moving parts inside the kiln (except when chains are added)

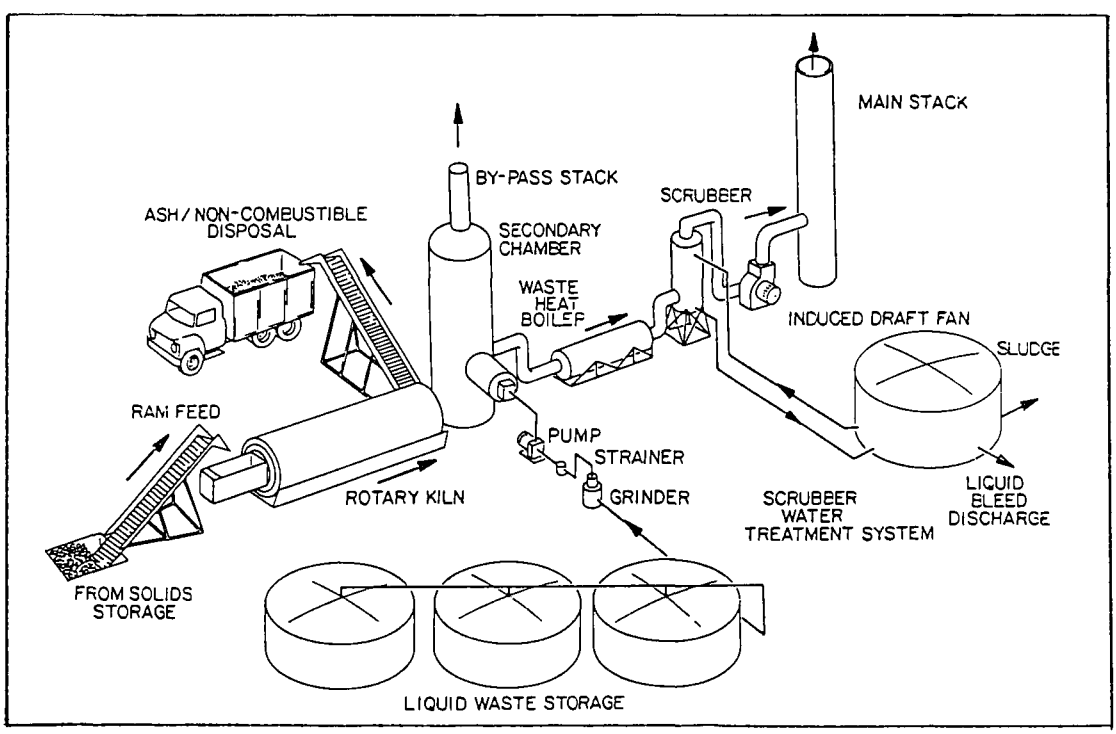

Figure 2
Hazardous Waste Rotary Kiln Incineration System

- Adaptable for use with a wet gas scrubbing system
- Retention or residence time of the non-volatile components can be controlled by adjusting the rotational speed
- Waste can be fed directly into the kiln without any preparation such as preheating, mixing, etc.
- Can be operated at temperatures in excess of 2,500 °F (1,400 °C), making them well suited for the destruction of toxic compounds that are difficult to thermally degrade.

Disadvantages of Rotary Kilns

- High capital cost
- Operating care is necessary to prevent refractory damage; thermal shock is a particularly damaging event
- Airborne particles may be carried out of the kiln before complete combustion
- Spherical or cylindrical items (such as disposable drums) may roll through the kiln before complete combustion of materials
- Frequently requires additional makeup air to make up for air leakage through the kiln end seals
- Drying or ignition grates, if used prior to the kiln, can cause problems with melt plugging of grates and grate mechanisms
- High particulate loadings
- Relatively low thermal efficiency

FLUIDIZED BED INCINERATOR

The Fluidized Bed Incinerator consists of the fixed bed, bubbling bed and circulating fluid bed. The units which are presently being used for soils decontamination are of the circulating fluid bed type, as shown in Figure 3. The circulating fluid unit consists of the combustion vessel with a refractory lining, a hot cyclone, a heat exchange device and a particulate and gaseous emission control system. The combustion chamber or vessel also includes a preheat burner assembly.

The Fluidized Bed Incinerator operating in the circulating bed mode operates at higher super surficial gas velocities than the conventional mode. In this mode, the bed material and fly ash are captured in the hot cyclone, collected in the cyclone bottom and reintroduced into the bed.

The hot combustion gases and particulate matter also leave the combustion vessel and enter the hot cyclone. Heavier particulate matter is returned to the combustor with the recycled bed material, while lighter particulate matter is routed with the hot gases through the heat exchanger and then through the particulate and gaseous pollution control systems.

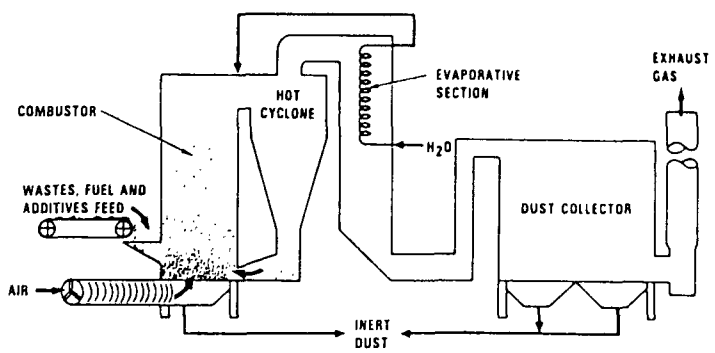

Figure 3
Circulating Fluidized Bed Combustor Unit

OPERATING CONDITIONS

A comparison of operating conditions of the two combustion units is presented in Table 1. In general, the rotary kiln/afterburner system is characterized by higher temperatures than the fluidized bed system. This condition is due primarily to the increased turbulence and mixing in the fluidized bed system which results in increased combustion efficiency.

Also, lower gas flow velocities in the fluidized bed may provide for a longer retention time than in the rotary kiln. This longer retention time also results in increased combustion efficiency.

Table 1
Comparison of Operating Parameters for Fluidized Bed and Rotary Kiln Incinerators for Decontamination of Soil at CERCLA Sites

PARAMETER	TYPE OF INCINERATOR ROTARY KILN	FLUIDIZED BED
Temperature/Primary (°F)	1200 - 1600	1350 - 1500
Temperature/Secondary (°F)	2000 - 2400	Not Applicable
Residence Time/Primary (sec)	0.5 1.5	0.75 2.5
Residence Time/Secondary (sec)	·2.0	Not Applicable
Heat Release Rate BTU/hr-ft³	25,000 40,000	20,000 35,000*
Airflow Requirements	50 200% excess air	15% excess air
Absolute Pressure (in H_2O W.C.)	-0.5 to -2.0	-1.0
Velocity (ft/sec)	25 30	15 - 18

*Based on limited data. In actuality, expected to be higher because of high turbulence conditions.

COMPARISON OF PCB DESTRUCTION EFFICIENCY

TSCA requires that destruction of PCBs in contaminated solids meet the following criteria:

(1) 99.99% destruction removal efficiency
(2) Exhaust stack PCBs fed to incinerator.

Although operational destruction efficiency data for PCB-contaminated soils are limited, some measured destruction efficiencies for the Rotary Kiln Incinerator and the Fluidized Bed Incinerators exist (Tables 2 and 3).

In general, both types of incinerators meet the required TSCA destruction efficiency criterion of 99.9999%.

Table 2
Rotary Kiln Performance Results
(PCB-Contaminated Soil Destruction Efficiency)

INCINERATOR	PCB DESTRUCTION EFFICIENCY (%)
Rollins/Deer Park	> 99.999964
Ensco	99.999943

COMPARISON OF COST AND SPACE REQUIREMENTS

A comparison of cost and space requirements of the two types of combustion units is presented in Table 4. In general, this table shows that, because of lower temperature requirements and greater heat release rates, the Fluidized Bed Incinerator should have lower operating costs and should require less space. However, the above conclusions are based on limited Fluidized Bed Incinerator data and also the effect of scale-up factor has not been established for the Fluidized Bed Incinerator.

Table 3
Fluidized Bed Performance Results
(PCB-Contaminated Solil Destruction Efficiency)

TEST NUMBER	1	2	3
CONDITIONS			
PCB concentration in soil, ppm	11,000	12,000	9,800
Soil feed rate, lb/hr	325	410	325
Combustion temperature, °F	1,800	1,800	1,800
Superficial velocity in combustion chamber, ft/sec	18.7	18.7	18.1
Excess oxygen, %	7.9	6.8	6.8
RESULTS			
Destruction and removal efficiency, (DRE), %	>99.999	>99.999	>99.999
PCB in bed ash, ppm	0.0035	0.0330	0.1860
PCB in fly ash, ppm	0.0660	0.0100	0.0320
Dioxin/furan in ash, ppm	------Not Detected---------		
Combustion efficiency, %	99.94	99.95	99.97

Table 4
Features of Fluidized Bed vs Rotary Kiln Incinerators

PARAMETER	COMMENTS
Space Requirements	FBC should require less space than RK due to greater heat release at same waste feed rate. Also fBC has no afterburner.
Instrumentation	No appreciable difference between FBC and RD
Operating Costs	FBC should have lower cost due to lower fuel consumption because of lower temperature requirement
Capital Costs	FBC should have lower cost due to smaller size and no afterburner.
Operator Skill	No appreciable difference between FBC and RK
Maintenance Cost	FBC should be slightly lower due to smaller size and no afterburner
Scale-up Problems	More data available for RK while FBC scale-up not established

CONCLUSIONS

It appears that either of the technologies for hazardous waste incineration discussed in this paper can be used for contaminated soil cleanup. The waste preparation and operating conditions will determine the resulting PCB destruction efficiency.

It appears that the circulated Fluid Bed Incinerator may have decided cost advantages and space benefits and could be moved more easily from site to site as a transportable unit. However, this conclusion is based on limited operational and test data.

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New Requirements for Underground Storage Tanks

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ABSTRACT

The Hazardous and Solid Waste Amendments of 1984 became law on Nov. 8, 1984 and, in addition to reauthorizing and making numerous changes to RCRA, a new Subtitle I was added that requires the U.S. EPA to establish a comprehensive program for the regulation of underground storage tanks. Subtitle I addresses underground storage in tanks of all substances regulated under CERCLA (except for hazardous waste storage tanks which already are regulated under Subtitle C of RCRA), as well as petroleum products. It is estimated that over one million underground tanks are subject to regulation under the new program.

Congress enacted the legislation for regulating underground storage tanks due to the increasing number and severity of environmental contamination incidents resulting from leaking underground tanks. There is growing evidence that leaking tanks are becoming a major cause of groundwater contamination.

The major provisions of Subtitle I include notification by owners of underground tanks to designated State or local agencies, an interim prohibition on the new installation of unprotected tanks, the development of technical standards for new and existing underground tanks including corrective action requirements for leaking tanks and tough new enforcement authorities to compel compliance with the new regulatory requirements. Subtitle I also allows the U.S. EPA to promulgate financial responsibility regulations for taking corrective action and compensating third parties for bodily injury and property damage caused by leaks from tanks. In addition, the U.S. EPA is required to authorize State programs regulating underground storage tanks in lieu of the Federal program provided that the State's program is no less stringent and provides for adequate enforcement.

INTRODUCTION

On Nov. 8, 1984, President Reagan signed into law the Hazardous and Solid Waste Amendments of 1984 which, several days earlier, had been approved by Congress. In addition to reauthorizing and making numerous changes to RCRA, a major new section was added to the RCRA statute requiring the U.S. EPA to establish a comprehensive program for the regulation of underground storage tanks. This new section, Subtitle I, addresses underground storage of most hazardous substances and petroleum products. It is estimated that over one million underground tanks will be subject to regulation under this new program. This paper describes the major statutory provisions of Subtitle I, the the U.S. EPA plans to implement these provisions and, finally, the effect this program may have on the regulated community.

PAST PROBLEMS

Congress enacted the legislation for regulating underground storage tanks due to the increasing number of incidents and severity of environmental contamination resulting from leaks from underground storage tanks (USTs). Leaks from underground tanks can create safety, health and environmental hazards. Leaks also can result in fires and explosions, even in structures remote from the tanks. Underground storage tank leaks are insidious—they can contaminate soil, groundwater and surface water, and yet the contamination usually is not identified until after significant damage has occurred. Oftentimes, the cost of cleanup greatly exceeds the cost of prevention in the first place.

There is growing evidence that leaking tanks are becoming a major cause of groundwater contamination. This contamination is of special concern since over one-half of the U.S. population relies upon groundwater for its drinking water supply. This increased endangerment to groundwater users is illustrated by the recent update of the U.S. EPA's National Priorities List (NPL) of hazardous wastes sites eligible for federal funding of remedial cleanup activities under CERCLA.

The October 1984 update to the NPL proposed the addition of 248 new sites to the existing list of 538 sites. Of the 248 new proposed sites, 19 were sites containing leaking storage tanks located in the Silicon Valley of California, an area previously thought to contain the pollution-free computer industry. Leaks from these tanks, primarily chlorinated organic solvents, have been linked to potential adverse health effects. Of the total of 786 sites on the NPL, at least 57 now are known to include chemical contamination in the environment due to leaking underground storage tanks. Since petroleum products were exempted by Congress under CERCLA, there are many problem sites which presently cannot be cleaned up using "Superfund" monies or CERCLA enforcement authorities.

Gasoline and other petroleum products stored in underground tanks (particularly those installed in the 1950s and 1960s) are in fact becoming increasingly identified as responsible for numerous safety, health and environmental contamination incidents around the country.[1] In one example, 30,000 gal of gasoline leaked into a New York community's groundwater supply in 1978 causing odor, safety and potential health problems for 27 families. The involved company's costs for cleanup and damages were estimated to be between 5 and 10 million dollars as of May 1984.

Gasoline from a leaking underground tank in Colorado in 1980 posed a continuing threat to nearby residents, thereby causing the courts to order the responsible company to purchase 41

houses at over twice their appraised value, an estimated total cost to the company of 10 million dollars. In a third example, 23 private water wells in Massachusetts were contaminated by oil leaking from nearby underground storage tanks in 1981. The company responsible was required to supply bottled water to the affected residences.

SCOPE OF NEW RCRA SUBTITLE I

The requirements for underground storage tanks are specified in the new Subtitle I of RCRA.The major provisions in this statute include notification by owners of underground tanks to designated State or local agencies, an interim prohibition on the new installation of unprotected tanks, the development of technical standards for new and existing underground tanks including corrective action requirements for releasing tanks and tough new enforcement authorities to compel compliance with new regulatory requirements. Subtitle I also allows the U.S. EPA to promulgate financial responsibility regulations for taking corrective action and compensating third parties for bodily injury and property damage caused by leaks from tanks. In addition, the U.S. EPA is required to authorize State programs regulating underground storage tanks in lieu of the Federal program provided that the State's program is no less stringent and provides for adequate enforcement.

Subtitle I is divided into ten parts, Sections 9001-9010. Table 1 provides a brief description of each section of the statute.

Table 1
Scope of RCRA Subtitle I

Section	Description
9001	Definitions and Exemptions
9002	Notification
9003	Release Detection, Prevention, Correction Regulations; Financial Responsibility; and Interim Prohibition
9004	Approval of State Programs
9005	Inspection, Monitoring and Testing
9006	Federal Enforcement & Penalties
9007	Federal Facilities
9008	State Authority
9009	Study of Underground Storage Tanks
9010	Authorization of Appropriations

Section 9001 of Subtitle I contains the definitions of key terms and also identifies exemptions to the statute. The reader should refer directly to the statute for the exact wording in order to determine the applicability of certain requirements to himself or his client. However, a few significant definitions and exemptions are briefly noted below.

The term "underground storage tank" has been defined as one or more tanks (including connected underground pipes) used to contain an accumulation of regulated substances with a volume which is 10% or more beneath the surface of the ground. Specifically exempted from this definition are:

- Farm or residential tanks with a capacity less than 1,100 gal used for storing motor fuel oil for non-commercial purposes
- Tanks used for storing heating oil for consumptive use on the premises
- Septic tanks
- Regulated pipeline facilities
- Surface impoundments
- Storm water or waste water collection systems
- Flow-through process tanks
- Liquid trap or gathering lines associated with oil or gas production operations
- Storage tanks situated in an underground area if the tanks are situated upon or above the surface of the floor.

The term "regulated substance" has been defined to include:

- Any substance defined as a hazardous substance under Section 101 of CERCLA (Superfund) but not including any substance already regulated under RCRA Subtitle C as a hazardous waste
- Petroleum, including crude oil or any fraction thereof, which is liquid at standard conditions of temperature and pressure

The term "release" has been defined to mean any spilling, leaking, emitting, discharging, escaping, leaching or disposing from an underground storage tank into groundwater or subsurface soils.

SUMMARY OF MAJOR PROVISIONS

Notification

Every owner of an existing underground storage tank holding petroleum or hazardous substances currently in use or taken out of operation after Jan. 1, 1974 (but left in the ground) must notify a designated State or local agency by May 8, 1986. Notification must specify the age, size, type, location and uses of the tank. Owners of tanks taken out of operation after Jan. 1, 1974 must also notify the appropriate government agency, the date the tank was taken out of service, the age of the tank on that date and the type and quantity of substances left stored in the tank. Exempted from this requirement are owners of tanks which have been removed from the ground, owners of tanks taken out of operation on or before Jan. 1, 1974 and owners who previously notified the U.S. EPA pursuant to Section 103(c) of CERCLA.

Any owner who brings into service a new underground storage tank containing regulated substances after May 8, 1986 is required to notify a designated State or local agency within thirty days of bringing the tank into use.

The U.S. EPA, in consultation with designated State and local officials and after public comment, prescribed on Nov. 8, 1985, the form of notice and the information it would contain. The U.S. EPA requires States to use the prescribed form unless they develop comparable forms that contain, as a minimum, the same information. A list of the designated State or local agencies to receive the notifications as well as a list of States whose form(s) complied with the notification requirements was published in the *Federal Register* with the form.

In addition to the above notification requirements for owners, Subtitle I also imposes obligations on persons who deposit regulated substances in underground storage tanks and tank sellers. Beginning Dec. 8, 1985 and lasting for a period of 18 months, any person who deposits substances in an underground storage tank is required to inform the owner and operation of such tank of the owner's notification obligations. Furthermore, beginning 30 days after the U.S. EPA publishes standards for new tanks, tank sellers are required to inform tank purchasers of their notification obligations.

Interim Prohibition

During the interim period, between May 7, 1985 and the effective date for new tank standards, Section 9003(g) of Subtitle I prohibits the new installation of any underground storage tank for the purpose of storing regulated substances unless it meets three criteria:

- It will prevent releases due to corrosion or structural failure for its operational life

- It is cathodically protected against corrosion, is constructed of non-corrosive material, is steel clad with a noncorrosive material or is designed to prevent the release or threatened release of any stored substance
- The material used in the construction or lining of the tank is compatible with the substances to be stored

A limited waiver is provided dealing with corrosion prevention. The statute specifically allows for tanks to be installed without corrosion protection if the soil has a resistivity value of 12,000 ohm/cm or more as measured in accordance with ASTM Standard G57-78.

At the time of this writing, the U.S. EPA has prepared an interpretive rule on the interim prohibition. An interpretive rule simply construes the language of the statute and does not impose any additional obligations. Its purpose is to provide clarification of the interim prohibition provisions necessary for implementation and enforcement purposes. The U.S. EPA also is preparing a guidance document that will discuss available methods and technologies which the U.S. EPA believes fulfill the interim prohibition requirements.

Technical Standards

Also under Section 9003 of Subtitle I, the U.S. EPA is required to develop regulations for the detection, prevention and correction of releases from tanks, as necessary to protect human health and the environment. These regulations are applicable to all owners and operators of underground storage tanks. In promulgating these regulations, the U.S. EPA may distinguish between tanks of different types, classes and ages. In making such distinctions, the U.S. EPA will consider many factors including: location of the tank, soil and climate conditions, uses of the tank, history of maintenance, age of the tank, current industry recommended practices, national consensus codes, hydrogeology, site-specific depth to water table, size of the tank, quantity of substances stored, technical capability of tank owners and operators and the compatability of the stored substances with the tank material.

The statute specifically states that, at a minimum, the release detection, prevention and correction regulations shall include requirements for:

- Maintaining a leak detection system, inventory control system or comparable system to identify releases
- Maintaining records of any leak detection or inventory control system
- Reporting releases and any corrective action taken
- Taking corrective action in response to a release from an underground storage tank
- Closing tanks to prevent future releases

The U.S. EPA also is required by Subtitle I to develop and issue performance standards for new underground storage tanks. These performance standards must cover design, construction, installation, release detection and compatibility requirements.

Finally, the statute specifies schedules and deadlines that the U.S. EPA must meet in issuing technical standards and regulations. These deadlines differentiate between regulations for new and existing tanks as well as for petroleum tanks and non-petroleum tanks. Table 2 provides a summary of the deadlines imposed on the U.S. EPA to develop technical standards.

Financial Responsibility

At the Administrator's discretion, the U.S. EPA is allowed to develop regulations containing requirements for maintaining evidence of financial responsibility as deemed necessary for taking corrective action and compensating third parties for bodily injury and property damage caused by releases from an underground storage tank. These requirements would apply to both sudden and nonsudden accidental releases.

Table 2
Summary of Subtitle I 9003 Statutory Deadlines

Tank Regulations Governing:	Statutory Deadline
New and Existing Petroleum Tanks	Promulgate by February 1987 (Effective May 1987)
New Hazardous Chemical Tanks	Promulgate by August 1987 (Effective November 1987)
Existing Hazardous Chemical Tanks	Promulgate by August 1988 (Effective November 1988)

The financial responsibility requirements may be established by any one or combination of the following mechanisms:

- Insurance
- Guarantee
- Surety bond
- Letter of credit
- Qualification as self-insurer

The U.S. EPA presently is planning to perform a study to determine the most effective mechanisms to maintain financial responsibility.

Federal Enforcement Authority

Section 9006 of Subtitle I establishes tough new federal enforcement authorities to compel compliance with the regulatory requirements for underground storage tanks. According to the statute, whenever the U.S. EPA determines that any person is in violation of any requirement of Subtitle I, the U.S. EPA may issue an administrative order requiring compliance or may commence a civil action in federal district court for appropriate relief, including a temporary or permanent injunction. If a violator fails to comply with a compliance order, he shall be liable for a civil penalty of up to $25,000 for each day of continued noncompliance.

Any tank owner who fails to notify or falsely notifies the U.S. EPA of his underground storage tanks shall be subject to a penalty of up to $10,000 for each tank. Additionally, any tank owner who fails to comply with any of the technical standards developed by the U.S. EPA or an approved State program or violates the interim prohibition provisions shall be subject to civil penalties of up to $10,000 per tank for each day of violation.

DEVELOPMENT OF THE U.S. EPA'S UNDERGROUND STORAGE TANK PROGRAM

While Congress was busy debating various provisions for underground storage tank legislation, the U.S. EPA already was preparing to implement what would likely be a new mandate for comprehensive regulation of underground storage tanks. In anticipation of extremely short deadlines for the development of regulations, the U.S. EPA's Office of Solid Waste and Emergency Response began formulating its own strategic plan for implementing new regulations for underground storage tanks. As a result, several weeks before the Hazardous and Solid Waste Amendments of 1984 became law on Nov. 8, 1984, the U.S. EPA already had prepared an "Organization and Strategic Plan" for implementing the new Subtitle I of RCRA.

The Strategic Plan specified the formation of several Workgroups to address the major provision of Subtitle I. These Workgroups were directed by a Steering Committee of senior U.S.

EPA managers. The goal of each Workgroup was to write a development plan for its respective topic. Each development plan was required to address major issues, recommended and alternative approaches, scheduling and resource needs.

The development plans are now officially in final draft and have been consolidated as chapters of the U.S. EPA's Development Plan on the Regulation of Underground Storage Tanks. General goals and objectives were identified during preparation of the development plans and are reflected in the chapters. These goals and objectives also will be reflected in any modifications to the plans as well as the implementation of the plans. These goals and objectives are as follows:

- The U.S. EPA will place high priority on regulation development in order to meet Congressional deadlines.
- In order to develop regulations as efficiently as possible, a common target date will be used for all regulations.
- Innovative approaches will be emphasized.
- Underground tank regulations will reflect the U.S. EPA's groundwater protection strategy to the extent possible.
- An extensive public out-reach and consultation program will be developed to involve the various sectors of the interested public.
- High priority will be given to State participation in the program development.
- Special considerations will be given to the problems of small businesses during development of the program.

INSPECTION AND ENFORCEMENT

A three-phased approach will be utilized to implement inspection and enforcement activities:

- Compliance promotion
- Compliance monitoring
- Enforcement response actions

This approach will be applied toward the provisions of the interim prohibition of non-protected tanks, notification requirements and all the regulatory requirements (such as tank standards and corrective action provisions) which are promulgated.

Compliance promotion activities will consist of an educational program implemented mostly through the extensive public outreach and consultation program which is being developed for the overall UST regulatory program. This communication program will involve various sectors of the interested public including trade associations, the Tank Coalition, the U.S. EPA's Small Business Ombudsman, trade journals and local government agencies. A section of the out-reach and consultation program will be tailored specifically toward promoting inspection and compliance activities. In addition to promoting the technical requirements of the Underground Storage Tank (UST) regulatory program, compliance promotion activities will point out the existence of tough penalties for noncompliance cited in Section 9006 of the statute.

The compliance monitoring program will discover noncompliance through innovative enforcement activities as well as traditional enforcement inspections. One such activity may be to develop a program which crosschecks local construction or building permit applications. Additional activities may include the use of self-monitoring reports, the existing RCRA hotline or a separate hotline for private citizens to report releases that may be threatening public health or the environment.

The targeting of inspections will be necessary due to the size of the regulated community. A targeting strategy will be developed using information from past problems and new data generated from the communications program. Of particular importance will be inspection of new tank installations, since improper installation appears to be the cause of many leaks. The UST inspection program also may be integrated with existing environmental inspection programs (such as the Spill Prevention and Countermeasures Controls program or the Mobile Sources gasoline station inspection program) to incorporate institutional experience and resources.

The final and most important enforcement phase in implementing UST inspection and enforcement activities is the establishment of a highly visible and effective enforcement presence through the active and successful use of enforcement response actions. This presence will be established through the active use of compliance orders, tough penalties and judicial actions in federal court.

Section 9006 provides the U.S. EPA authority to enforce the provisions of Subtitle I through administrative orders and civil judicial actions for injunctive relief or penalties. When a significant violation such as failure to have a monitoring system is discovered, an administrative order will be issued promptly and an appropriate penalty will be levied. If compliance is not attained, further penalties will be levied in accordance with the U.S. EPA's RCRA penalty policy and the enforcement action will be escalated to a judicial action.

The following penalties are specified in Subtitle I for certain violations of Subtitle I: up to $25,000 for each day for the violation of an administrative order issued under Section 9006; up to $10,000 for each tank each day a violation continues for any requirement or standard promulgated under section 9003 (or section 9004 in approved states); up to $10,000 for each tank each day it remains in violation of the interim prohibition of section 9003 (g).

Section 9006 orders also will be used to require compliance with corrective action provisions of regulations to be issued under section 9003. This type of order will enable enforcement personnel to require responsible parties to perform complete cleanup of releases. Depending on corrective action requirements, the order can be phased using compliance schedules.

In situations where there exists an imminent and substantial endangerment to human health and the environment, other enforcement authorities such as RCRA 7003 and CERCLA 106 and 107 will be considered in determining enforcement responses.

CONCLUSIONS

- The regulatory program for underground storage tanks is, perhaps, the largest and potentially most costly regulatory program the U.S. EPA has had to develop to date.
- The tough provisions for federal enforcement make non-compliance a very risky and potentially costly alternative.
- Given the technical difficulties, high costs and legal liabilities of cleaning up releases from underground storage tanks, the best strategy for an owner or operator is to perform everything in his power to prevent leaks or releases. In the long run, this is clearly the best approach.

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Cost-Effectiveness Evaluation of Leak Detection and Monitoring Technologies for Leaking Underground Storage Tanks

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ABSTRACT

In recent years the contamination of groundwater by leaking underground storage tanks (LUST) has become a major environmental concern. Local, state and federal governments have responded by passing legislation and promulgating regulations for the control of LUST. These government regulations are applicable to both new and existing underground storage facilities. Tank owners/operators are having to replace or retrofit existing facilities and have little information and guidance available to them on the cost and effectiveness of leak control options.

Under most UST regulations, owners of UST facilities typically have a variety of leak prevention, detection/monitoring, containment and cleanup options available. In particular, there are many options for leak detection and monitoring. The cost-effectiveness of leak detection monitoring techniques has been examined in the course of several U.S. EPA and private client sponsored studies on UST.

This evaluation consists of the following analysis:

- Type of detection/monitoring techniques
- Applicability of detectors/monitors
- Cost comparisons
- Effectiveness analysis
- Cost-effectiveness analysis

A comprehensive survey was conducted to investigate commercially available detectors and monitoring equipment. Data of accuracy, response time, detection limits, sensitivities, application ranges, costs and constraints were analyzed and compared. Models were developed to evaluate the effectiveness based on the extent of leakage/contamination possible before detection can be achieved. Capital, O&M and associated soil and groundwater cleanup costs were analyzed under a variety of scenarios.

INTRODUCTION

With the recent increased concern for protection of groundwater from contamination by leaking underground storage tanks (LUST) being translated into new governmental regulations, both tank owners and government agencies charged with overseeing the problem have to decide what leak detection/monitoring technologies are appropriate for their needs. There is much information available on detecting and monitoring for contamination in the vadose zone and in the groundwater, but there still is not much published literature analyzing either the effectiveness or the costs of various technologies for LUST. Analyses and comparisons of vadose zone and groundwater monitoring techniques are available for leak monitoring technologies.[1,2,3] There is also some information available on effectiveness of leak detection technologies.[4] At this time, analyses of the costs of technologies and costs of cleanup in the event of a leak are needed by those having to set up leak detection/monitoring programs for underground tanks.

To address this need, we have compiled and analyzed information from the literature and information on costs and characteristics of leak detection/monitoring technologies gathered from vendors as part of a U.S. EPA sponsored study on LUST. The effectiveness of a technology and associated costs are reviewed and summarized. Costs of soil and groundwater contamination also are arrived at for each technology with the use of liquid and vapor transport models for the vadose zone and saturated zone.

EXISTING TECHNOLOGIES

For identifying leaks from underground storage tanks, there are a wide variety of technologies available. These technologies can be classified into two categories for assessing effectiveness and for identification purposes. One category, Leak Detection, includes methods which, when applied to the tank itself, will determine if the tank if presently leaking. A second category, Leak Monitoring, includes methods for use outside the tank and will identify both present and past leaks. Leak detection includes inventory reconciliation, interstitial monitoring of the space between primary and secondary containment (e.g., monitoring the anular space of a double-walled tank) and the use of tank "tightness testing" for leak identification. Leak monitoring in the environment outside of the tank and any secondary containment systems includes visual monitoring (of the tank and soil), soil monitoring, air monitoring, vadose zone monitoring (gas and liquids) and groundwater monitoring.

Some devices used in the above mentioned methods are appropriate for both leak detection and leak monitoring. Various sensors for detecting the presence of specific liquids or gases are utilized for interstitial, vadose-zone or groundwater monitoring. These detection devices and other practical leak detection/monitoring methods are listed in Tables 1, 2 and 3.

A summary of advantages and disadvantages for each method is included in these tables. Table 1 includes various tank integrity (tank tightness tests), inventory reconciliation and visual observation for the above ground portion of a tank. Table 2 summarizes the characteristics of gas/vapor detection techniques for air or vadose zone monitoring. Table 3 presents various liquid detection techniques including visual observation of the tank and of the soil/backfill around the tank.

Table 1
Comparisons of Some Tank Integrity Tests

Technique/ Device	Advantage	Disadvantage
Inventory Reconciliation	Quick and relatively inexpensive Quantifiable leak rate In very small tanks--sensitive to small leaks Wide applicability No down time No damage potential Fair reliability Few restrictions	With larger tank is less sensitive to a given leak rate (e.g. 0.05 gph) Sensitive to ground water fluctuations in location of tank Can't locate leaks
Pneumatic Tests	Very sensitive to small leaks A reliable test	Sensitive to vapor "pockets" Can damage tank/piping Can worsen leak Tests only for portion of tank/piping isolated for pressurizing/depressurization Significant down time Can't locate leaks
J-Tube Manometer	Very sensitive Quantifiable leak rate Wide applicability Low damage potential Few restrictions	Local groundwater levels can effect test Sensitive to temperature changes and temperature distribution in tank Down time 1-10 hrs Can't locate leaks in piping versus tank
ARCO HTC	Very sensitive test Good quantification of leak rate Wide applicability Low damage potential Few restrictions Reliable Temperature compensated	Sensitive to local groundwater fluctuations Only test tank at 75%-82% full Down time 4-8 hrs.
Hunter Leak Lokator (Sunmark)	Very sensitive Good quantification of leak rate Wide applicability Reliable Detects leaks in tank vs. pipe Few restrictions Corrects for temperature	Sensitive to vapor pockets Overfill technique Potential damage due to overfill Downtime 2-5 hrs.
Heath Petrotite (Kent-Moore)	Good sensitivity Good quantification of leak rate Wide applicability Reliable Few restrictions Corrects for temperature	Sensitive to vapor pockets Overfill technique Potential damage due to overfill Down time 3-9 hrs. Can't locate leaks
Horner Ezy-Check	Good sensitivity Good quantification of leak rate Wide applicability Reliable Detects leaks in pipe vs. tank Few restrictions Corrects for temperature	Sensitive to vapor pockets Overfill technique Potential damage due to overfill Down time 1-3 hrs.
Ainly Tank Integrity Tester	Good sensitivity Good quantification of leak rate Wide applicability Reliable Few restrictions Corrects for temperature	Sensitive to vapor pockets Pressure/overfill technique Potential damage due to pressure/overfill Down time 1-3 hrs. Can't locate leaks

(continued)

APPLICABILITY OF DETECTORS AND MONITORS

Tables 1 through 3 illustrate a number of points regarding the application of existing leak detection/monitoring technologies to underground storage tanks. A particular technique may be reliable, have good sensitivity (and low limit of detection), have low potential for damaging the tank and yet not be widely applicable for a number of reasons. The technique may be useful only for a limited number of compounds and/or require direct contact with the leaking liquid for leak detection. For some facilities, specific tank integrity tests may be inappropriate due to the amount of time the tank would have to be out of service (the "downtime"). Some tank integrity tests, in addition, are not able to detect leaks in all sections of the tank and/or discriminate between leaks in the tank and associated piping. A particular method or device also may be limited by environmental conditions. "Background" contamination or local groundwater levels may preclude the use of a technique.

Table 1 (continued)

Technique/ Device	Advantage	Disadvantage
Mooney Tank Leak Detector	Good sensitivity Good quantification of leak rate Wide applicability Reliable Detects leaks in tank vs. pipe Few restrictions Corrects for temperature	Sensitive to vapor pockets Overfill technique Potential damage due to overfill Down time 2-4 hrs.
Helium Sniffer	Very sensitive Can pinpoint location of the leak Wide applicability Few restrictions - Insensitive to temperature changes	Expensive Some down time Only rough guess for leak rate Pressure technique Possible damage to tank/pipes due to pressurization
Other Tracer Techniques	Few restrictions Wide applicability Very sensitive Temperature insensitive No down time	Rough guess for leak rate - Some are pressure techniques Can't locate leak
Acoustic Techniques	Sensitive Widely applicable Not affected by temperature	Some down time No quantification of leak rate Some techniques sensitive to groundwater level Some possibility of damage due to depressurization/pressurization Can't locate leak
Monitoring Level in Tank	Fair to poor sensitivity Instantaneous response Fair quantification of leak rate Widely applicable Reliable No down time No potential for damage	Temperature sensitive Sensitive to local groundwater levels Sensitivity depends upon size/dimensions of the tank Can't locate leak
Monitoring for Water in tank	Fair to good sensitivity Widely applicable Reliable No down time No potential for damage Few restrictions Insensitive to temperature	- Limited to organic compounds/halogenated HC's Sensitive to groundwater level Sensitivity depends on tank size Not quantifiable Can't locate leak

Tank integrity tests and inventory reconciliation in general have wide applicability in terms of range of compounds, size of tanks and environmental conditions. Some tightness tests are limited, however, to detection of leaks in a tank which is less than 100% full (Table 1). These tests may not be used to detect leaks in the upper portion of a tank and possibly in the associated piping.

Techniques for detecting the volatilized portion of a leaking liquid in the vadose zone can be very sensitive in addition to having wide applicability. Methods which entail taking a vapor sample for subsequent laboratory analysis are appropriate for a wide range of compounds, environmental conditions and monitoring situations.

Additional techniques for vadose zone vapor monitoring include the placement of a sensor in the ground or sampling of several vapor wells with a portable gas detection instrument (Table 2). There are many types of sensors and instruments available, and all vary in the range of compounds they will detect, their sensitivity and reliability. Typically, there is a "tradeoff" between the sensitivity (or limits of detection) and the reliability of the instrument.

Monitoring for liquid product in the vadose zone or in groundwater is more difficult because placement of the sampling points may not intercept all possible leaks. Fluctuations in groundwater level may limit the use of some methods for laboratory monitoring in the vadose zone. Except for methods utilizing liquid tracers and/or laboratory analysis, most techniques rely on devices which are limited to use with specific classes of compounds or which are sensitive to environmental conditions (groundwater level or background contamination).

Most techniques used for leak monitoring also can be used for leak detection in the interstitial space of tanks between primary and secondary containment. In this technology, placement of monitoring points is less critical than for environmental monitoring, and specific sensors or laboratory analysis can be tailored for each tank.

COST-EFFECTIVE METHODOLOGY

Two approaches are used for the cost-effectiveness analysis of underground tank detectors and monitors. One approach is based on the technology itself (i.e., technical effectiveness, implementation costs and O&M costs); the other is based on the technology evaluation plus the potential liability (i.e., cleanup costs) if leaks occur. Evaluation of the latter case is considered necessary owing to the inherent problems of some of the detectors/monitors. For example, vadose zone or groundwater monitors will not detect problems until a leachate plume reaches the sensors. Tank tightness tests can only detect leaks at the moment of the test. Inventory control (reconciliation) may never detect leaks if leak rates are lower than 0.2 gal/hr (as in most cases). Due to the complexity of the second approach, only case examples are given in this report.

Table 2
Comparisons of Vapor/Gas Sensing Technologies

Technique/ Device	Advantage	Disadvantage
Odor Detection	Quick and inexpensive No down time Sensitive for some compounds Reliable Insensitive to temperature No damage potential for tank	Not suitable for all compounds (only volatile) Leak rate is not quantifiable Restrictions due to Health & Safety concerns Can't locate leaks
Adsorption Sensitive Resistor (sensor probe)	No down time Wide applicability for volatile compounds Fair to good sensitivity No damage potential Excellent reliability Few restrictions Adjustable for "background" contamination Temperature compensated	Limited to volatile compounds and gases Leak rate is not quantifiable Can't locate leaks
Metal Oxide Semiconductor Gas Detectors (probe)	No down time Very good sensitivity Wide applicability for volatile compounds No potential for damage to tanks Reliable Few restrictions Adjustable for "background" contamination Temperature compensated	Limited to volatile compounds and gases Leak rate is not quantifiable Can't locate leaks
Synthetic Filament Probes (e.g., polypropylene)	No down time Inexpensive devices Fair sensitivity Reliable No potential for damage to tanks Few restrictions Temperature insensitive	Limited to volatile hydrocarbons (e.g., gasoline) Leak rate is not quantifiable Can't locate leaks Sensitive to background contamination
Photo-Ionization Gas Detector (survey instrument)	No down time Excellent sensitivity Reliable No damage potential Few restrictions Temperature insensitive Wide applicability for volatile compounds Can compensate for background contamination	Limited to volatile compounds and gases Leak rate is not quantifiable Can't locate leaks
Flame-Ionization Gas Detectors (survey instrument)	No down time Excellent sensitivity Reliable No damage potential Few restrictions Temperature insensitive Can compensate for background contamination Wide applicability for volatile compounds	Limited to volatile compounds - Doesn't detect inorganic gases Leak rate is not quantifiable Can't locate leaks
Combustible Gas Meters (varous types) (survey instrument)	No down time Good sensitivity Very reliable No potential for damage to tank Few restrictions Temperature insensitive Can compensate for background contamination Wide applicability for volatile compounds	Limited to combustible vapors and gases Leak rate is not quantifiable Can't locate leaks
Tracer Gas with Intermittent Sampling Program	No down time/no damage to tank Wide applicability - Very sensitive Temperature insensitive - Few restrictions Insensitive to background contamination Reliable	Leak rate is not quantifiable - Can't locate leaks
Air Sample Traps with Lab Analysis or "Draeger" Tubes	No down time/no damage to tank Wide applicability Good to excellent sensitivity Temperature insensitive Few restrictions Reliable Can compensate for background contamination	Leak rate is not quantifiable Can't locate leaks

Table 3
Comparisons of Liquid Sensing Technologies

Technique/ Device	Advantage	Disadvantage
Synthetic Filament Devices (e.g., polypropylene)	No down time Reliable Fair sensitivity No damage potential for tanks Few restrictions Temperature insensitive	Limited to specific classes of compounds Requires contact or close proximity to leaks Sensitive to background contamination Can't determine leak rate Can't locate leak source
Psychometers or Tensiometers	No down time Fair sensitivity No damage potential for tank Few restrictions Temperature compensated	Require contact or close proximity to leaks Affected by local groundwater fluctuations Can't determine leak rate Can't locate leak source
Electrical Conductivity Sensor (Electrodes)	No down time Reliable Fair sensitivity No damage potential for tank Few restrictions Adjustable for background contamination Insensitive to temperature	Limited for use with hydrocarbons Leak rate is not quantifiable Can't locate leak source Can't differentiate between H_2O, some halogenated hydrocarbons or other compounds Requires contact with liquid
Thermal Conductivity Sensors	No down time Reliable Fair sensitivity No potential for damage to tank Few restrictions Adjustable for background contamination Compensates for temperature Wide applicability	Leak rate is not quantifiable Can't locate leak source Requires contact with liquid
Contact Sensitive Coated Wires (Electrical resistance change)	No down time Reliable Rough guess of leak location with a network of wires Fair sensitivity No damage to tank Few restrictions Temperature insensitive Wide applicability	Limited to specific classes of compounds Requires contact with liquid Sensitive to background contamination Can't determine leak rate
Geophysical Techniques (e.g., resistivity of soil/groundwater)	No down time Fair-Good sensitivity Fair-Good applicability No damage potential for tank Few restrictions Temperature compensated	Problem with background contamination Can't determine leak rate Can't determine leak location Affected by groundwater conditions Expensive and requires expertise
Visual Observation of Tank and Soil	Quick and relatively inexpensive Sensitive to small leaks Applicable to a wide range of compounds No down time No potential for damage to tank Good reliability No restrictions	Limited to parts of tank with access Only a rough guess for leak rate
Lysimeter Sample with Lab Analysis or Soil Core Sample with Lab Analysis or Tracer with Lab Analysis of Soil/Groundwater Samples	No down time Fair sensitivity-excellent sensitivity No damage potential for tank Temperature insensitive Wide applicability Compensates for background contamination Reliable Few restrictions	Requires contact with plume or contaminated aquifer Affected by groundwater conditions Can't determine leak rate Can't locate leak source

Evaluation Based on Technology

The cost-effective evaluation of leak detection/monitoring technologies is based on a two-level rating scheme which can be expressed by the three equations in matrix form as shown in Figure 1.

In these relationships, A_{ij} is the first level rating factor which grades the relative rating of cost or effectiveness of detection/monitoring alternatives, "i", under different factors, "j", affecting the rating. As will be discussed later in this report, A_{ij}s for effectiveness analysis range from 0 to 3 with 3 being the best. A_{ij}s for cost analysis are based on the following equation:

$$A_{ij} \text{ cost rating} = \log \frac{10^5}{x} \quad (4)$$

where x = Annualized cost for leak detection/monitoring.

$$A = \begin{pmatrix} A_{11} & A_{12} & A_{13} & \cdots & A_{1j} \\ A_{21} & A_{22} & A_{23} & \cdots & A_{2j} \\ & & & & \\ A_{i1} & A_{i2} & A_{i3} & \cdots & A_{ij} \end{pmatrix} \quad \text{-------} \quad (1)$$

$$R = \begin{pmatrix} r_1 \\ r_2 \\ \\ r_j \end{pmatrix} \quad \text{----------} \quad (2)$$

and

$$P = A \times R \quad \text{----------} \quad (3)$$

Figure 1
Two-Level Rating Scheme for Cost-Effectiveness Evaluation

The second level rating factor, r_j, represents the relative importance of each different factor, j. After multiplication of A, R [i.e., Equations (1) and (2)] and a conversion factor, $1/K_j$, the results, P_i, will represent the weighted overall cost-effectiveness of a certain leak detection/monitoring option, i, that is

$$P_i = \sum_{j=1}^{j} \frac{1}{K_j} A_{ij} V_j \quad (5)$$

Where K_j is equal to the maximum value of A_{ij}, in most cases, $K_j = 3$. A comparison among P_is will give a relative rating of leak detection/monitoring technologies in terms of their cost-effectiveness at controlling leaking underground storage tanks.

Evaluation Based on Technology and Liability

For the second type of cost-effectiveness evaluation, the future liability should be considered. The future liability is associated with the cleanup costs required to decontaminate soil and groundwater. The soil and groundwater contamination volumes are used to calculate the costs of cleanup for a particular leak. If a technology is based upon sampling at regular intervals, then it is assumed that the leak just reached the sampling point at one sampling time and is detected at the next sampling time (i.e., the worst-case condition).

For the determination of contaminated volume of soil due to vapor migration, a vapor diffusion model is used. The model used is an analytical diffusion equation for a continuous point source in an infinite volume.[3,5] For the model, it is assumed that the soil is homogenous and isotropic and that 5% of the volume of a leak (at 0.05 gal/hr) is volatilized. Other model inputs include liquid density and the effective diffusion coefficient for the compound of interest. The diffusion coefficient of a compound in air is corrected for the available soil porosity (assumed to be 30%) and for tortuosity.[3] The model was run for hexane, octane and xylene (major components of gasoline) and also for trichloroethylene (TCE). The detection times for hexane, octane and xylene were averaged and used to represent the detection times for gasoline at various limits of detection. The detection times for TCE were within 30% of the average value of hexane, xylene and octane.

Due to the complexity of the subsurface environment and unknown nature of the pure or concentrated organic solvent migrating in the vadose zone, rational approaches were used to estimate the extent of soil contamination due to leachate migration. Two types of rational approach were selected:

- Modified Darcy's Law
- Solution Routing Technique

To simplify the calculation, the following assumptions were made:

- Soil beneath the LUST is anisotropic and only one type of soil is involved
- Two extremes of leak patterns, i.e., one leak opening and multiple leak openings (i.e., assuming leaks occur throughout the entire horizontal projection area of the tank)
- The horizontal extent of migration is calculated based on the ratio of horizontal permeability to vertical permeability
- For organic solvents lighter than water (e.g., gasoline), the vertical extent of contamination is limited by the groundwater table

Modified Darcy's Law

Darcy's law (i.e., $v = ki$, where v, k and i are flow velocity, permeability and hydraulic gradient, respectively) needs to be modified for the unsaturated condition of the vadose zone. The equation can be modified by relating the degree of saturation to the relative permeability (ratio of effective permeability to absolute or saturated permeability). Degree of saturation is defined as the solvent occupied soil pore volume to the total soil pore volume. In the subject case, two types of solvents are involved—water moisture and leaking organic (e.g., gasoline). Since the water moisture in the vadose zone, below the root zone area, is mainly affected by infiltrating precipitation, fluctuation of the degree of saturation may occur. If there is no pavement on the surface of the ground, water moisture fluctuation is assumed to be between "wilting point" under dry weather conditions and "field capacity" under wet weather conditions. If there is pavement above the tank, a moisture content equivalent to the midpoint between field capacity and wilting point is assumed. The extent of soil contamination is derived as follows:

For one leak opening:

Volume of Contaminated Soil
$= V_D$
$= \text{Conic volume}$
$= \frac{\pi}{3} (K_h t)^2 (K_v t) \quad (6)$

where:

$K_v t < h$;

K_v = vertical permeability of leaking solvent
K_h = horizontal permeability of leaking solvent (usually $K_h = 1$ to $4\ K_v$)
h = distance between tank bottom and groundwater table
t = leak period

(For gasoline, assume $K_v = K_h$)

Solution Routing Technique

The solution routing technique is based on the premise that the infiltrating solvent fills the voids in a layer of the soil to field

capacity before migrating to the layer beneath. It is again assumed that, under the no pavement condition, the moisture content in the soil fluctuates between field capacity and wilting point. With the existence of pavement, the available solvent absorption capacity can be calculated as follows:

$$A = \text{Absorption Capacity (volume \%)} = F - \frac{(F + W)}{2} \quad (7)$$

where

F = field capacity (in %)
W = wilting point (in %)

Therefore:

$$V_F = \frac{vt}{A} \quad (8)$$

where:

V_F = volume of contaminated soil
V = leak rate (in terms of volume/time)
t = leak period

The above three equations (Eqs. 6 to 8) are applicable only when the vertical extent of migration is above the groundwater table. For floatable chemicals (e.g., gasoline), the extent of soil contamination, V_G, will be limited by the depth of groundwater table as shown below:

For one leak opening:

$$V_G = \pi \frac{(hK_h)^2 h}{kv} \quad (9)$$

Since either the leak source or the soil characteristic (i.e., permeability) may become the limiting factor for controlling the rate of migration, the volume of the contaminated soil was selected based on the smallest value among V_D, V_F and V_G.

For groundwater contamination, it is assumed that the contaminant is less dense than water and will float on the surface of the groundwater. Furthermore, the spread of the contaminant on the groundwater surface is radial and equal in all directions. The thickness of the contaminant on the top of the groundwater is assumed to be equivalent to 2 in. of product. The radial spread of this layer then is used to determine the point in time at which the leak can be detected by groundwater monitoring.

EFFECTIVENESS ANALYSIS

Effectiveness is a combination of qualitative and quantitative non-cost measures. Different methodologies of preference can be applied in assessing effectiveness. Our approach was based on evaluation of the following 13 non-cost measures:

- Accuracy (j = 01)
- Detection Limit/Sensitivity (j = 02)
- Observation Frequency (j = 03)
- Application Range (Types of Materials can be measured) (j = 04)
- Leak Rate Quantification (j = 05)
- Leak Location/Source Determination (j = 06)
- Early Warning Capability (j = 07)
- Down-time to the Tank (j = 08)
- Reliability/Completeness of Coverage (j = 09)
- Environmental Effects (e.g., temperature, evaporation, pressure, vapor pockets, groundwater conditions, geologic/soil conditions, contamination) (j = 10)
- Health Effects (j = 11)
- Constructability (e.g., ease of implementation, space limitation, installation time) (j = 12)
- Special Limitations (e.g., weather, damage to tank/pipe, restricted to certain tank types or locations and any other limitations not included above (j = 13)

Results of the effectiveness evaluation of underground tank detectors/monitors are shown in Table 4. Accuracy is defined as the deviation of the test results from the true leak or non-leak conditions. Among the control technologies evaluated, interstitial monitoring (i.e., i = 7-9), tightness test by liquid-level measurement (i.e., i = 3), tracer techniques (i.e., i = 6), vadose zone vapor monitoring (i.e., i = 12-19) and vadose zone liquid sampling and laboratory analysis (i.e., i = 29, 30) are believed to be better techniques in terms of accuracy. Detection limit/sensitivity is defined as the lowest leak rate or the smallest detectable change which can be detected by the detector/monitor. Again, all the interstitial monitoring techniques, i.e., i = 7-9) and some of the tightness tests (i.e., i = 3,6) and vadose zone vapor monitors (i.e., i = 15-17, 19) can achieve desirable levels (e.g., less than 0.05 gal/hr or 1 mg/l) of results.

Observation frequency represents, practically, how often the technique can detect leaks. If the technique can be applied continuously and automatically, a highest rating (i.e., A_{ij} = 3) is given.

Application range refers to the types of stored material that can be measured. If there is virtually no material limitation, a highest rating is assigned (as shown in Table 4).

Leak rate quantification is rated based on the following results: 0 = leak rate determination impossible, 1 = very rough guess of leak rate, 2 = leak rate quantification based on rough guess by calculation and 3 = quantitative measurement of leak rates. Leak location or leak source determination (i.e., j = 06) is defined by the following: 0 = impossible, 1 = only part of tank and/or piping, 2 = all of tank versus all of piping and 3 = exact location. None of the detector/monitors evaluated could be rated 3 in terms of leak location/source determination. Some liquid-level tightness tests (i.e., i = 3) are the only type of technique that can differentiate between tank and pipe leaks (i.e., A_{ij} = 2).

Early warning capability (i.e., j = 7) is one of the most important factors for effectiveness rating. Interstitial monitoring techniques are found to be the best techniques for early warning of tank leaks. Downtime to the tank (j = 08) during testing, although not directly related to the leak detection, is considered because of its effects on normal tank operation.

Tightness tests are found to be the only type of technique which require significant downtime (i.e., a few hours to a day). Reliability and completeness of coverage (i.e., j = 09) include downtime of the technique, level of confidence and radius of distance the detecting equipment can cover. Lower reliability/completeness ratings were found for most of the techniques applied outside the tanks.

Environmental effects (i.e., j = 10) which may affect the test results also were evaluated. Temperature changes, evaporation during testing, barometric pressure changes, existence of vapor pockets inside tanks, groundwater conditions, geologic/soil conditions and contamination are major environmental effects evaluated. Results have shown that interstitial monitoring and tightness tests are less affected by environmental effects.

Health effects (j = 11) was also selected for evaluation, because, consideration of this factor is required for the use of cleanup related control technologies by paragraph 300.68(h) of the NCP. Almost all techniques, with the exception of sensory monitoring (i = 10, 11) evaluated to not pose any significant health effects.

Constructability (j = 12), which refers to ease of implementation, space limitation and installation time required, is roughly rated equal for most of the techniques evaluated.

Table 4
Effectiveness Evaluation of Underground Tank Leak Detectors and Monitors
(Values of the First-Level Rating Factor, A_{ij})

TYPE OF DETECTOR/MONITOR		i	A_{ij}													TOTAL
			j* 01	j = 02	j = 03	j = 04	j = 05	j = 06	j = 07	j = 08	j = 09	j = 10	j = 11	j = 12	j = 13	
INVENTORY CONTROL	Manual	1	1	1	2	3	1	0	1	3	2	1	3	3	2	23
	Automatic	2	2	2	3	3	1/2	0	2	3	2	1	3	3	3	28.5
TIGHTNESS TESTING	Liquid-Level Measurements	3	3	3	1	3	3	1/2	1/2	1	2/3	2/3	3	2/3	2	29.5
	Acoustic Measurements	4	2	2	1	3	0	0	1/2	1	2/3	2/3	3	3	2	23.5
	Pressure Tests	5	2	1/2	1	3	0	0	1/2	1	2/3	2/3	3	2	2	21
	Tracer Techniques	6	3	2/3	1	2	0	0/1	1	2	2	2/3	2/3	2	2	23.0
INTERSTITIAL MONITORING	Liquid Monitoring	7	3	3	3	3	0	0	3	3	3	3	3	3	3	33
	Vapor Monitoring	8	3	3	3	2/3	0	0	3	3	3	3	3	3	3	32.5
	Pressure Monitoring	9	3	3	3	3	0	0	3	3	3	3	3	2	2	31
SENSORY MONITORING	Visual Monitoring	10	1	1	2	1	0	0/1	0/1	3	1	2	2	3	1	18
	Sense of Smell	11	1	1	2	1	0	0/1	0/1	3	1	2	2	3	1	18
VADOSE & AMBIENT AIR MONITORING	Adsorption Sensitive Resistors	12	2/3	1	2/3	2/3	0	0/1	1/2	3	1	2	3	2/3	2	24
	Combustible Gas Detectors	12	2/3	2	2/3	2/3	0	0.1	1	3	1	2	3	2/3	2	24.5
	Synthetic Filaments	14	2/3	1	2/3	2	0	0/1	1/2	3	1	2	3	2/3	2	23.5
	Photo-ionization Gas Detectors	15	2/3	2/3	2/3	2/3	0	0/1	1	3	1	2	3	2/3	2	25
	Flame-Ionization Gas Detectors	16	2/3	2/3	2/3	2/3	0	0/1	1	3	1	2	3	2/3	2	25
	Infrared Analyzers	17	2/3	2/3	2/3	2/3	0	0/1	1	3	1	2	3	2/3	2	25
	Draeger Tubes	18	2/3	2	1	2/3	0	0/1	0/1	3	1	2	3	2/3	2	22.5
	Sample Traps with Lab Analysis	19	2/3	2/3	1	3	0	0/1	0/1	3	1	2	3	2/3	2	23.5
VADOSE LIQUID MONITORING	Synthetic Filament Devices	20	2	1	3	2	0	0/1	1/2	3	1	2	3	2/3	2	23.5
	Electrical Conductivity Sensors	21	2	2	3	2/3	0	0/1	1/2	3	1	1	3	2/3	2	24

(continued)

Table 4 (continued)

TYPE OF DETECTOR/MONITOR		i	A_{ij} j=01	j=02	j=03	j=04	j=05	j=06	j=07	j=08	j=09	j=10	j=11	j=12	j=13	TOTAL
VADOSE LIQUID MONITORING (Continued)	Thermal Conductivity Sensors	22	2	2	3	2/3	0	0/1	1/2	3	1	2	3	2/3	2	25
	Contact Sensitive Coated Wires	23	2	2	3	2/3	0	0/1	1/2	3	1	1	3	2/3	2	24
	Psychrometers	24	2	2	3	1/2	0	0/1	1/2	3	1	2	3	2/3	2	24
	Tensiometers	25	2	1	3	1/2	0	0/1	1/2	3	1	2	3	2/3	2	23
	Neutron Moderation Method	26	2	2	1	2	0	0/1	0	3	1	2	3	2	2	20.5
	Soil Resistance	27	2	1	1	2	0	0/1	0/1	3	1	2	3	2/3	2	20.5
	Gamma Ray Transmission	28	2	1	1	2	0	0/1	0	3	1	2	3	2	2	19.5
	Vacuum-Pressure Lysimeter Sample/Lab Analysis	29	2/3	1	1	3	0/1	0/1	0	3	1	2	3	2	2	21.5
	Core Sample Lab Analysis	30	2/3	2	1	3	1/2	0/1	0	3	1	2	3	2	2	23.5
GROUNDWATER MONITORING	In-Situ Measurements	31	2	2	3	2	0	0/1	0/1	3	1	1/2	3	2/3	2	23
	Sampling/ Lab Analysis	32	2	2	1	3	0	0/1	0	3	1	1/2	3	2/3	2	21.5

* j	Evaluation Factor (see text for details)
01	Accuracy
02	Detection Limit/Sensitivity
03	Observation Frequency
04	Application Range
05	Leak Rate Quantification
06	Leak Location/Source Determination
07	Early Warning Capability
08	Down Town to the Tank
09	Reliability/Completeness of Coverage
10	Environmental Effects
11	Health Effects
12	Constructability
13	Special Limitations

Other limitations (j = 13) mainly refer to the effects of any factors which are not covered by the above listed factors (i.e., j = 1 to 12). Sensory monitoring techniques (i = 10, 11) are lowly rated for j = 13 because they are unscientific and subjective. Ratings for monitoring techniques applied outside the tanks are also relatively low (A_{ij} = 2) in terms of other limitations (j = 13) because weather effects such as precipitation and wind could easily change readings for some of these monitors.

The overall second-level rating factors (i.e., $\sum_{j=1}^{13} r_j$) were subjectively assigned as 70%. That means the relative importance of effectiveness and cost is at a ratio of 7:3. The second-level rating factors for the 13 factors evaluated above are selected as follows:

j	r_j
01	6%
02	8%
03	4%
04	3%
05	6%
06	4%
07	16%
08	4%
09	10%
10	4%
11	1%
12	3%
13	1%
Total	70%

Based on the above r_j values and A_{ij} values listed in Table 4, the P_i values for effectiveness rating can be calculated, and the results are shown in Table 5.

Table 5
Results of Effectiveness Evaluation (P_i Values)

Type of Detector/Monitor (i)	P_i (%)
1	34.4
2	47.0
3	50.8
4	38.6
5	35.9
6	37.6
7	60.0
8	59.5
9	58.7
10	25.8
11	25.8
12	36.4
13	36.3
14	35.9
15	37.7
16	37.7
17	37.7
18	31.7
19	33.6
20	35.6
21	37.3
22	38.7
23	37.3
24	37.7
25	34.6
26	27.0
27	27.6
28	24.4
29	27.4
30	32.0
31	29.6
32	25.2

Results of effectiveness evaluation show that interstitial monitoring may be the best technique in terms of effectiveness. Tightness test by liquid-level measurement is found to be the second choice for underground tank leak detection. The top five types of leak detection/monitoring techniques are shown below:

(1) Interstitial monitoring (all types of monitoring equipment)
(2) Tightness test by liquid-level measurements
(3) Automatic inventory control
(4) Thermal conductivity sensor for vadose zone monitoring, or tightness test by acoustic measurements
(5) Vadose zone vapor or liquid monitoring by ionization, infrared methods or psychrometers, or tightness test by tracer techniques

COST COMPARISONS

Survey of Technology Costs

For the estimation of the capital costs of various leak detection or monitoring technologies, vendors from all regions of the United States were surveyed. Average cost and range were calculated based upon the survey. In the case where only 1 vendor was found for a particular technology, the cost from that vendor was assumed to be typical for that particular technology. Operation and maintenance (O&M) costs were calculated based upon best professional judgment. Tables 6 and 7 summarize the typical capital and annual costs of each control technology (based on 1986 prices) for vapor detection, liquid detection and tank integrity testing. When using these techniques for interstitial monitoring (between primary and secondary containment), an additional capital cost will be incurred for the secondary containment. This cost is typically in the range of $3,300 to $6,000 for a 10,000 gallon tank. The costs from this table are used to calculate the annualized costs for each control technology.

Cost Ratings

Cost comparisons for leak detection/monitoring are conducted in two ways. One is based purely on the cost required for the implementation and O&M of the technologies. The other includes the potential cleanup costs or costs which might result because of the inherent disadvantages of the technologies. In this section, the former type of cost comparison is presented. The latter type of cost comparison is site-specific and will be discussed in the Cost-Effectiveness Analysis section below.

Table 8 presents results of cost evaluation based on methodology described previously. Assumptions used for the calculation of annual costs are shown at the end of the table. As mentioned previously, a 30% rating was assigned to the second-level rating factor (r_j). As can be expected, manual or sensory methods, without the use of equipment, have higher P_i values. For non-continuous detection/monitoring techniques (e.g., tightness tests) costs are greatly affected by the measurement frequencies. In order to compare the effects of measurement frequencies, weekly, monthly, quarterly, semi-yearly and yearly frequencies are selected.

CONCLUSIONS OF COST-EFFECTIVE ANALYSIS STUDY

Evaluation Based on Technology

Table 9 shows the results of the cost-effectiveness evaluation for various detectors and monitors. Based on this evaluation, it is found that the interstitial monitoring techniques appear to be the best alternatives for underground tank leak detection/monitoring. Tightness test by liquid-level measurements may be the second most cost-effective alternative approach if test frequencies are longer than bi-yearly. Automatic inventory control is the next alternative for selection. Neutron moderation and gamma ray transmission techniques are not cost-effective and should not be considered for underground tank leak detection/monitoring.

Evaluation Based on Technology and Liability

A "case study" is presented for a number of leak detection/monitoring technologies for the evaluation of cost-effectiveness based on both technology and future liability. The assumptions are that a 10,000 gal gasoline tank begins leaking at a point in time such that the leak is detected 10 years after installation. The extent of soil and groundwater contamination were determined by the methods discussed previously. Table 10 presents the results of our case study where a leak is detected 10 years after installation. Cleanup and annual costs are assumed to be constant for the 10-year period (expressed in 1986 dollars). Table 11 presents a summary of information used to produce the 10-year cost totals in Table 10. This summary is based upon information from the nationwide survey of technology costs. This exercise suggests that interstitial space leak detection and vadose zone vapor monitoring (for volatile compounds only) are the most cost effective technologies over this representative time span.

Table 6
Costs of Liquid Detection and Monitoring Techniques and Tank Tightness Tests

Principle of Device/Technique	Sensor/Sampler[1]	Measurement Device/ Technique[1]	Annual Costs (O&M)[2]
Electrical Conductivity Sensors	540 (450 - 800)	1,500 (1,400 - 1,600)	400
Thermal Conductivity Sensors	900	1,450	400
Contact-Sensitive Coated Wires	230	1,400	400
Contact Sensitive Filaments (e.g. polypropylene)	300	--	400
Tensiometers Survey Instrument	--	40 (20 - 155)	450
Psychrometers (Soil probe) Survey Instrument	35	1,930	450
Geophysical Techniques (Soil Resistivity)	--	1,930 (3,300 - 8,000)	400
Vadose Liquid Sampling and Lab Analysis (Lysimeter)	500 (325 - 1,000)	142/test (45 - 550 per test)	450 (+142/test)
Groundwater Sampling and Lab Analysis (bailer)	150 (50 - 200)	142/test (45 - 550 per test)	600 (+142/test)
Vadose Zone Well (One 15 ft. well, 2" dia.)	--	400 (300 - 700)	--
Groundwater Well (One 60 ft. well, 2" dia.)	--	1,400 (1,100 - 2,100)	--
Tank Tightness Tests	--	600/test (400 - 800 per test)	600/test

1. Based on average or typical prices from vendor survey. Price range is in parentheses.
2. Costs assigned.

Table 7
Costs of Vapor/Gas Detection and Monitoring Techniques

Principle of Device/Technique	Sensor/Sampler[1]	Measurement Device/ Technique[1]	Annual Costs (O&M)[2]
Odor Detection	--	--	400
Adsorbtion Sensitive Resistor Probe	325 (100 550)	1,500	400
Metal-Oxide Semiconductor Probe	600 (480-760)	1,350	400
Synthetic Filament Probe (e.g. polypropylene)	300	--	400
Photoionization Detector Survey Instrument	--	3,950 (2,900 - 5,000)	400
Flame Ionization Detector Survey Instrument	--	5,200	400
Combustible Gas Meter Survey Instrument	--	1,100 (800 - 1,600)	400
Vapor Sampling and Lab Analysis (Lysimeter)	500 (325 - 1,000)	142/test (45 - 550 per test)	450 (+142/test)
Vadose Zone Well (One 15 ft. well, 2" dia.)	--	400 (300 - 700)	--

1. Based on average or typical prices from vendor survey. Price range is in parentheses.
2. Costs assigned.

Table 8
Results of Cost Evaluation (P_i Values)*

TYPE OF DETECTOR/MONITOR		i	Annualized Cost ($) (x)	$A_{ij} = \log(10^5/x)$	K_j	r_j (in %)	P_i (in %)
INVENTORY CONTROL	Manual (Weekly)	1	400	2.40	3	30	24.0
	Automatic	2	620	2.21	3	30	22.1
TIGHTNESS TESTING	Liquid-Level Measurements (Monthly)	3A	7,200	1.14	3	30	11.4
	Liquid-Level Measurements (Quarterly)	3B	2,400	1.62	3	30	16.2
	Liquid-Level Measurements (Bi-yearly)	3C	1,200	1.92	3	30	19.2
	Liquid-Level Measurements (Yearly)	3D	600	2.22	3	30	22.2
	Acoustic Measurements (Monthly)	4A	7,200	1.14	3	30	11.4
	Acoustic Measurements (Quarterly)	4B	2,400	1.62	3	30	16.2
	Acoustic Measurements (Bi-yearly)	4C	1,200	1.92	3	30	19.2
	Acoustic Measurements (Yearly)	4D	600	2.22	3	30	22.2
	Pressure Tests (Monthly)	5A	7,200	1.14	3	30	11.4
	Pressure Tests (Quarterly)	5B	2,400	1.62	3	30	16.2
	Pressure Tests (Bi-yearly)	5C	1,200	1.92	3	30	19.2
	Pressure Tests (Yearly)	5D	600	2.22	3	30	22.2
	Tracer Techniques (Monthly)	6A	5,270	1.28	3	30	12.8
	Tracer Techniques (Quarterly)	6B	1,910	1.72	3	30	17.2
	Tracer Techniques (Bi-yearly)	6C	1,070	1.97	3	30	19.7
	Tracer Techniques (Yearly)	6D	650	2.19	3	30	21.9

* See text for details.

(continued)

Table 8 (continued)

TYPE OF DETECTOR/MONITOR		i	Annualized Cost ($) (x)	$A_{ij} \equiv \log(10^5/x)$	K_j	r_i (in %)	P_i (in %)
INTERSTITIAL MONITORING (Continuous)	Liquid Monitoring	7	620	2.21	3	30	22.1
	Vapor Monitoring	8	620	2.21	3	30	22.1
	Pressure Monitoring	9	420	2.38	3	30	23.8
SENSORY MONITORING (Weekly)	Visual Monitoring	10	400	2.40	3	30	24.0
	Sense of Smell	11	400	2.40	3	30	24.0
VADOSE & AMBIENT AIR MONITORING	Adsorption Sensitive Resistors	12	1,700	1.77	3	30	17.7
	Combustible Gas Detectors	13	800	2.10	3	30	21.0
	Synthetic Filaments	14	820	2.09	3	30	20.9
	Photo-ionization Gas Detectors (Monthly)	15	1,240	1.91	3	30	19.1
	Flame-Ionization Gas Detectors (Monthly)	16	1,440	1.84	3	30	18.4
	Infrared Analyzers (Monthly)	17	1,200	1.92	3	30	19.2
	Draeger Tubes (Monthly)	18	830	2.08	3	30	20.8
	Sample Traps with Lab Analysis (Monthly)	19	910	2.04	3	30	20.4
VADOSE LIQUID MONITORING	Synthetic Filament Devices	20	820	2.09	3	30	20.9
	Electrical Conductivity Sensors	21	1,830	1.74	3	30	17.4
	Thermal Conductivity Sensors	22	2,020	1.69	3	30	16.9
	Contact Sensitive Coated Wires	23	1,600	1.80	3	30	18.0
	Psychrometers	24	800	2.10	3	30	21.0

(continued)

Table 8 (continued)

TYPE OF DETECTOR/MONITOR		i	Annualized Cost ($)(x)	$A_{ij} = \log(10^5/x)$	K_j	r_j (in %)	P_j (in %)
VADOSE LIQUID MONITORING (Continued)	Tensiometers	25	710	2.15	3	30	21.5
	Neutron Moderation Method (Monthly)	26	20,000	0.70	3	30	7.0
	Soil Resistance	27	3,350	1.47	3	30	14.7
	Gamma Ray Transmission (Monthly)	28	20,000	0.70	3	30	7.0
	Vacuum-Pressure Lysimeter Sampling/ Lab Analysis (Monthly)	29	1,120	1.95	3	30	19.5
	Core Sample/ Lab Analysis (Monthly)	30	1,400	1.85	3	30	18.5
GROUNDWATER MONITORING	In-Situ Measurements	31	2,000	1.70	3	30	17.0
	Sampling/ Lab Analysis (Monthly)	32	1,650	1.78	3	30	17.8

Assumptions:

1. Useful life of detectors/monitors is 15 years.
2. Interest rate for amortization = 12%.
3. Four in-situ monitoring wells are used for calculation for both vadose and groundwater zones monitoring.
4. Four monitoring wells or monitoring points are used for tracer techniques.

Table 9
Results of Cost-Effectiveness Evaluation

TYPE OF DETECTOR/MONITOR		i	Effectiveness P_i (in %)	Cost P_i (in %)	Overall P_i (in %)
INVENTORY CONTROL	Manual (Weekly)	1	34.4	24.0	58.4
	Automatic	2	47.0	22.1	69.1
TIGHTNESS TESTING	Liquid-Level Measurements (Monthly)	3A	50.8	11.4	62.2
	Liquid-Level Measurements (Quarterly)	3B	50.8	16.2	67.0
	Liquid-Level Measurements (Bi-yearly)	3C	50.8	19.2	70.0
	Liquid-Level Measurements (Yearly)	3D	50.8	22.2	73.0
	Acoustic Measurements (Monthly)	4A	38.6	11.4	50.0
	Acoustic Measurements (Quarterly)	4B	38.6	16.2	54.8
	Acoustic Measurements (Bi-yearly)	4C	38.6	19.2	57.8
	Acoustic Measurements (Yearly)	4D	38.6	22.2	60.8
	Pressure Tests (Monthly)	5A	35.9	11.4	47.3
	Pressure Tests (Quarterly)	5B	35.9	16.2	52.1
	Pressure Tests (Bi-yearly)	5C	35.9	19.2	55.1
	Pressure Tests (Yearly)	5D	35.9	22.2	58.1
	Tracer Techniques (Monthly)	6A	37.6	12.8	50.4
	Tracer Techniques (Quarterly)	6B	37.6	17.2	54.8
	Tracer Techniques (Bi-yearly)	6C	37.6	19.7	57.3
	Tracer Techniques (Yearly)	6D	37.6	21.9	59.5

(continued)

Table 9 (continued)

TYPE OF DETECTOR/MONITOR		i	Effectiveness P_i (in %)	Cost P_i (in %)	Overall P_i (in %)
INTERSTITIAL MONITORING (Continuous)	Liquid Monitoring	7	60.0	22.1	82.1
	Vapor Monitoring	8	59.5	22.1	81.6
	Pressure Monitoring	9	58.7	23.8	82.5
SENSORY MONITORING (Weekly)	Visual Monitoring	10	25.8	24.0	49.8
	Sense of Smell	11	25.8	24.0	49.8
VADOSE & AMBIENT AIR MONITORING	Adsorption Sensitive Resistors	12	36.4	17.7	54.1
	Combustible Gas Detectors	13	36.3	21.0	57.3
	Synthetic Filaments	14	35.9	20.9	56.8
	Photo-ionization Gas Detectors (Monthly)	15	37.7	19.1	56.8
	Flame-Ionization Gas Detectors (Monthly)	16	37.7	18.4	56.1
	Infrared Analyzers (Monthly)	17	37.7	19.2	56.9
	Draeger Tubes (Monthly)	18	31.7	20.8	52.5
	Sample Traps with Lab Analysis (Monthly)	19	33.6	20.4	54.0
VADOSE LIQUID MONITORING	Synthetic Filament Devices	20	35.6	20.9	56.5
	Electrical Conductivity Sensors	21	37.3	17.4	54.7
	Thermal Conductivity Sensors	22	38.7	16.9	55.6
	Contact Sensitive Coated Wires	23	37.3	18.0	55.3
	Psychrometers	24	37.7	21.0	58.7

(continued)

Table 9 (continued)

TYPE OF DETECTOR/MONITOR		i	Effectiveness P_i (in %)	Cost P_i (in %)	Overall P_i (in %)
VADOSE LIQUID MONITORING (Continued)	Tensiometers	25	34.6	21.5	56.1
	Neutron Moderation Method (Monthly)	26	27.0	7.0	34.0
	Soil Resistance	27	27.6	14.7	42.3
	Gamma Ray Transmission (Monthly)	28	24.4	7.0	31.4
	Vacuum-Pressure Lysimeter Sampling/ Lab Analysis (Monthly)	29	27.4	19.5	46.9
	Core Sample/ Lab Analysis (Monthly)	30	32.0	18.5	50.5
GROUNDWATER MONITORING	In-Situ Measurements	31	29.6	17.0	46.6
	Sampling/ Lab Analysis (Monthly)	32	25.2	17.8	43.0

Table 10
10-Year Cost-Effectiveness Case-Study of Technologies

Technology	Ten-Year Cumulative Cost(1)
Manual Inventory Reconciliation with Annual Tank Integrity Testing	25,873
Monthly Tank Integrity Testing	75,573
6-Month Tank Integrity Testing	20,455
Interstitial Space Liquid Detection (Liner System)	
- Contact Sensitive Coated Wire	11,117
Electrical Conductivity Sensor	11,587
Thermal Conductivity Sensor	11,897
Interstitial Space Vapor Detection (Double-Walled Tank)	
Adsorption Sensitive Resistor Sensor	11,797
MOS Combustible Gas Sensor	11,922
Vadose Zone Liquid Monitoring	
Electrical Conductivity Sensor	16,810
- Lysimeter with Lab Analysis (3-Month Interval)	15,770
Vadose Zone Vapor Monitoring	
MOS Combustible Gas Sensor	9,405
Photoionization Survey Instrument (Monthly)	11,405
Groundwater Monitoring	
Thermal Conductivity Sensor	180,968
Well Bailing and Lab Analysis (3-Month Interval)	193,078

1. Cumulative costs based upon complete payment of capital cost in first year and constant annual costs. Model systems for 10,000 gallon tank and a 0.05 gph leak rate.

Table 11
Costs of Technologies and Contamination Cleanup

Technology	Cost of Technology ($) Capital	Annual	Volume of Contaminated Soil before Detection (yd^3)	Cost of Tank and Soil/Groundwater Cleanup ($)[4]
Manual Inventory Reconciliation (Weekly) (With Annual Tank Integrity Test)	--	1,000	66.8	15,873
Tank Tightness Test (liquid level)				
Monthly Testing	--	7,200	5.5	2,573
6-month Testing	--	1,200	33.4	7,455
Interstitial Space Liquid Detection[1] (Liner System with Carbon Steel Tank)				
Contact Sensitive Coated Wire	5,567	400	Backfill	1,610
Electrical Conductivity Sensor	5,977	400	Backfill	1,610
Thermal Conductivity Sensor	6,287	400	Backfill	1,610
Interstitial Space Vapor Detection[2] (Double-Walled FRP Tank)				
Adsorbtion Sensitive Resister Sensor	7,797	400	--	--
Combustible Gas Sensor (i.e., metal-oxide semiconductor, MOS)	7,922	400	--	--
Vadose Zone Liquid Monitoring (Two 20 ft. wells)				
Electrical Conductivity Sensor	2,940	400	47.2	9,870
Lysimeter Sample with Analysis (at 3-month Intervals)	1,400	450	47.2	9,870
Vadose Zone Vapor Monitoring (Two 20 ft. wells)				
Combustible Gas Sensor (MOS)	2,850	400	5.4	2,555
Photoionization Survey Instrument (Monthly)	4,850	400	5.4	2,555
Ground Water Monitoring[3] (One 60 ft. well)				
Thermal Conductivity Sensor	3,440	400	68.1	173,528
Well Bailing and Lab Analysis (At 3-month Intervals)	1,550	1,200	68.1	173,528

1 The cost of liner system and a backfill monitoring well is included in the capital cost ($4,337)

2 The additional cost of a double-walled Fibreglass Reinforced Plastic (FRP) tank is included in the capital cost ($5,972)

3 Groundwater level is assumed to be 30 feet below the bottom of the tank

4 Leak rate is 0.05 gph (average rate) and the soil is Sandy Soil (Because inventory reconciliation is only sensitive to a leak of about 0.1 to 0.2 gph, it is assumed that yearly tank integrity testing will detect a leak 2 years after it has started and the leak is less than 0.5 gph for the first year.)

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Underground Storage System Assessment, Testing and Remediation

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INTRODUCTION

It is estimated that groundwater supplies 24% of the Nation's domestic, agricultural and industrial water. Reliance on groundwater has increased greatly over the past few decades with over 50% of the U.S. population utilizing it for its potable water supply.

Groundwater reserves are threatened by a variety of contaminant sources. A major, though often overlooked, source of contamination is leaking underground storage tanks. The U.S. EPA estimates that nearly 11 million gallons of gasoline alone may be leaking from underground storage tanks. Gasoline, however, is only one of the substances stored in underground tanks. Other substances include hazardous materials and wastes and nearly every type of petroleum product. Most of these storage tanks are constructed of bare steel, which the American Petroleum Institute estimates to have only a 15-year service life before leaking will occur.

To address this situation, governments at the state, local and federal levels have begun to implement legislation to govern new and existing underground storage systems. These programs implement a registration system for existing tanks to define the extent of underground storage. Design standards also are being implemented for new underground facilities, as well as a tank integrity testing program for existing underground storage systems.

In this paper, the authors discuss the regulatory aspects of the underground tank issue and the method by which O'Brien & Gere conducts underground storage system evaluations, including site assessment and priority modeling, leak detection, recovery of product and site remediation. The paper will begin with an overview of existing and proposed federal legislation governing underground storage of petroleum products, hazardous materials and wastes. The paper then will discuss the methodology for predicting leakage from, and for the testing and monitoring of, underground storage systems.

O'Brien & Gere's approach to conducting a site assessment begins with the gathering of tank and site-specific data and, using a computer, modeling and prioritizing the tanks. Once an assessment and priority list have been established, an action plan is developed and system testing may begin. Various aspects of the subsequent tank testing, using the Petro-Tite® method, will be discussed in detail.

REGULATORY REQUIREMENTS

As the problem of leaking underground storage tanks became more apparent, legislation was adopted to prevent and control it. In the late 1970s, the federal government and many state legislatures adopted oil spill prevention laws which regulated oil storage facilities. These regulations stated that facilities having greater than 42,000 gal of underground petroleum storage must develop plans to prevent and control oil spills. During the early 1980s, the federal government and several state agencies realized the widespread problem associated with the underground storage of petroleum and other hazardous chemicals. Federal legislation was subsequently developed governing petroleum storage of 1,100 gal or more at both new and existing systems. The Hazardous and Solid Waste Amendments of 1984 (HSWA), which amended RCRA, contain provisions for the regulation of underground storage systems. The U.S. EPA has also proposed changes to Subtitle J of RCRA, which governs underground storage of hazardous waste. The following sections describe those aspects of the federal regulations which apply to underground storage tanks.

HAZARDOUS AND SOLID WASTE AMENDMENTS OF 1984

The HSWA of 1984 enacted Subtitle I—Regulation of Underground Storage Tanks (RUST) as a part of RCRA. Subtitle I (RUST Program) regulates all petroleum products and all hazardous substances as defined in CERCLA that are stored in underground tanks. For the purpose of this regulation, an underground tank is defined as any tank with 10% or more of its volume, including all attached piping, located below the ground surface. For those systems under the jurisdiction of RUST, the U.S. EPA has authorized several programs dealing with underground storage systems. These programs include:

- *Registration/Inventory:* This underground tank registration/inventory program calls for registration of new and existing tanks with the designated state and/or local regulatory agencies. This has resulted in the proposed rule 40 CFR 280—Notification Requirements for Owners of Underground Storage Tanks. This rule describes the registration forms and the information which must be contained.
- *U.S. EPA Regulations:* The U.S. EPA will issue regulations regarding all underground storage tanks. These regulations shall contain the elements necessary to protect human health and the environment and include, but not be limited to, requirements for:
  -leak detection or inventory control and tank testing
  -record keeping and reporting
  -corrective action
  -financial responsibility, as necessary or desirable, for corrective action and third party liability
  -closure
- *Interim Standards:* Interim standards for the installation of new underground tanks will be established. These standards will require that a new tank for the storage of regulated substances may not be installed unless the tank:

-will prevent releases due to corrosion or structural failure for the operational life of the tank
-is cathodically protected against corrosion, constructed of non-corrosive material, steel clad with a non-corrosive material, or designed in a manner to prevent the release or threatened release of any stored substance
-is constructed or lined with material that is compatible with the substance to be stored; however, a storage tank may be installed without corrosion protection if the soil resistivity is 12,000 ohm/cm or more

- *Performance Standards:* The U.S. EPA must issue permanent performance standards for the installation of new underground systems. These standards shall include, but not be limited to, design, construction, installation, release detection and compatibility standards.
- *State Programs:* RUST establishes that states may administer the underground tank program in lieu of the U.S. EPA. The states' requirements must be no less stringent than those established by the U.S. EPA.
- *Further Study:* The U.S. EPA must conduct studies of petroleum and other regulated substances contained in underground tanks.
- *Enforcement:* RUST provides for the enforcement of the established laws and regulations.

RCRA AMENDMENTS

In addition to HSWA, the U.S. EPA proposes to amend regulations under RCRA for control of tank systems storing or treating hazardous waste. These regulations provide for secondary containment of all new underground tanks storing hazardous wastes.

The secondary containment systems must:

- Be designed, installed and operated to prevent waste or liquid from escaping to soil or water for the life of the tank
- Be capable of detecting and collecting waste or leakage until removal of material
- Be constructed or lined with materials compatible with the waste and be of sufficient strength to prevent failure from pressure, climate, traffic and daily use
- Have an adequate base or foundation to resist settlement, compression and uplift
- Have a leak detection system capable of detecting leaks within 24 hours of occurrence
- Be sloped or drained to remove leaks, spills and precipitation with provisions for accumulation to be removed as soon as possible, but within 24 hours of release
- Be designed or operated to contain 110% of the design capacity of the largest tank within the containment boundary
- Prevent run-on or infiltration of precipitation unless the collection system has excess capacity over the 110% to contain precipitation from the 25-year, 24-hour rainstorm

Existing tanks can avoid the secondary containment requirements by developing a groundwater monitoring system combined with a scheduled tank testing program.

The above regulations clearly show that the federal government has implemented a major program to control the problem of leaking underground storage tanks. In addition to these federal constraints, states also have begun to administer regulations for underground storage systems. In most instances, these are more stringent than the federal regulations.

UNDERGROUND STORAGE SYSTEM ASSESSMENTS

O'Brien & Gere has developed an approach for evaluating the integrity of an underground storage system which combines the use of a mathematical model for predicting environmental hazard with the procedures for the testing and monitoring of underground storage tanks. When this approach is utilized with background information relating to the design of storage systems and the development of environmental remediation programs, the result is a complete program for assessing underground storage systems. The approach utilized consists of four basic tasks which are described in detail in the sections below.

Task 1—Facility Survey:

A survey of an underground storage system consists of obtaining site-specific data and using these data to determine a system's potential to corrode and, hence, leak. The survey is conducted utilizing a questionnaire. The questionnaire is structured to be easily modified and used at facilities in various states. The data pertain to three major areas of coverage: (1) regulatory information, (2) tank data and (3) environmental data. The regulatory aspects of the questionnaire include the elements identified by the U.S. EPA in the proposed rule of 40 CFR Part 280—Notification Requirements for Owners of Underground Storage Tanks. In instances where requirements stipulated by the state in which the facility is located exceed the part 280 requirements, these state provisions also are addressed.

Technical information to be obtained for each tank includes tank design features, such as dimensions and capacity, materials of construction, location, depth of cover and a description of pipes, pumps and other appropriate appurtenances. Information regarding the tanks' history such as age, material stored, past leaks, repairs and previous testing also is obtained.

To facilitate the prioritization, which is accomplished in Task 2, available environmental information also is requested. These data include site hydrogeologic and soil characteristics, distance to nearest water supply, distance to nearest residence, adjacent population densities and other issues relating to environmental sensitivity. A site plan, identifying the approximate location of each tank, also is developed.

To ensure consistency in data generation, a set of user's instructions has been developed to accompany the questionnaire. These instructions include a concise explanation of each entry on the questionnaire and recommended terminology. The questionnaire then is completed by either O'Brien & Gere or facility personnel. As the data are obtained, they are collated, entered into a computer data file and a master list of underground tanks and information is developed. Following completion of the master list, the next task, ranking the tanks in a prioritized order, is initiated.

Task 2—Rank Tanks in Priority Order:

Utilizing the information obtained and compiled in Task 1, the storage systems are ranked using a site-specific mathematical model. Based upon the results of this prioritization, recommendations for further action on each tank are identified within this ranking. The priority ranking saves time by providing a concise listing of those tanks which are likely to represent existing or potential problems.

The information necessary to rank the tanks is supplied on the survey forms completed in Task 1. These data are composed of three basic types: (1) tank data, (2) environmental data and (3) leak hazard data. These tank data consist of physical data related to the tank such as tank age, the tank's materials of construction and any existing protective coatings or devices. Environmental data include the relative location of groundwater and its users, the relative location of surface water bodies and their users and the types of soil surrounding the tank. The leak hazard data consist of the past history of the tank concerning leaks and/or re-

Table 1
Underground Storage System Assessment
Priority Ranking Model Data Descriptions

Data Parameters	Description
Tank Data:	
1. Tank age	-The API estimates that 50% of bare steel tanks leak after 15 years. Therefore, this is the most important factor for steel tanks.
2. Materials of construction	-i.e., carbon steel, fiberglas, reinforced plastic, stainless steel.
3. Internal protection	-Coating and lining, such as glass, zinc or plastic.
4. External protection	Coatings and coverings such as FRP, asphalt or epoxy
5. Cathodic protection	Sacrificial anode or impressed current.
6. Secondary containment	Such as double-walled tanks, concrete vaults or lined excavations.
Environmental Data:	
1. Depth to groundwater	-Depth of average groundwater surface below the ground surface.
2. Distance to nearest groundwater well	-Distance to nearest potential groundwater receptor.
3. Distance to nearest surface water body	-Potential lakes or streams to be impacted by a leak.
4. Soil type surrounding tank	-Porosity and resistivity affect movement of leaked material and corrosion of tank.
Leak Hazard Data:	
1. Tank status	-Is tank currently active or inactive, empty or full?
2. Tank repair frequency	-History of past tank repairs and methods used.
3. Previous leak testing	-Test methods used (i.e., Petro-Tite® or static heat test) and results.
4. Previous leaks detected	-Frequency of past leaks.
5. Material stored	-Hazard ratings of the different materials were ranked according to such things as toxicity, carcinogenicity, flammability, etc.

pairs, the hazard rating of materials stored in the tank and the status of the tanks, either active or inactive. Table 1 lists the parameters which are used to rank the tanks, descriptions and examples.

The information for each tank regarding the data identified in Table 1 will be gathered through the use of the survey forms developed during Task 1. For each parameter, various specific input variables are possible. The mathematical model assigns a value to each specific variable based on whether it increases or decreases the tank's potential for leaking. The separate data points are weighted according to their importance in determining a tank's leak potential.

To develop the weighting factor, tanks are divided into two categories: steel or fiberglass reinforced plastic (FRP). The weighting of tank parameters differs for these two types. For steel tanks, the age of the tank and the corrosion protection methods employed are the most important parameters. For FRP tanks, which do not corrode due to soil moisture, the installation method, location of the tank with respect to traffic and groundwater or frost upheaval and compatibility with the material stored become the most important factors. After the weighting factors are applied, each input variable is assigned a specific value which is combined numerically to generate a total tank ranking value.

The total tank ranking value represents a certain hazard rating for the tanks. Ranges of ranking values have been developed for each hazard rating based on empirical data and modified to facilitate ease of use. The hazard ratings are divided into the following four categories:

- Remove Tank
- High Hazard Rating
- Medium Hazard Rating
- Low Hazard Rating

Tanks previously tested and information about other tanks which O'Brien & Gere has worked with have been ranked using the mathematical model. The ranking scores which were generated were then combined with their leak history to develop the ranges for the above four ratings. The model is used on each tank tested, and the outcome of the test is used to refine the sensitivity of the hazard rating ranges.

The mathematical model is incorporated into the computer data base file developed in Task 1. In this way, as the information gathered during Task 1 is entered into the computer file, the program automatically assigns a ranking score and hazard rating to the tank. Using these individual ratings, a prioritized schedule for the testing of the tanks is developed.

Task 3—Site and Tank Assessment:

Based upon the finalized testing schedule established in Task 2, an assessment of each site relative to its potential for having tank testing performed is conducted. Following the assessment and any necessary modifications, the tanks are tested following the schedule developed in Task 2.

Currently, several methods exist for testing underground tank systems; however, there are only a limited number which meet the stringent requirements of NFPA. Six methods which propose to meet these requirements are:

- Petro-Tite® (formerly Kent-Moore)
- ARCO-HTC
- Leak-Lokator
- Tank Auditor
- Horner EZY-CHEK
- Ainlay Tank Tegrity Tester

The testing method used by O'Brien & Gere is the Petro-Trite® method. A brief description of the method is given below.

Petro-Tite® (formerly Kent-Moore) Method:

The Petro-Tite® method of testing underground storage systems consists of a hydrostatic test that compensates for temperature, pressure and viscosity variation and enables the detection of leaks as small as 0.01 gal/hr. The Petro-Tite® test apparatus exerts a static pressure head on the tank using a standpipe filled with the same liquid stored in the tank. A pump is used to circulate the liquid and produce a uniform temperature throughout the tank, and a thermal sensor monitors temperature changes to account for expansion and contraction of the liquid. Volumetric changes are then calculated due to these changes in temperature. The Petro-Tite® test accurately measures the amount of product added to or removed from the standpipe to maintain a constant head. By comparing the product added or drained with the volumetric variances anticipated due to temperature changes, it is possible to reliably detect a leak as small as 0.01 gal/hr. The method compensates for tank-end wall deflection by elimination of deflection. This is accomplished by a pressure reduction induced during the test. Due to the intricate nature of the test and the need for a skilled technician, the Petro-Tite® test requires several hours to complete. In addition, the tank must be out of service, and full, in order to conduct the test.

To perform the Petro-Tite® test, the following conditions must be met:

- The tank must be out of service and have one testing access port per 10,000 gal of tank capacity.

- The access ports must be straight down into the tank, must be 3 to 4 in. in diameter and must not contain a drop tube.
- The depth of groundwater in contact with the tank must be known.
- The tanks must be able to be isolated from piping.
- Power supplies must be located within 100 ft of the tank. The power available must consist of a 110 volt AC service with a 20 amp breaker for tanks of 12,000 gal or less, or two separate 110 volt AC circuits, one having a 20 amp breaker and one having a 30 amp breaker, for tanks of 12,000- to 30,000-gal capacity.
- The viscosity of the material must be such that the liquid can be pumped.
- No more than 1 in. of water is allowable in the bottom of the tank (unless testing with water). Sludge on the bottom of the tank may not be greater than 1 in. in depth.

Prior to initiating the tank testing activities, a survey of the site will be conducted to determine if these conditions are met. After the tanks have been retrofitted to meet the above criteria, the tanks would be tested according to the schedule determined in Task 2. The initial test utilized is a system test (tank and pipelines) which tests the entire tank system. Should the results of testing indicate the system is not leaking (less than the NFPA 0.05 gal/hr rate), the tank system will be certified as non-leaking. If the testing shows leakage, it would not be defined from this initial test whether the leak is in the tank or the pipeline. At this time, Task 4 would be initiated for those systems which are leaking. Task 4, which is described in the following section, is conducted concurrently with Task 3, only upon detection of a tank leak. This coordination of tasks precludes any interruption of service and ensures project progression in the most economic manner.

Task 4—Leak Characterization and Initial Environmental Testing:

The location of a leak identified in the initial testing of Task 3 will be determined immediately following its detection. There are two methods by which this will be accomplished. The first includes isolating the tank from the pipelines by installation of valves or capping the tank and pipelines and retesting the affected tank or pipelines. This method would produce a numerical result identifying the leakage rate in both the tank and the pipeline. The second method includes excavating the soil from over the pipelines and retesting the affected tank while visually observing the piping for leakage. Each method offers distinct advantages and disadvantages depending on the situation at hand. O'Brien & Gere would, depending on the actual field situation, recommend the most cost-effective method with which to proceed.

When the location of the leak has been determined, a sampling program is developed for each facility to determine if there has been environmental contamination. This sampling program could include the collection of surficial soil samples and subsequent analysis, installation of soil borings with continuous split-spoon sampling of soils and subsequent analysis, the installation of groundwater monitoring wells and the collection of groundwater samples for subsequent analysis. All sampling and analysis is conducted utilizing U.S. EPA-approved procedures. Samples generally are analyzed in the laboratory for petroleum fractions including benzene, toluene, xylene and total hydrocarbons.

At the completion of the initial environmental assessment, a report is prepared which presents the results of the leak characterization and environmental testing. This report provides an indication of the magnitude of contamination, recommendations for tank or line remediation and recommendations for further environmental investigations to define the full extent of contamination. The implementation of these recommendations and subsequent activities associated with remedial alternatives and design are discussed in the following sections of this paper.

Those systems found to be leaking in Tasks 3 and 4 of the above-described evaluation are scheduled for replacement and/or repair in accordance with available regulations and technologies. Those facilities identified as contaminated are then further investigated and remedial alternatives are developed, evaluated and selected.

Replacements and/or repairs should be conducted in accordance with guidelines established by API, NFPA, Underwriters Laboratories (UL) and the Steel Tank Institute (STI), among others. Construction should proceed with structurally sound materials compatible with the product to be stored. The system should intrinsically, or by design, prevent corrosion from occurring and include safety features such as overfill prevention devices, secondary containment and leak monitoring.

Depending on the severity of the situation, system repair may be as simple as replacing a valve or fitting, or as involved as relining an entire tank. Regardless, it must be understood that these types of repairs are only temporary and should be considered interim until a suitable replacement is financially feasible.

If necessary, a full investigation to determine the extent of environmental contamination is conducted concurrent with tank and line rehabilitation. A program would be developed that could utilize the following:

- Additional soil sampling and analysis
- Additional soil boring installation
- Additional groundwater monitoring well installation
- Additional groundwater sampling and analysis
- Geophysical investigations
- Site Water Budget Analyses
- Contaminant Mass Transport Modeling and
- Risk Assessment

The information gathered from these investigations is utilized to identify the most feasible remedial alternative, including no action, product recovery or in-place containment. This alternative then is designed and implemented utilizing the best available technology.

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Case Study of Product Detection in Groundwater

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ABSTRACT

This study describes the systematic procedures taken to assess groundwater contamination in the vicinity of a gasoline station having five underground storage tanks installed 15 to 20 years ago. A gasoline odor in the basement of an adjacent office building was detected. Because of its proximity, it was believed that the source of gasoline in the groundwater was the nearby gasoline station. Leaking pump and storage tanks were the suspected sources. Tests on water samples from a sump pump in the office building confirmed high concentrations of benzene, toluene and xylene in the groundwater.

A groundwater monitoring program was developed consistent with the geologic and hydrogeologic conditions of the locality. The program consisted of installing six observation wells 20 to 30 ft deep. Two monitoring wells in the vicinity of two underground tanks and one well adjacent to a leaking gasoline pump showed evidence of high concentrations of gasoline. The two underground tanks then were tested for leaks using the Ainlay Tank Tegrity Testing Method. Test results were evaluated in terms of soil and groundwater conditions. Discussion of a product recovery well designed to recover the product is also presented.

INTRODUCTION

Bringing underground storage tanks into compliance with the 1984 amendments to RCRA will have a significant effect on the regulated community. Subtitle I of the amended RCRA provides a comprehensive regulatory program for underground tanks that contain petroleum and other regulated substances. The U.S. EPA has estimated that between 100,000 and 400,000 underground tanks in the United States are leaking and are thought to be a source of a substantial number of groundwater contamination cases.

Leaking underground tanks and piping systems used for the storage of liquid chemicals and fuels is an important issue for the U.S. EPA and industry to address over the next few years. Tank leakage problems have many similarities to hazardous waste sites in their requirements for remedial action. Groundwater and soil contamination can be very difficult and very expensive to correct.

For tank owners, insuring against non-sudden accidental pollution occurrences such as tank leakage is becoming extremely difficult. The condition and operating history of underground storage and piping systems is coming under much closer scrutiny in plant/facility environmental control systems.

The emergence of legislation and concomitant regulations regarding registration, monitoring of existing tanks and design and installation of new tanks has also increased interest and concern for the status of underground tank installations. Finally, the development of national and state groundwater policy legislation and regulations has placed further focus on the problem of underground tanks. These factors, coupled with the aging and inevitable failure of tanks, makes the management of the problem unique.

This paper presents a systematic evaluation of groundwater contamination in the vicinity of a gasoline station. The program for this investigation included background data collection, a review of site geology and hydrogeology, water quality testing, a review of applicable groundwater quality standards, tank testing, assessment of adverse impact on groundwater and product recovery from soil and groundwater.

BACKGROUND

The gasoline station is located in a suburban area. An office building is located immediately west of the gasoline station. In early 1985, a gasoline odor in the basement of the office building was detected. The basement has two sump pumps located in the northwest and southeast corners. During high groundwater periods, these sump pumps operate frequently. These sumps were the source of the odor. Because of the proximity of the office building to the gasoline station, it was believed that the source of gasoline was the station. The Wisconsin Department of Natural Resources directed the owner of the station to conduct an investigation to determine the source of gasoline in the nearby building.

Investigation indicated that the super unleaded pump was leaking; it was repaired on Jan. 28, 1985. Two samples of water were collected from the sumps on Mar. 29, 1985. Test results confirmed the presence of petroleum products in the sump water. The concentration of the product was highest in the northwest sump pit.

Records indicated that there had been a small farm house located close to the southern edge of the office building, parallel to the gasoline station property. It was learned that a drain tile was buried about 6 ft below the existing grade at the farm house. The location and flow direction of the drain tile was not known. Based on the groundwater flow direction at the site, it was anticipated that the drain tile was laid in a north-south direction.

The layout of sanitary and storm sewers and water supply lines is shown in Figure 1. The sanitary sewers were installed in 1964 approximately 6 to 8 ft below the existing ground surface. Water supply lines were placed at the same depth in the same trench. These pipes were embedded in granular backfill.

The piping from the underground storage tanks to the filling station (Fig. 1) was laid in a trench filled with granular fill.

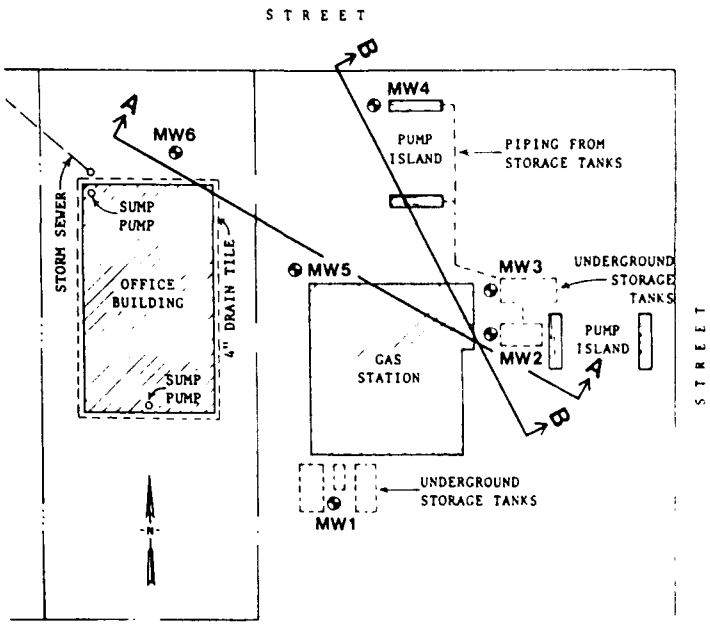

Figure 1
Gasoline Station and Monitoring Well Layout

METHODOLOGY

The investigation included installing six test borings from 20-30 ft deep, installing six observation wells and conducting field and laboratory testing. The well locations are shown on Figure 1. Standard field sampling techniques were employed in accordance with applicable standards. Drilling was performed using 8-in. diameter hollow stem augers. Final boring logs were prepared; these logs included boring methods, sample method, depth of samples, amount of recovery and description of subsoil types and groundwater levels.

Observation wells were installed in accordance with the guidelines established by the Wisconsin Department of Natural Resources (WDNR).[1] Monitoring wells were developed and sampled in accordance with the standards set forth by the WDNR.[2-4] Water samples were tested for benzene, toluene, xylene, pH and conductivity.

Two of the station's underground tanks having 8,000 and 10,000 gal capacities were tested using the Ainlay Tank Tegrity Testing method. They were found to be structurally tight.

Groundwater quality standards, as established under NR140, were reviewed and an assessment was made of any adverse impact on groundwater. Test results were evaluated in view of site geology and hydrogeology.

WISCONSIN GROUNDWATER QUALITY STANDARDS

WDNR has established groundwater quality standards for substances detected in, or having a reasonable probability of entering, the groundwater resources of the State. The standards include procedures for determining whether a parameter has been exceeded and procedures for establishing points of standard application.

The groundwater quality standards for substances of public health concern are listed in a WDNR publication.[5] For all substances that have carcinogenic, mutagenic or teratogenic properties or interactive effects, the preventive limit is 20% of the enforcement standard for all other substances that are of public health concern.

For each substance of public health concern, the preventive action limit is 50% of the established enforcement standard. For each indicator parameter, the preventive action limit is established based on a change of water quality with respect to the background concentration of the parameter. Background water quality means groundwater quality near a facility which has not been affected by the facility. If, based on the monitoring results from a point of standard application, a preventive action limit or enforcement standard for a substance of public health or welfare concern is exceeded, appropriate additional sampling and testing is required by the WDNR.

SITE CHARACTERIZATION

In Eastern Wisconsin, consolidated rocks consist mainly of sandstone, dolomite, shale and possibly some limestone, all of the Paleozoic Age. These rocks are covered largely by soil deposits of Pleistocene and Recent Age.

There is evidence of the advance and retreat of at least four major ice sheets in the northern United States. Although all four overrode the subject area, only the most recent one, designated as the Wisconsinan Stage, left soil deposits in quantities of engineering significance. The Wisconsin ice sheets generally flowed south through Wisconsin and the neighboring states. They deposited lithologically uniform sheets of tills separated by discontinuous lacustrine and outwash deposits. The tills were deposited beneath the ice sheets and are classified as lodgement tills. The outwash and lacustrine sediments were deposited in proglacial lakes.

The individual till sheets have been grouped into three till units on the basis of their lithologic characteristics. They are referred to as Till 1, Till 2 and Till 3; Till 1 being the oldest.[6] The general characteristics of the soil units are summarized by Singh, *et al.*[7]

The geology of the site described here is dependent on data obtained from the six soil borings and several water supply wells in a 2,000 ft radius of the facility. Also, several publications were reviewed. Based on the water supply well logs, I concluded that the bedrock elevation changed from about 802 to 606 ft USGS elevation; the depth to bedrock ranges from 70 to 200 ft; the bedrock surface slopes to the east with a gradient of about 50 to 100 ft/mile.

The bedrock underlies a sand and gravel layer. The sand and gravel layer in turn underlies an older soil unit characterized as Till 2, which is a fine grained soil and ranges from sandy silt to silty clay. It contains numerous cobbles and boulders. The Till 2 soil is overlain by lacustrine sand and silt and clay layers, which are, in turn, masked by a silty clay layer characterized as Till 3. The Till 3 soil at the site is overlain by 2 to 14 ft of fill which ranges from sand to gravel. The top 4 in. are asphalt pavement.

SUBSURFACE CONDITIONS

Construction of commercial buildings and utilities have significantly changed the subsoils at the site which is typical of an urban environment. The changes in subsoil generally are limited to the top 2 to 4 ft of soils which consist of coarse-grained sand and gravel fill. In general, the fill thickness is about 2 to 4 ft and approximately 10 ft or more at the locations of the underground storage tanks.

The two underground tanks in the vicinity of Monitoring Wells MW-2 and MW-3 are 9 ft in diameter and buried about 4 ft below the existing grade. These two tanks are 17 and 21 ft long. The remaining three underground storage tanks in the vicinity of Monitoring Well MW-1 are 7 to 9 ft in diameter and 14 to 17 ft in length. These tanks are also approximately 4 ft below the existing grade and are embedded in granular backfill. The trenches for piping from the storage tanks to the service station also are filled with granular backfill. These trenches are approximately 4 ft deep.

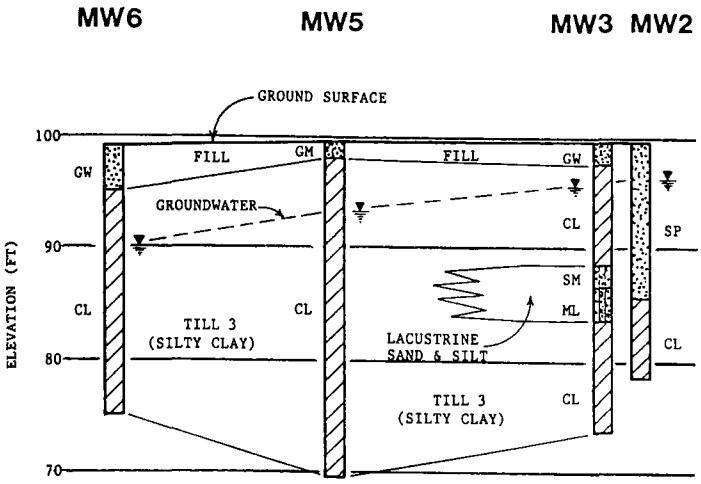

Figure 2
Soil Profile — Section A-A

Reconstruction of the office building has altered the subsoil conditions at the site. The fill thickness at the building is approximately 4.5 ft. Backfill at the perimeter of the deepest building foundation extends down to approximately 10 ft below existing grade.

The subsoils underlying the fill are rather uniform and consist of very stiff to hard reddish brown silty clay. Occasional cobbles were noted. This soil is characterized as Till 3; it is encountered throughout the site, except where excavation for utilities was made. The silty clay (Till 3) is underlain by discontinuous layers of lacustrine sand and silt as shown in the soil profiles in Figures 2 and 3. These subsoils are water-bearing and moderately permeable. This layer is underlain by silty clay soil of very still to hard consistency. This layer has a low permeability, estimated to be on the order of 10^{-7} cm/sec.

SITE HYDROGEOLOGY

The topography of the area in the proximity of the gasoline station ranges from slightly rolling to generally flat. The site is located on the crest of a ridge with an elevation of approximately 882 ft (USGS) which extends in a northerly direction with a rise in elevation to about 900 ft. The ridge acts as a groundwater divide for surface water and also for groundwater. The surface runoff drains to the east and west from the site.

Water supply wells installed at the Silurian dolomite and basal sand and gravel aquifer indicate that groundwater is approximately 10 to 75 ft below grade. The variation in groundwater level is attributed to a highly variable drift thickness and considerable relief in the bedrock surface. The groundwater flow direction in the bedrock is easterly from the ridge which agrees with the regional groundwater flow direction in the consolidated sediments.

In general, groundwater flow in the unconsolidated sediments appears to divide westerly and easterly based on the topography of the area. In proximity to the site, groundwater flow in the shallow aquifer is northwesterly to westerly (Fig. 2). Groundwater elevations in the six monitoring wells at the site are approximately 3 to 10 ft below existing grade.

Based on the data gathered, I concluded that the basal sand and gravel aquifer and the shallow aquifer are not hydraulically connected. These two aquifers are separated by thick layers of tills.

The sensing zone for the monitoring wells was the discontinuous layer of lacustrine sand and silt and Till 3 layers. Permeability of silty sand and sandy silt was estimated to be 10^{-5} cm/sec, which is typical of such soils. The permeability of silty clay soils was estimated to be on the order of 10^{-7} cm/sec or less. These estimates of permeability for clay and low hydraulic gradients indicate that movement of groundwater is very slow.

WATER QUALITY ASSESSMENT

Water samples from the sump in the building were tested for gasoline, benzene, xylene, toluene and ethylbenzene. Product concentrations ranged from 820 to 3,100 μg/l for gasoline; 230 to 860 μg/l for xylene; 33 to 140 μg/l for toluene; and 1.3 to 67 μg/l for benzene. The enforcement limits for benzene, toluene and xylene in groundwater are 0.067, 68 and 126 μg/l, respectively, under WDNR regulation 140(5). Concentrations of product in the water samples significantly exceeded the enforcement standards. The decision was made first to determine the source of product and second the transport mechanism of product from the source to the building.

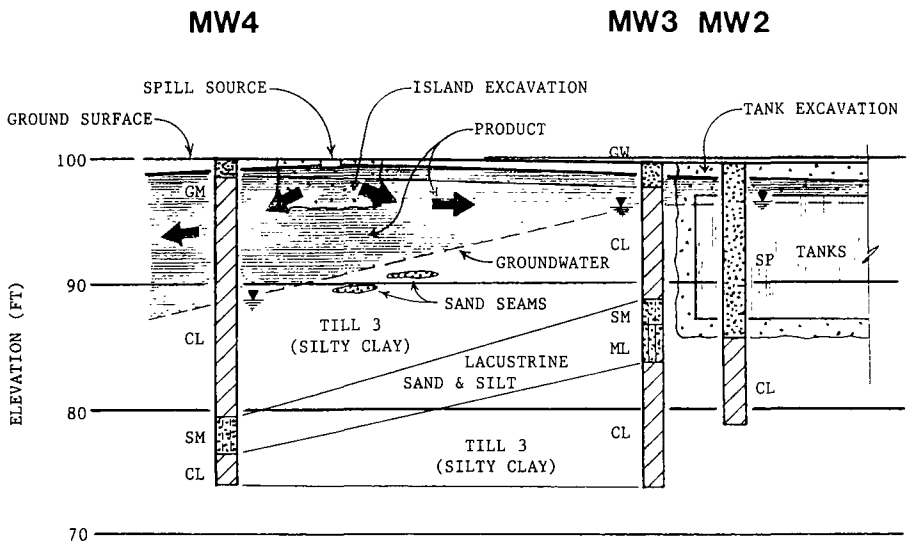

Figure 3
Product Transport Path — Section B-B

To assess the source of product, three Monitoring Wells (MW-1, MW-2 and MW-3) were placed in the vicinity of the five storage tanks. Since the storage tanks were built in the late 1960s, it was possible that they were leaking. Also, granular bedding for the tanks and piping may have provided a channel for product transport from the source of leak to the tanks. Monitoring Well M-4 was located in proximity to the gasoline station where the owner reported surface leakage. Monitoring Wells MW-5 and MW-6 were placed to evaluate both the groundwater movement and the transport of product in the groundwater. Monitoring Well MW-6 was installed in proximity to the nearby office building.

Three rounds of testing over a five-month period were conducted to determine the concentration of product in water samples. In addition, samples of gasoline from super unleaded, regular and regular unleaded tanks were also tested for comparison purposes. The test results are summarized in Table 1.

Table 1
Summary of Water Quality Test Results

	Date	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6
	10/02	--	--	--	--	--	<0.001
Gasoline	6/26	<0.001	79.0	9.6	160.0	1.4	<0.001
(mg/l)	5/28	<0.01	62.0	40.0	95.0	1.8	<0.001
	10/02	--	7.9	0.19	10.0	0.16	<0.001
Benzene	6/26	<0.001	9.1	0.5	15.0	0.29	<0.001
(mg/l)	5/28	<0.001	10.0	2.1	4.8	0.5	<0.001
Ethyl	10/02	--	3.5	0.013	6.1	0.0098	<0.001
Benzene	6/26	<0.001	2.7	0.010	2.8	0.001	<0.001
(mg/l)	5/28	<0.001	3.0	1.80	2.4	0.002	<0.001
	10/02	--	6.0	0.14	28.0	0.002	<0.001
Toluene	6/26	<0.001	15.0	0.70	43.0	0.018	<0.001
(mg/l)	5/28	<0.001	17.0	12.0	46.0	0.44	<0.001
	10/02	--	22.0	0.70	17.0	0.007	<0.001
Xylene	6/26	<0.001	14.0	2.0	11.0	0.038	<0.001
(mg/l)	5/28	--	13.0	12.0	12.0	0.310	<0.001
	10/02	--	6.7	7.1	6.8	6.8	7.1
pH	6/26	7.0	6.6	--	--	7.0	7.1
	5/28	7.3	6.4	7.1	6.9	7.1	7.8
Conduc-	10/02	--	3920	1352	2020	1530	1278
tivity	6/26	1990	5110	1470	2140	1629	1390
(μmhos/cm)	5/28	--	--	--	--	--	--

SOURCE IDENTIFICATION

Water samples from Monitoring Well MW-1 had no detectable product. These data confirmed that three tanks in the vicinity of Monitoring Well MW-1 were not leaking.

Product was found in Monitoring Wells MW-2 and MW-3. Concentrations in MW-2 were much higher than in MW-3. This result may be attributed to the leakage both from the unleaded and regular gasoline storage tanks/fittings near Monitoring Wells MW-2 and MW-3.

Further testing of the tanks in the vicinity of Monitoring Wells MW-2 and MW-3 indicated that tank leaks were on the order of the limit of testing procedures (0.02 gal/hr). For practical purposes, such tanks are considered structurally tight. Further, if the tanks were the source of leakage, product odor in the adjacent buildings should have been noted earlier.

Consistently, the product concentration in Monitoring Well MW-4 was noted to be high, the source is attributed to the leakage of the super unleaded gasoline at the filling station.

Reference samples of regular, unleaded and super unleaded gasolines were tested three times. For a given gasoline, the concentrations of benzene, xylene and ethylbenzene varied considerably. Because of wide variation of the concentrations of the various hydrocarbons in the gasoline, it was not possible to identify the source of leak based on water quality testing alone. Minor leakage of tanks in conjunction with the occurrences of spill caused by a leaking pump made the determination of source of leak difficult.

Concentrations of xylene, toluene, benzene and ethylbenzene in the sump pump and MW-6 were not detectable in the last round of testing. This result is attributed to the decomposition of product by micro-organisms in the top 2 to 4 ft of soil—indicating that product leakage was small; the leakage resulted from the super unleaded pump.

PRODUCT MOVEMENT IN GROUNDWATER

Super unleaded gasoline leaked in the proximity of the filling station (Monitoring Well MW-4) and flowed westerly underneath the pavement through the granular backfill. The lateral movement of super unleaded gasoline was intercepted by the granular backfill at the east foundation wall of the office building which served as a conduit for downward flow of product. Because of high groundwater level and the frequent pumping of water from the sump pump, the product found its way into the basement.

Product also moved laterally through the sand and gravel bedding surrounding the piping toward wells MW-2 and MW-3; this conclusion is based on the high concentrations of product found in the last round of testing. It is evident that the soils in the vicinity of the tanks have high product concentrations. Because the leakage of super unleaded at the pump and detection of product in the basement occurred within 3 to 4 weeks, it is highly likely that the product in the basement was from the super unleaded pump.

Also, silty clay soils tend to attentuate product strength during movement through them. Hence, even if some product transport took place through the silty clay soil, the concentration would be attenuated significantly by the time the product reached the building. Low concentrations of product were noted in the samples of wells MW-5 and MW-6. Low hydraulic gradients and low permeability of soils confirm that the product movement did not take place through silty clay.

PRODUCT RECOVERY WELL

Consistently high concentrations of product in wells MW-2 and MW-3 indicate that product transport occurred through the granular bedding in the piping trench. Because the soils around the trench for the tanks are predominantly silty clay, the product is confined within the granular fill around the tanks.

A product recovery program consisting of a 10-in. diameter well 15 ft deep was developed to recover the product from the granular fill. A minimum of 2 in. of gravel pack was placed around the 10-ft section of No. 20 slot screen. Since groundwater is about 5 ft below the grade, water will be pumped through a suction pipe placed in the well.

Treatment and disposal of the wastewater to be recovered were investigated. Techniques to be used depend on the volume of water and its degree of contamination. A large volume of contaminated wastewater can be too difficult and costly to transport to an acceptable disposal facility.

In such cases, it would be necessary to construct an on-site treatment unit or redesign the recovery system to reduce the volume of recovered wastewater. Uncontaminated groundwater taken from the well may be disposed into sanitary or storm sewer systems or into ditches or streams with appropriate approval of the WDNR and other regulatory agencies.

CONCLUSIONS

An investigation was conducted to determine the source of petroleum products and its transport mechanism in soil. The following conclusions were reached:

- Tanks in the vicinity of Monitoring Well MW-1 have not shown any evidence of leaking.
- Although the gasoline tanks adjacent to Monitoring Wells MW-2 and MW-3 are considered structurally tight, they may be leaking at a rate of 0.02 gal/hr.
- An inventory of gasoline in regular and unleaded storage tanks is necessary. Any unaccounted-for loss in gasoline will confirm leakage from tanks.
- Existing monitoring wells were monitored periodically for product thickness and for spread of contamination caused by product.
- The transport of product in the soil and groundwater was through the granular backfill in the subsoil.
- A pump will be placed in the vicinity of regular and unleaded tanks in the sand and gravel fill. As discussed earlier, product present in the granular material can be pumped.

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Underground Storage Tanks— Leak Prevention, Leak Detection, and Design

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ABSTRACT

Three to five million underground storage tanks containing hazardous substances exist in the United States. Several thousand of these tanks are leaking and causing contamination of groundwater, and the U.S. EPA has been charged with the implementation of RCRA to control this problem.

In response to this problem, leak prevention and detection provisions are becoming an integral part of the design and construction of underground storage tanks. Although several standards and codes are in existence to yield proper design, many of these are consensus standards and perhaps may not ensure structural safety for all anticipated loading conditions.

This paper presents the details of leak prevention and detection techniques. In addition, the important aspects of structural design of these tanks are discussed.

INTRODUCTION

In the Silicone Valley of northern California, leaking underground storage tanks containing trichloroethylene led to the promulgation of model underground ordinances which cover overfill protection equipment, secondary containment and leak monitoring systems for all new facilities.[4] The neighborhood gas stations in Rhode Island had storage tanks that leaked and contaminated the water supply. The owners of the gas stations were found liable for the cost of cleaning up the water supply and supplying clean water to area residences. A Massachusetts gas station owner was found liable for the cleanup of the contaminated groundwater caused by a leaking underground storage tank. In Long Island, leaks from underground storage tanks contaminated 25 basements. The owner of the tanks was forced to purchase the 25 homes affected by the spill.

Oliveira and Sitar[13] have reported the details of over 100 cases of underground storage tank leaks and spills involving organic chemicals in the Santa Clara Valley of California. In most of these cases, the groundwater was contaminated. These case histories indicate only the tip of the iceberg.

Three to five million underground storage tanks containing hazardous substances exist in the United States. Of these, 100,000 are presently leaking and another 350,000 are expected to start leaking within the next 5 years.[10] The users of these underground storage tanks are listed in Table 1.

Table 1
Users of Underground Storage Tanks

- Airports
- Auto Dealers
- Auto/Truck Rental
- Auto Repair Shops
- Banks
- Carwashes
- Cemetaries
- Churches
- Colleges
- Commercial/Industrial
  - Office Buildings
- Construction Companies
- County & Local Governments
  - Fire Department
  - Police Department
  - Prisons
  - Sanitation Department
  - Public Bus System
  - Water Treatment Plant
  - Municipal Building
  - Highway Department
- Convenience Store
- Delivery Services (UPS, Department Stores, Emery, etc.)
- Distribution Companies
- Elementary & High Schools
- Farms
- Federal Government
  - Dams
  - Federal Highway Department
  - Military Bases
  - Office Buildings
  - Post Office Department
  - Prisons
- Home Owners
- Hospitals
- Hotels
- Independently Owned Service Stations
- Grocery Stores
- Jobber Bulk Terminal
- Major Oil Bulk Terminal
- Major Oil Service Stations
- Manufacturing Plants
- Marinas
- Mining Companies
- Motels
- Nursing Homes
- Recreational Facilities
- Residential Apartment Buildings
- Restaurants
- State Governments
  - Prisons
  - Highway Department
  - State Office Buildings
- School Bus Garages
- Shopping Centers
- Tire Stores
- Transportation Services (Taxi, Limousine, Bus Lines)
- Truck Stops
- Trucking Firms
- Utility Companies

FEDERAL LEGISLATION

RCRA was passed to control this growing problem. The act covers a wide range of items which include the storage of hazardous materials in underground storage tanks. RCRA was revised by the Hazardous and Solid Waste Amendments of 1984.[14] These amendments define underground storage tank as any one or a combination of tanks (including underground pipes connected thereto) used to contain an accumulation of regulated substances where the volume (including the volume of the underground pipes connected thereto) is 10% or more beneath the surface of the ground.

The amendment also requires the following items to be included in the regulations:

- Requirements for maintaining a leak detection system, an inventory control system together with tank testing or a comparable system or method designed to identify releases in a manner consistent with the protection of human health and the environment

- Requirements for maintaining records of any monitoring or leak detection system or inventory control system or tank testing or comparable system
- Requirements for reporting releases and corrective action taken in response to a release from an underground storage tank
- Requirements for taking corrective action in response to a release from an underground storage tank
- Requirements for the closure of tanks to prevent future releases of regulated substances into the environment

The promulgation of any regulation takes time. In order to minimize potential leaks of tanks which currently are being constructed, an interim prohibition of underground storage tanks was immediately imposed by the Hazardous and Solid Waste Amendments of 1984. The interim prohibition states:

> "(1) Until the effective date of the standards promulgated by the administrator under subsection (e) and after one hundred and eight days after the date of the enactment of the Hazardous and Solid Waste Amendments of 1984, no person may install an underground storage tank for the purpose of storing regulated substances unless such tank (whether of single or double wall construction)—
>
> (a) will prevent releases due to corrosion or structural failure for the operational life of the tank;
>
> (b) is cathodically protected against corrosion (Fig. 1), constructed of noncorrosive material, steel clad with a noncorrosive material, or designed in a manner to prevent the release or threatened release of any stored substance; and
>
> (c) the material used in the construction or lining of the tank is compatible with the substances to be stored.
>
> (2) Notwithstanding paragraph (1), if soil tests conducted in accordance with ASTM Standard G57-78, or another standard approved by the Administrator, show that soil resistivity in an installation location is 12,000 ohm/cm or more (unless a more stringent standard is prescribed by the Administrator by rule), a storage tank without corrosion protection may be installed in that location during the period referred to in paragraph (1)."

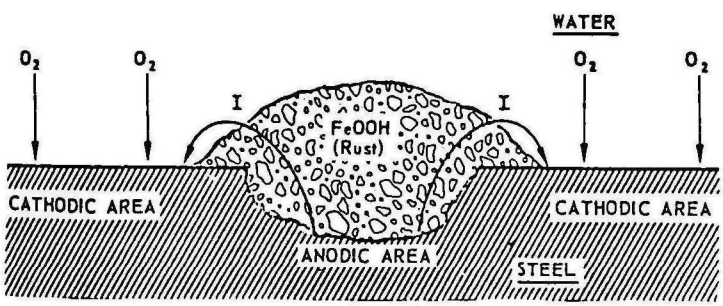


Figure 1
Phenomenon of Corrosion

The amendment also establishes civil penalties of up to $10,000/tank/day for any owner or operator who fails to comply with either state or federal regulations regarding underground storage tanks.

These regulations are the initial steps taken to reduce the threat of leaking underground storage tanks contaminating groundwater. The implementation of these RCRA-UST regulations is in progress and is continuing to gain momentum. As part of the RCRA regulation promulgation, a proposed rule (The Hazardous Waste Management System; Standards for Hazardous Waste Storage and Treatment Tank Systems) was published in the *Federal Register* on June 16, 1985.[9]

Statistics provided by the proposed rule on leaks due to corrosion cause concern about the integrity of existing tanks and the requirements for future tanks. "Seventy to eighty-five percent of the leaks were due to tank and/or piping failures from subsurface corrosion," states a study of over 2,000 cases of leaking underground storage tanks by the American Petroleum Institute (API). A study conducted for API entitled "Underground Unprotected Steel Tank Study-Statistical Analysis of Corrosion Failure" indicated that 50% of all unprotected steel tanks will develop a leak by the time they are 16 years old. The National Association of Corrosion Engineers (NACE) reported that after 5 years, the accumulated number of leaks in underground piping increases by a factor of 10 every 5 years.

The U.S. EPA and those involved in the design of underground storage tanks are convinced that any tank will leak and a secondary confinement is the most cost-effective way to address this problem. Secondary confinement will determine the cause of a leak, ensure detection of the leak and perhaps contain the leaking material to avoid contamination of groundwater.

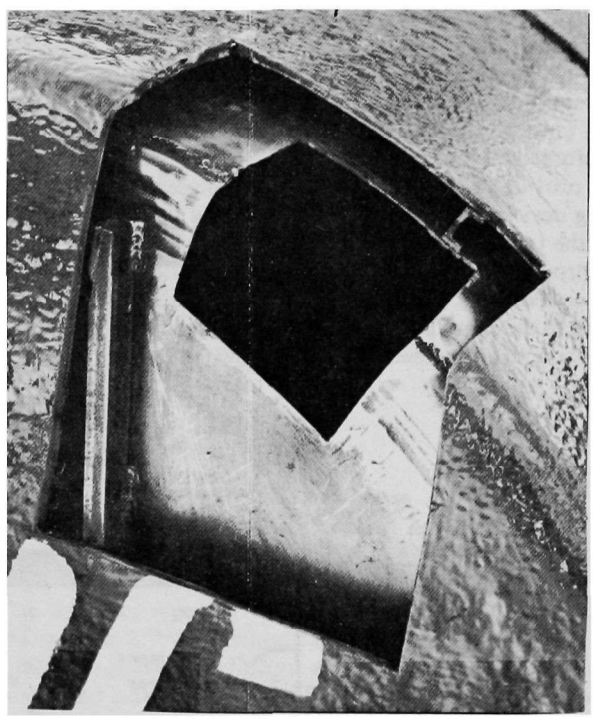


Figure 2
Rigid Double Wall Tank

SECONDARY CONTAINMENT

A concept which has become an important ingredient in leak prevention and monitoring required by new RCRA is secondary containment. A general definition of secondary containment is the construction of a barrier to resist free flow between the tank and the environment. The barrier may be another tank wall or shell (double walled tanks or jacketed tanks),[22,23] as shown in Figures 2 and 3. The shell may be a concrete pit (Fig. 4), a liner composed of soils (Figs. 5 and 6) or a layer of soil sealant such as

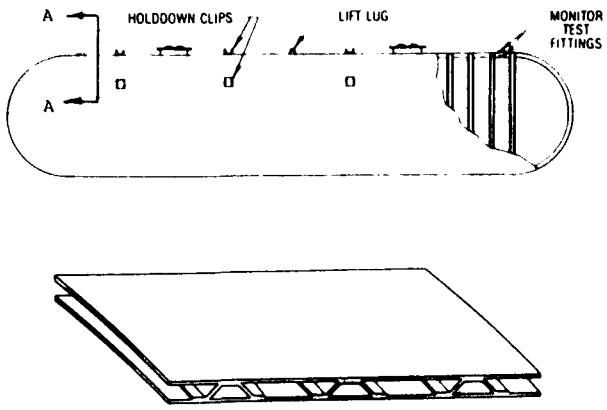


Figure 3
Flexible Double Wall Tank

soil cement, bentonite, engineered low permeability soil surrounding the tank. Secondary containment systems are designed to be installed at the time of initial tank installation. Secondary containment systems can be retrofitted to existing tanks, but this usually means excavating and removing the existing tank to install the system.

Leak detection and monitoring are easier on systems which have secondary containment for two reasons: (1) the leaking material must penetrate two barriers to get to the environment and therefore takes more time; and (2) the space between the two barriers provides a good location for the placement of leak monitoring devices, since material which leaked through the first barrier (the tank wall) would accumulate in this space prior to leaking through the second barrier. Because of these reasons, secondary containment systems always have a leak sensing system connected to the space between the two barriers. Pipes also may have a secondary confinement system as shown in Figure 7.

LEAK DETECTION AND MONITORING METHODS

The federal legislation which is being implemented places emphasis on keeping leaks in underground storage tanks to a minimum. There is also the need to detect leaks early so that immediate remedial action can be taken. To understand how leaks can be eliminated best, it is beneficial to explore the causes of leaks in underground storage tanks.

Table 2
Corrosion Types; Causes & Cures

Corrosion Types	Causes	Cures
Galvanic	1. Occurs when dissimilar metals are connected by an electrolyte.	1. Insulate dissimilar metals one from another.
	2. Occurs when structural pipe or tank joins to different soil types.	2. Insulate structure from soils.
	3. Dissimilarities on the surface of the pipe.	3. Close adherence to correct manufacturing procedures.
	4. Differential aeration of the soil around the pipe.	4. Thoroughly tamp backfill to one ft above the pipe.
	5. Backfilling with mixed stratified layers (local corrosion).	5. Control backfill material. (Backfill with homogenous material.)
Stray Currents	1. Direct current is discharged from the pipe wall. (Other sources of current near underground structures with the ground as part of their circuit.)	1. Must be defined for each specific instance.
Stress Corrosion	1. Points of concentrated stress near areas of uniform stress in the presence of an electrolyte.	1. Reduce number and magnitude of concentrated stress areas in the tank and pipeline.
Biochemical	1. Bacteria in the soil affecting the concentration of ions in the electrolyte.	1. Thoroughly tamp backfill to one ft above the structure. Remove all deleterious materials from the backfill.
Direct Chemical Attack	1. Chemicals directly attacking the structures (i.e., road salt).	1. Seal the surface from infiltration.

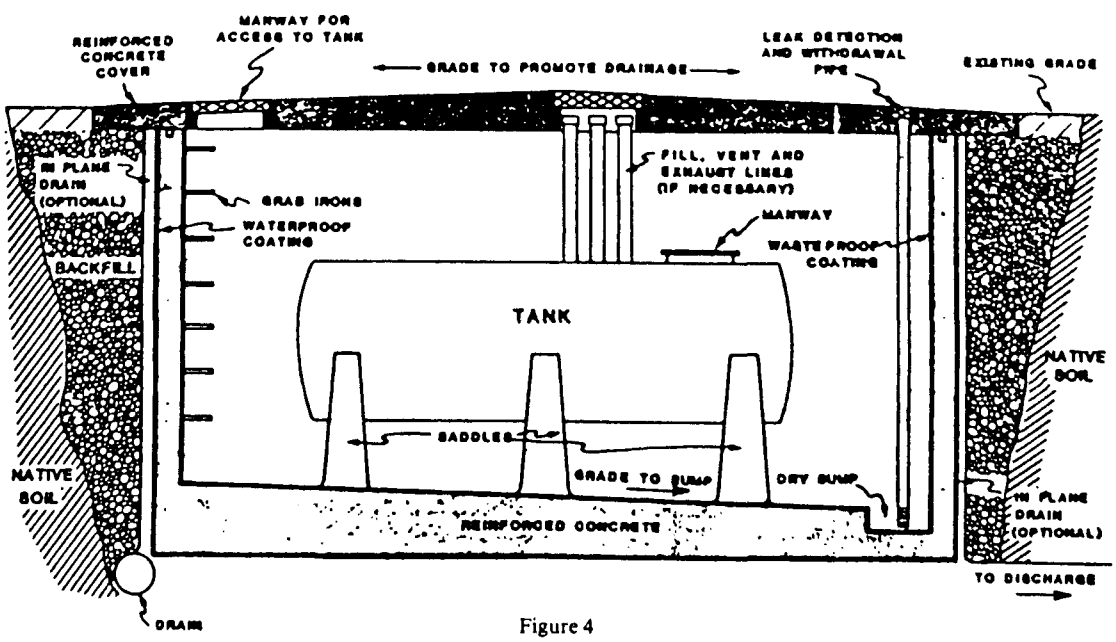


Figure 4
Tank in Concrete Vault

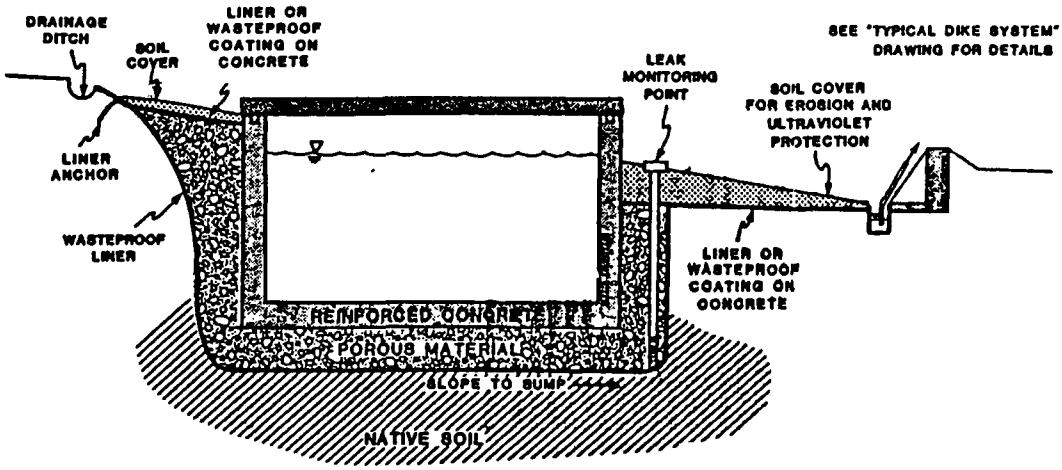


Figure 5
New Inground Tank

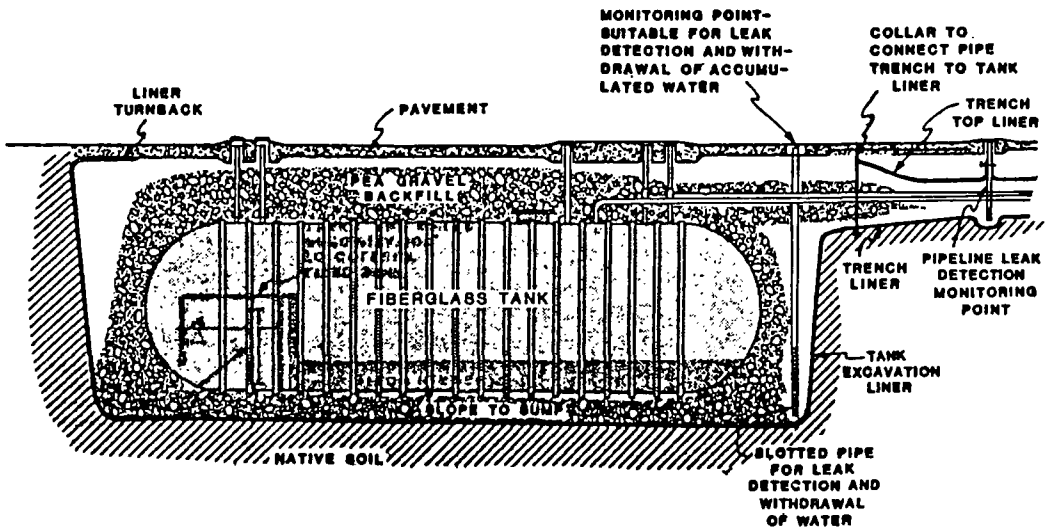


Figure 6
Synthetic Membranes Around Tanks

Causes of Leaks

External underground corrosion is by far the most common cause of leaks in steel tanks. Underground corrosion involves chemical reactions and the flow of electrical current. Therefore, corrosion occurs through an electrochemical process. The soil, with its water content, acts as an electrolyte. Corrosion occurs when metal atoms go into solution and are transformed into compounds as shown in Figure 1.[26]

It may be helpful to visualize the process of external corrosion of an underground storage tank by viewing the tank/soil system as an electrolytic cell. The corroding area of the tank is the mode, the soil is the electrolyte and another area of the tank forms the cathode. An anode is the electrode of an electrolytic cell at which direct current is discharged and corrosion occurs.[24] The cathode is the electrode of an electrolytic cell at which reduction or prevention of corrosion occurs. When an area of a tank wall corrodes to the extent that the useful wall thickness cannot carry external pressures or internal pressures, a leak develops.

The different types of corrosion, their causes and cures are listed in Table 2.[24,26,27] Cathodic protection is an important measure taken to prevent corrosion. A sacrificial metal is placed near the tank and acts as the anode. Current flows from the sacrificial metal through the soil to the tank which acts as the cathode. The tank shall be protected from corrosion as long as the sacrificial metal can transmit a current to the tank.

Internal corrosion accounts for 10-29% of corrosion induced failures.[9] Internal corrosion has the same causes and cures as external corrosion, plus the additional factors of dynamic impact loads of the gauging stick and the loads caused when filling the tank. Installing a striker plate below the fill pipe eliminates the possibility of scratching the liner with the gauging stick; it also diverts the incoming hazardous material, thus minimizing the impingement at the bottom of the tank.[11]

Inadequate installation and design procedures are another cause of leaks. Improper handling of coated steel tanks may cause scratches in the lining which expose the steel to corrosive activity.

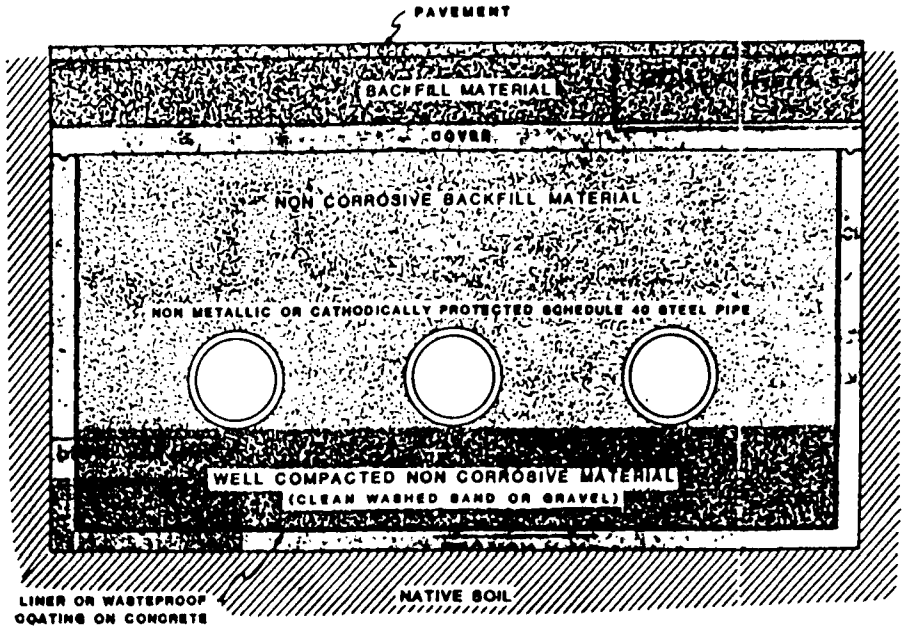


Figure 7
Underground Lined Trench for Piping

Neglecting hold-down straps or underdesigning them may cause uplift of the tank when groundwater surrounds the empty tank. Poor quality backfill or improper backfilling procedures may cause excessive strains in flexible tanks. Filling the tank prior to backfilling also may cause rupture of the tank due to lack of lateral support from the backfill.

Poor operating procedures can create leaks in underground storage tanks. Puncture of the tank wall by the gauging stick or filling/discharge pipe may cause a leak. Overfilling causes spills and unexpected pressure head within the tank. Proper operational practices such as the use of a level sensing device, level indicating device, high level alarm, automatic shutoff control system, bypass prevention of overfill prevention system and interlocking loading process with overfill prevention system so loading cannot occur without the overfill prevention system being activated,[11] will prevent spills which account for a large portion (± 40%) of contamination.[9]

Leak Detection

Tanks cannot be designed to be virtually leak proof even at a significant cost. Thus, vendors take the approach of designing tanks to last 30 to 50 years. Since tanks will inevitably leak due to one of many causes, it is best to design the tank with leak detection and monitoring. Early detection and remedial action can save millions of dollars.

Testing for leaks can be classified into four general groups:[42]

- Volumetric leak tests (quantitative)
- Non-volumetric leak tests (qualitative)
- Inventory control and reconciliation analysis (trends)
- Effects monitoring (perceivable environmental changes)

Volumetric Testing

Volumetric leak tests provide data which can determine if a tank is leaking and at what rate it is leaking. This is perhaps the most helpful information a tank owner or regulator can obtain. Knowing the rate of the leak helps to determine the needed level of corrective action.

The rate of leak is found by determining the volume of decrease of stored product by measuring properties associated with the change in volume. The volume of the stored material is monitored constantly by a float inside the tank or by a pressure sensor in the bottom of the tank. Since the temperature of the stored material has an important effect on the volume of the material, it must be measured. A small change in temperature, particularly with a large volume as seen in Figure 8, may change the volume of the material significantly. Vapor pockets within the tank may influence the measured volume of the material (for tests that require a full tank) because air or vapors expand and contract at different rates than fluids.

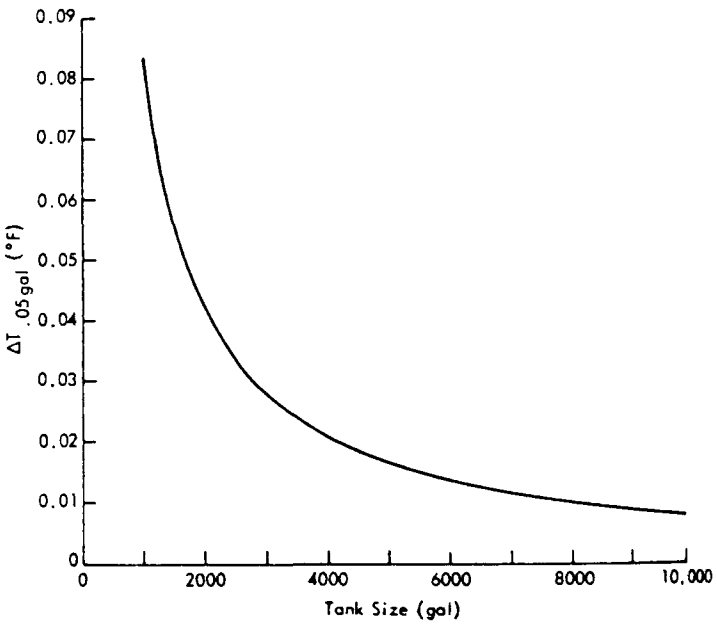


Figure 8
Change in Temperature of Gasoline Needed to Produce a 0.05 Gallon Volume Change as a Function of Tank Size

Vibrations of vehicle traffic or mechanical machines can cause a surface ripple in the stored substance causing the float to move erratically. Since the measurement of the depth of stored material must be within fractions of an inch, any vibration movement should be eliminated.

The presence of groundwater around the tank will not affect the volume of the stored substance, but will affect the rate at which the substance leaks. This change in rate is due to a decrease in differential pressure between the inside and outside of the tank. Evaporation and condensation within the tank may cause errors in volumetric testing. These usually cause problems only if the stored material is not sealed to atmospheric conditions and can be remedied by placing the cap back on the fill pipe. Volumetric testing requires trained personnel and very accurate measurements. These elements make volumetric testing expensive and time consuming.

Non-Volumetric Testing

Data from non-volumetric tests determine if a tank is leaking or not but do not determine the leak rate. These data are valuable but not as useful as a volumetric test. Non-volumetric tests, however, are cheaper and easier to perform and may be used to determine which tanks, within a field of multiple tanks, need further testing or may be used as a first alert for more serious potential problems.

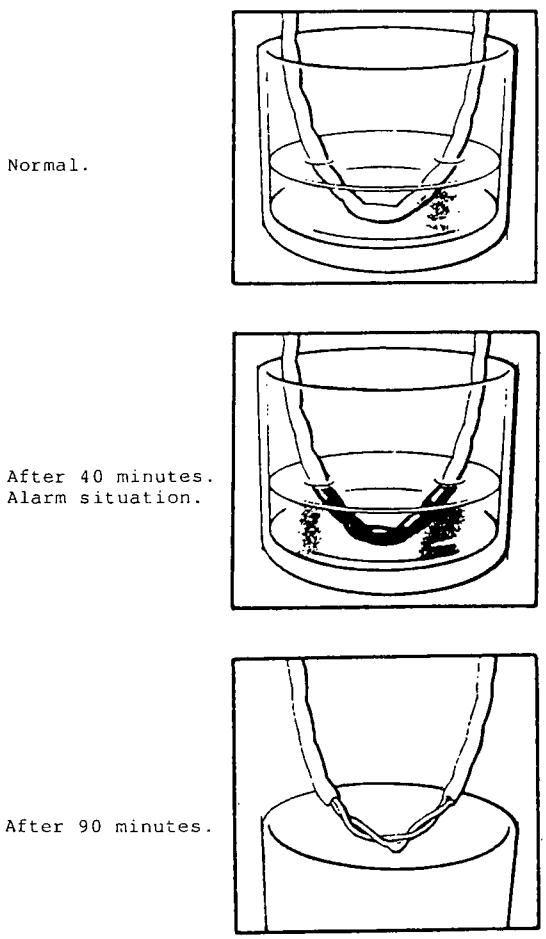


Figure 9
Direct Buried Cable for Leak Testing

Several methods are used for non-volumetric testing. Helium leak detectors commonly are used: helium vapor pressurizes the in situ tank and the amount of helium that diffuses through the leak back to the surface is monitored. Although helium can diffuse through asphalt and concrete, it takes time and, therefore, boreholes may be cored for quicker detection.

The vacuum/hydrophone tests involve creating a vacuum in a sealed tank greater than the static head pressure of the liquid in the tank. The tank then is monitored with hydrophones for the sound of bubbles being drawn in through the leaks. If the groundwater table surrounds any of the tank, then the amount of water within the tank should be determined before and after the test to see if any water was drawn in through the leak.

Direct buried cable sensing is useful in long-term constant monitoring situations.[39] Two wires are placed within an insulation jacket, as shown in Figure 9, which dissolves in the presence of petroleum; when the jacket dissolves, the two wires touch and signal an alarm. Since the cable is buried directly, it can be placed in areas where it will do the most good as shown in Figures 10 and 11.

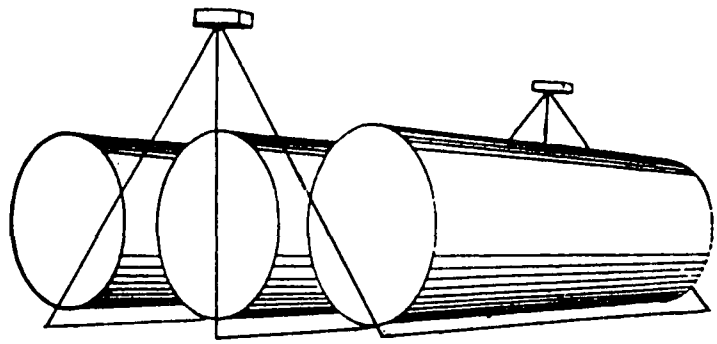


Figure 10
Direct Buried Cable Placement for No Water Table

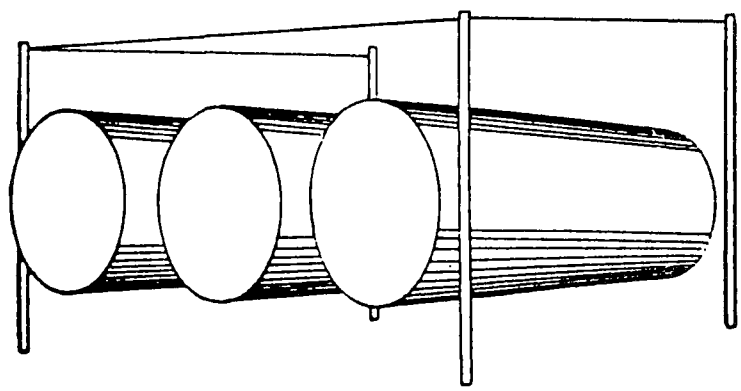


Figure 11
Direct Buried Cable Placement for High Water Table

Vapor testing can be performed in the soil next to the tank system within the space between the two walls of a double-walled tank, called interstitial testing, or within the space between the other secondary confinement structures. This test utilizes a vacuum to draw the vapors through the monitoring device. Observation wells with either temporary or continuous monitoring[34] can be used.

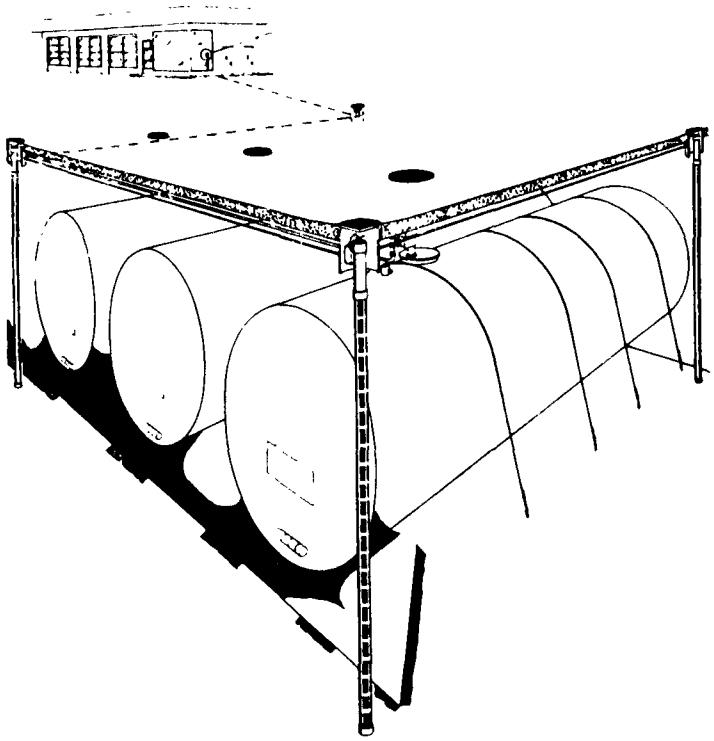


Figure 12
Typical Service Station Tank Installation

In the case of petroleum, continuous monitoring is done by placing a float within the monitoring well as shown in Figures 12 and 13. The float is equipped with petroleum sensing equipment which can sense as little as 0.25 in. of petroleum floating on top of the water table. Direct sampling of the water can be done with wells to determine the chemical make-up of the water.

Interstitial flooding can determine a leak in one of the two walls of a double-walled tank. The interstitial space is flooded with a liquid and the height of this liquid in the fill pipe to the interstitial space is monitored as shown in Figures 14 and 15. If the liquid suddenly goes down, this decrease in liquid level indicates that there is a leak in either of the two walls.

In the dye method, a dye is used in the stored substance. If this dye shows up in surrounding storm sewers, sanitary sewers, ditches, basements or any other low area, its presence indicates a leak in the pipe or the tank.

It should be noted that these non-volumetric tests are versatile, and various tests may be combined or altered to collect more data. For example, a dye may be flooded into the interstitial space of a leaking tank to see if the inside wall is leaking, in which case the stored material will carry the dye color, or if the outside wall is leaking, in which case the backfill will become dyed. The directly buried cable also could be placed in the interstitial space to check the leaks.

Inventory Monitoring and Reconciliation

Symptoms of leaks can be observed if careful inventory monitoring of the stored substance is used.[25] Leaks cannot be directly detected or measured by this method, but it can be a helpful tool in determining where there is a strong possibility of a leak. Symptoms which appear when there is a leaking tank are an apparent loss or gain of stored substance when the substance has not been dispensed or filled, differences in the amount of substance dispensed and received, a hesitation in the delivery of the material from a standard dispensing pump indicating a leak in the suction pipeline and odors of the stored material in places below ground.

Factors which influence the inventory control method are temperature related volume changes of the stored substance, faulty or erroneous dipstick readings and displays. Computer analysis of the data enhances the interpretation of the data, but the data must first be as accurate as possible.

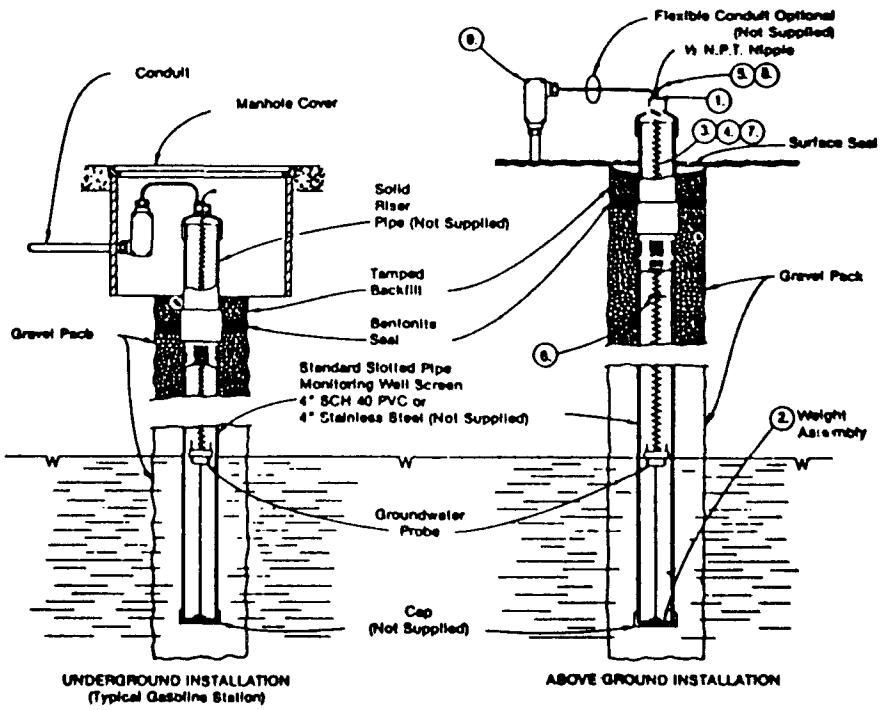


Figure 13
Monitoring Wells

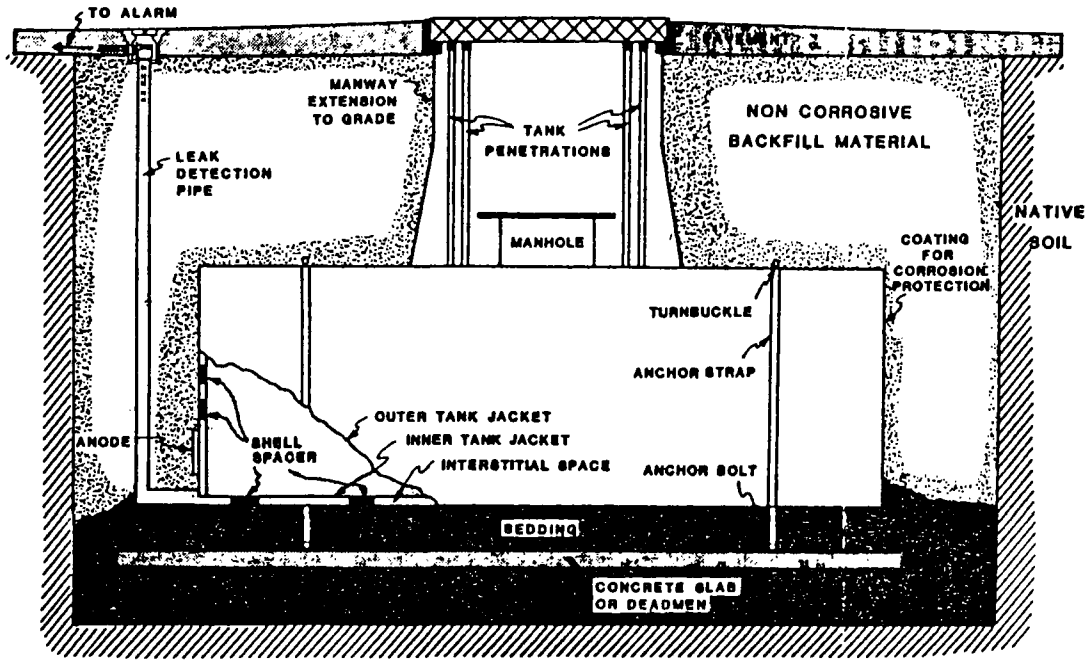


Figure 14
Double Wall Steel Tank

Leak Effects

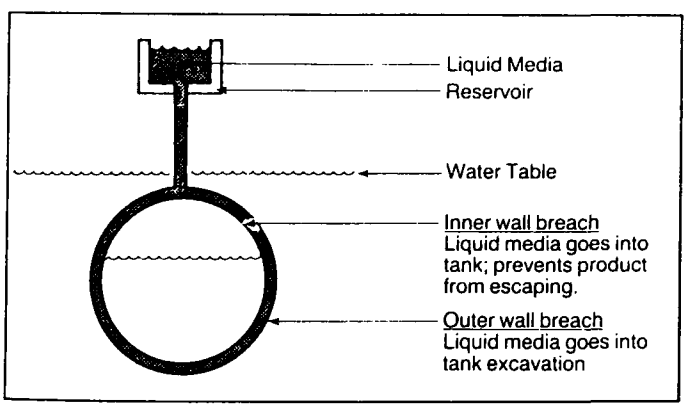
Monitoring the environment immediately adjacent to the underground storage tank locations for any changes due to leaks is another qualitative method of finding leaks. A leak may be discovered, but the quantity of leakage and the exact locations, particularly if there is more than one tank at the location, will not be known.

Monitoring Methods

Proposed legislation will require proof of monitoring and, therefore, records will have to be kept. There are three basic methods of compiling these records: (1) by hand, (2) by mechanical means (or computer), or (3) by a combination of these two means.

Continuous monitoring almost always is compiled by mechanical means. Few continuous monitoring techniques yield continuous data such as the direct buried cable, but will set off an alarm whenever a leak is detected, even by a modem to the owner's remote location.

Routine or scheduled compiling could verify such continuous monitoring. This monitoring would entail a daily or weekly checking of devices in place. Scheduled air samples or water samples could be taken and tested. Good record keeping will be the owner's responsibility. Spot check monitoring with volumetric tests should be done when inventory reconciliation or leak detection alarms are triggered.



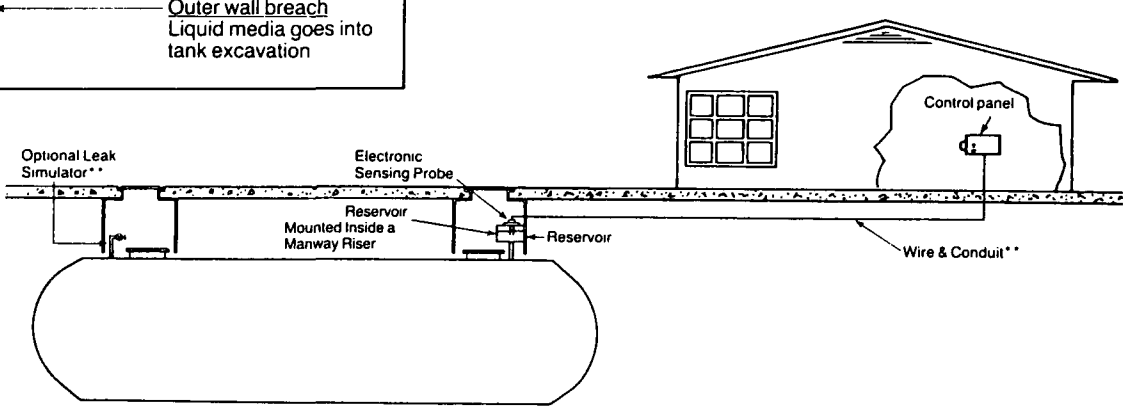


Figure 15
Interstitial Monitoring System

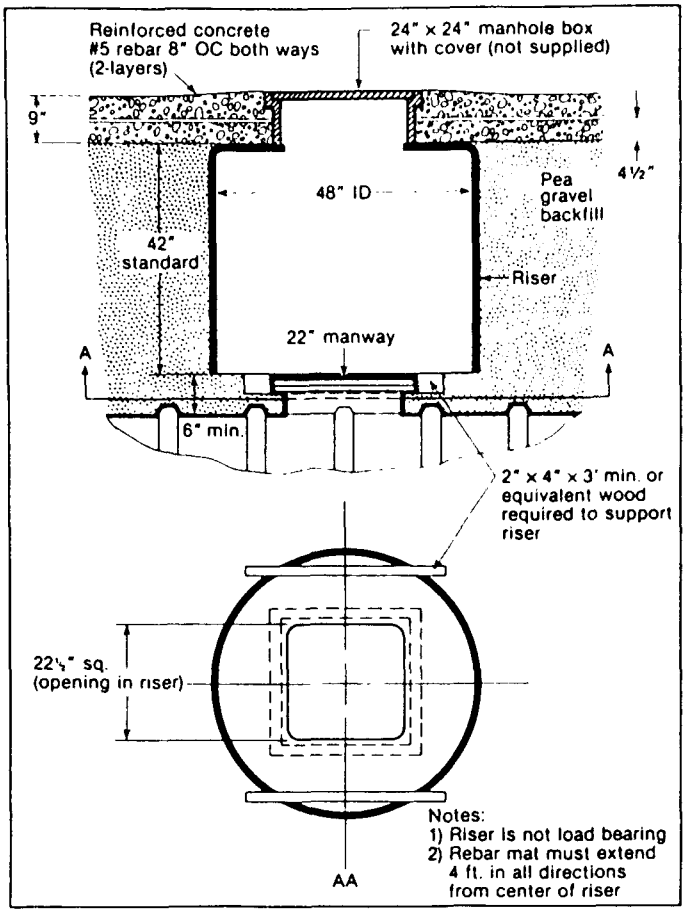
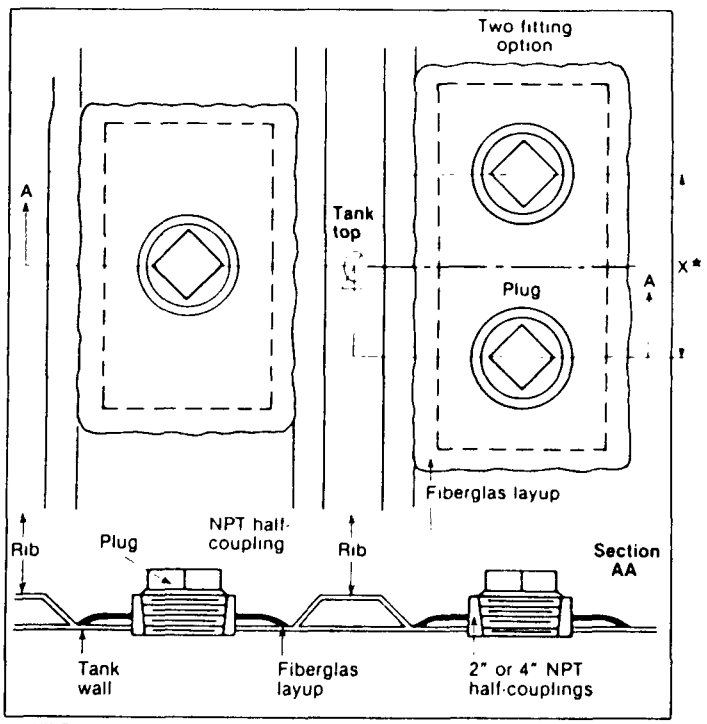


Figure 16
Manway Riser Pipe



★ "X" Dimension on Double 2" Fittings Equals 5"
"X" Dimension on Double 4" Fittings Equals 9"

Figure 17
Steel NPT Fittings

Tank Appurtenances

In addition to requirements about leak detection devices, the new tanks should include several types of key appurtenances. These include manway riser pipes, fittings, heating coils and ladders for visual inspection as shown in Figures 16-19.

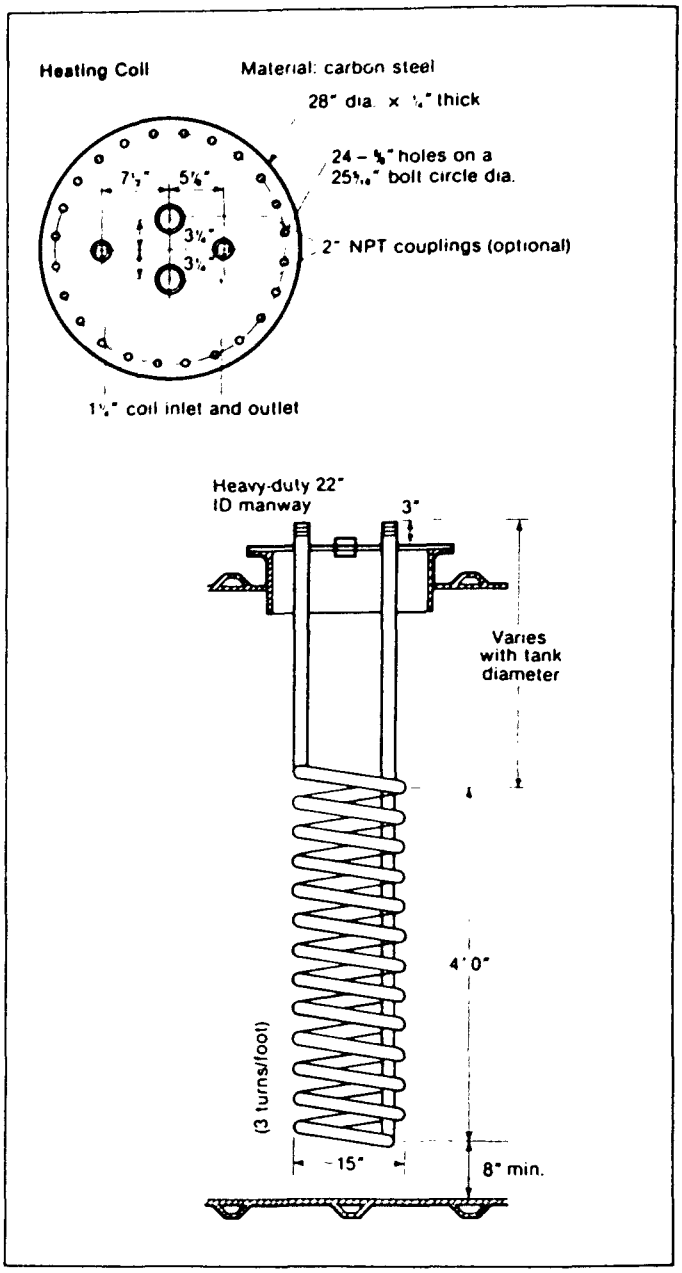


Figure 18
Helical Heating Coils

STANDARDS AND CODES

One of the attempts tank manufacturers have undertaken to minimize leaks is the use of standards and codes for the design of underground storage tanks. The following codes and standards pertain to the design and performance of reinforced fiberglass and steel underground storage tanks:

- American Petroleum Institute Standard 620[2]
- American Society for Testing and Materials D 4021-18[3]
- National Association of Corrosion Engineers RP-01-69[28]

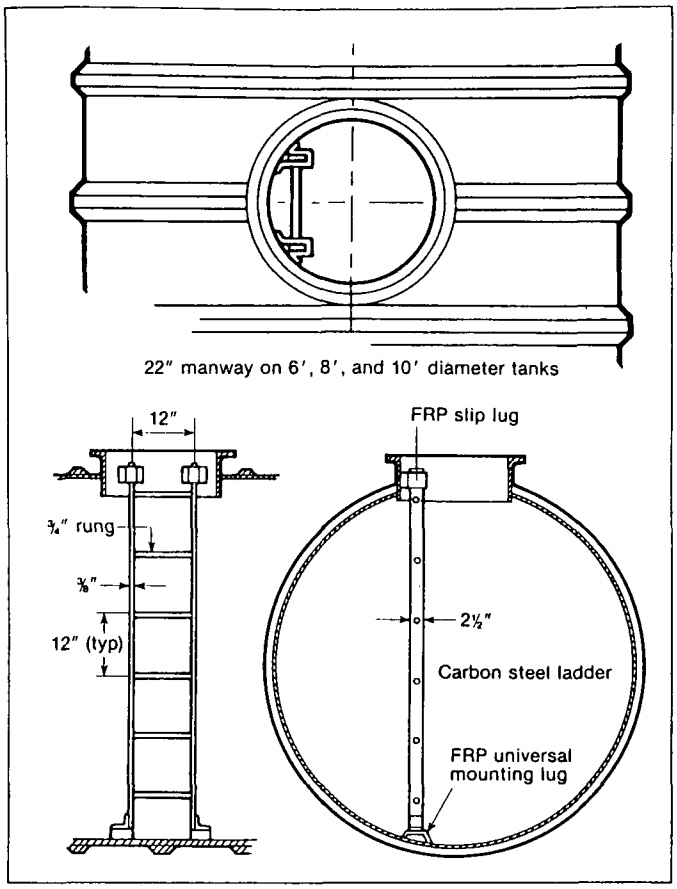


Figure 19
Tank Ladders

- National Fire Protection Association Codes 30 and 31 and Handbook[29-31]
- Underwriters Laboratory Codes 58 and 1316[40,41]

There are three types of standards or codes for underground storage tanks. The first are the standards to be followed when designing these structures. The second are performance standards which list a series of tests or qualifications that must be passed by the manufactured underground storage tanks. The third are standards or codes which specify how the manufactured tank should be installed and operated.

Steel Tanks

The standards which govern steel underground storage tank design are UL 58,[40] API 620[2] and NACE RP-01-69. The UL 58 is the standard for steel underground tanks for flammable and combustible liquids. The requirements include: capacities, dimensions, metal thicknesses, materials, shell seams, heads and head joints, compartment tanks, pipe connections, manholes, heating coils and hot wells, manufacturing and production tests and markings.

API 620 contains recommended rules for the design and construction of large, welded, low-pressure storage tanks. The text includes: materials; design of walls, roofs, internal and external structural members, wall openings, nozzle necks, bolted flange connections, cover plates and joints (welds); inspection and tests; and pressure and vacuum-relieving devices. The recommended rule also contains a number of helpful appendices which include suggested good practices regarding foundations, corrosion allowance, attachment structures (internal and external), peening, installation, supporting structures and determination of relieving capacity required.

NACE RP-01-69 is a recommended practice of control of external corrosion on underground or submerged metallic piping systems and pertains to underground steel structures. This standard is somewhat detailed in dealing with corrosion control. The standard deals with the following list of thems: structural design of corrosion resistance; coatings for corrosion resistance and their applicability; cathode protection and its criteria, design, installation, operation and maintenance; control of interference currents; and corrosion control records.

Fiberglass Tanks

The two codes listed for reinforced fiberglass tanks are both performance standards. These codes are described below.

The ASTM D 4021-81 contains standard specifications for glass-fiber-reinforced polyester underground petroleum storage tanks and prescribes a number of requirements the finished product must fulfill.[3] Tests include the concentrated load test, external hydrostatic load test, internal pressure tests, fitting moment test, fitting torque test, leakage test, internal impact test, lifting lug strength test, negative pressure test, material property tests and chemical resistance tests. Minimum thickness for shell, pipe fittings and flange also are given in this standard.

The UL 1316 is a standard for glass-fiber-reinforced plastic underground storage tank for petroleum products and this gives a number of tests that must be fulfilled by the finished product.[41] The test titles are virtually the same as those in ASTM D 4021-81 standards, but the procedures are somewhat different. The UL 1316 standard also has additional marking requirements along with manufacturer installation requirements.

Finally, the installation, usage and monitoring codes pertain to all tanks regardless of the material used in making the tank. These codes are: NFPA 30 "Flammable and Combustible Liquids Code,"[24] NFPA 30 "Oil Burning Equipment Code,"[30] and the NFPA "Fire Protection Handbook,"[31] These standards consider the possibility of fires and thus are written to reduce the risk. Methods of construction and abandonment of existing underground storage tanks also are detailed in these standards.

DESIGN CONSIDERATIONS

A successful design of underground storage tanks should consider the following:

- Loads
- Materials and properties
- Compatibility and life
- Tests
- Handling
- Installation
- Procedures for analysis
- Monitoring and management

The design of underground storage tanks must take into account the various loadings that the tank will experience. Failure to recognize these loads could result in collapse of structures as shown in Figure 20. These loads include internal pressures (or vacuum) caused by liquids and gases, the weight of the tank itself and external loads. The external loads consist of traffic loads, soil loads, reactions at the supports and pipe connections, wind loads, seismic loads, frost loads and hydrostatic loads. Fatigue loads caused by filling and unfilling the tank also should be addressed.

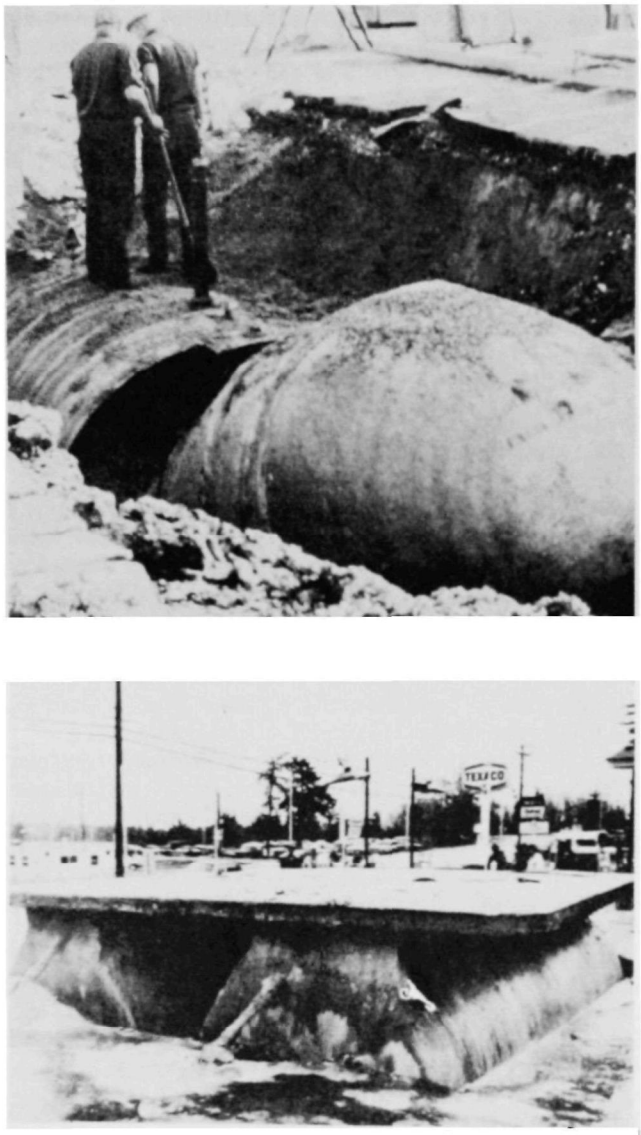


Figure 20
Tank Failures

Loads

The internal pressure loads depend on the properties of the material being stored and the geometry and filling/unfilling procedures of the tank system. For example, if the material stored is delivered hot and evaporates, it may cause a vapor pressure within the closed tank system. If the filling pipe extends to an appreciable height vertically above the tank and is filled to the top, high pressure heads in the liquid will develop. The weight of the tank can be determined prior to the installation. This load becomes important in empty tanks and tanks that are simply at their ends.

The external loads may be more difficult to determine than the previously mentioned loads. The site at which the tank is to be installed must be characterized adequately to determine these loads. Traffic loads are the dynamic loads transmitted by moving vehicles through the soil to the tank. These loads are a function of the weight of the vehicle, size of the tire, the vertical and the horizontal distance from the load to the tank and the soil asphalt-concrete structure between the load and the tank.

Soil loads are a function of the type of soil surrounding the tank, the depth of burial of the tank and the pressure of any load producing structures such as foundations adjacent to the tank. The weight of the soil above the tank minus any arching affect the soil may possess, will load the tank. Dynamic loads such as a foundation supporting vibrating machines or equipment may induce additional loads on the tank and the piping system.

Reactions at supports tend to localize the external loads on the tank at the support areas. This increases the shear and moment induced stresses and strains within the tank wall. The tank wall material must be designed to withstand these stresses and strains.

Wind, seismic and frost loads also should be taken into account if they are applicable. Sites must be evaluated for the severity and likelihood of these loads.

Hydrostatic loads are loads imposed on the tank due to the presence of water in the soil surrounding the tank. If the water-table or the presence of static or flowing water is never encountered by the tank, the hydrostatic loads may be neglected. If the tank is not designed with any hold down mechanisms and the buoyant force is greater than the weight of the tank and the stored materials and the resistance from the soil-asphalt-concrete above the tank, the tank will float out of the ground. Straps and anchors should be designed approximately to withstand these forces.

Fatigue loads caused by filling and discharging the tank also should be considered in the design. This consideration may include the design of a spill plate below the filling pipe and extra reinforcing around pump and pipe connections within the tank. In addition, temperature effects and Poisson's effects need to be considered.

The various types of loads which need to be considered were discussed in the previous section. The properties of materials constituting the tank wall required to complete the design are as follows:

- Strengths under tensile, compressive and shear loads
- Moduli under tensile, compressive and shear loads
- Stress-strain curves
- Poisson's ratio

Material Compatibility

In order to ensure long life for the designed tank, the compatibility of the stored materials with the tank wall, stress corrosion, strain corrosion and creep need to be accounted for in the analyses, and proper allowances need to be made in the final design alternatives.

Handling and Installation

Proper handling and installation of the tank are important for the tank to function adequately during its anticipated life. After the underground storage tank has passed a number of manufacturing tests (such as the 5 lb/in.^{2} air test and the x-ray test) and has passed on-site delivery inspection, it is ready to be placed in the ground. Care must be taken when handling these tanks, especially the more flexible tanks, to avoid unnecessary protective coatings and other expenditures. Manufacturers have recommendations to follow to meet installation requirements.

Once the tank is in place on its appropriate bedding material, backfilling may begin. Most tank installation instructions prevent filling the tank with the contents prior to backfilling. Because of the need to reduce the pressure of water and to provide adequate lateral soil support, it is necessary to use a granular material which is backfilled and compacted in one foot lifts. Methods of compaction to ensure uniform and complete compaction require the use of proper equipment to suit the types of backfill and tank used. A technique used to evaluate how well compaction is achieved is to compare the field densities to standard or modified Proctor laboratory test data on samples of soil. If the field

density is less than that required by the designer's specifications, the backfill should be recompacted.

It may be of interest that there is an optimum water content of the soil where the soil compacts easiest. This value is obtained by the Proctor test. Field densities can be determined by the sand cone method or by a nuclear density test. Emphasis should be placed on the importance of properly placed backfill to ensure tank longevity.

Once the tank has been backfilled, the ancillary equipment and piping system can be installed. The whole system should be constructed to achieve easy accessibility for tank inspection (i.e., measuring stick, etc.), tank filling and emptying. Access manholes and vents should be located under low overhangs or adjacent to a wall.

After installation, the 5 lb/in.^{2} air pressure (or water pressure) test should be run on the underground storage tank and its piping system. The entire system is pressurized by air (or water), and the amount of pressure drop over a certain time period is measured. If the leakage rate is too excessive, corrective measures must be taken.

Analysis

The soil tank interaction behavior also needs to be analyzed for groundwater induced seepage pressures, settlement, live load induced stresses, longitudinal stresses and circumferential stresses. Finite element models provide reliable means of analyzing even the most complex situations in the field. The senior author has developed a series of analysis procedures for performing the above design computations. Further details are given in Jeyapalan *et al.*[16-21] The analysis procedures also permit the following types of investigations:

- To assess the structural adequacy of existing tanks
- To assess the remaining life of existing tanks before these need replacement
- To assess the adequacy of new tanks sold by various vendors
- To provide backup analysis when outdated codes and standards are inadequate to ensure structural safety

These procedures have been found useful when examining several underground installations. Additional information can be found in Jeyapalan, *et al.*[15-21]

TESTING UNDERGROUND TANKS

There are a number of non-destructive testing (NDT) methods available to test the integrity of the underground storage tank walls[4] (Table 3). Most of these methods require access to both sides of the tank wall, but two methods can be performed with access to only one side of the tank wall. These methods may be able to test in situ tanks if inside (or outside) access to the tank is safe and available.

Ultrasonic Testing

The first method is ultrasonic testing.[4,6,13] This method is used to inspect voids, cracks and non-metallic inclusions and to determine the thickness of the tank wall. Residual strains within the tank wall can be measured, although material anisotropy makes this measurement difficult. This method requires a smooth surface, a couplant between the probe face and the material being tested, point by point testing and skilled personnel to run the test. Both steel and FRP tanks can be tested in this manner.

Acoustic Emission Testing

The second method is the acoustic emission test using stress waves.[4,36] When a defect such as a crack within a tank wall extends within a metal or FRP storage tank, it generates stress waves which can be detected. A tank is tested under a loading to determine the extent of defects in the wall. The results can be interpreted in terms of rate of crack growth, the quality of material and the potential of failure of the structure.

Table 3
Comparison of Common Nondestructive Testing Methods

Method	Characteristics Detected	Advantages	Limitations	Example of Use
Ultrasonics	Changes in acoustic impedance caused by cracks, nonbonds, inclusions, or interfaces.	Can penetrate thick materials; excellent for crack detection; can be automated.	Normally requires coupling either by contact to surface or immersion in a fluid. Orientation can present problems in detection or interpretation of defect.	Adhesive assemblies for bond integrity. Detection of cracks.
Radiography	Changes in material density from voids, inclusions, material variations; placement of internal parts.	Can be used to inspect wide range of materials and thicknesses; versatile; film provides record of inspection.	Radiation safety requires precautions; expensive; detection of cracks can be difficult.	Pipeline welds for penetration, inclusions, voids. Verification of parts in assemblies.
Eddy Currents	Changes in electrical conductivity or magnetic permeability caused by material variations, cracks, voids, or inclusions.	Readily automated; moderate cost.	Limited to electrically conducting materials; limited penetration depth. Interpretation of defect signals can be difficult.	Heat exchanger tubes for wall thinning and cracks. Verification of material heat treatment.
Visual-Optical	Surface characteristics such as finish, scratches, cracks, or color; strain in transparent materials.	Often convenient; can be automated.	Can be applied only to surfaces, through surface openings, or to transparent material.	Paper, wood, or metal for surface finish and uniformity.
Liquid Penetrant	Surface openings due to cracks, porosity, seams, or folds.	Inexpensive, easy to use, readily portable, sensitive to small surface flaws.	Flaw must be open to surface. Not useful on porous materials.	Turbine blades for surface cracks or porosity.
Magnetic Particles	Leakage magnetic flux caused by surface or near-surface cracks, voids, inclusions, material or geometry changes.	Inexpensive, sensitive both to surface and near-surface flaws.	Limited to ferromagnetic material; surface preparation and post-inspection demagnetization may be required.	Railroad wheels for cracks. Detection of weld defects.

Non-destructive testing methods which require access to both sides of the tank wall are: radiographic inspection (i.e., x-rays),[4,13,5] eddy-current techniques which can be performed on electrical conducting tanks,[4,13,8] liquid penetrant which detects cracks on the surface of tanks, magnetic particle testing which detects surface or near surface cracks, voids, inclusions and material or geometric changes in ferromagnetic material and visual inspection. Visual inspection may be an inexpensive initial step of tank integrity investigation. Internal inspection of a tank, either through direct access or by the use of mirrors, may give the first clues to the condition of the tank.

New methods which eventually will be used by the industry include lasers and holographic methods.[7]

CONCLUSIONS

The construction of many chemical industries, gasoline stations and other facilities storing hazardous materials in large quantities led to the installation of thousands of underground storage tanks during the period from 1950 to 1970 throughout the United States. Many of these tanks have exceeded their useful lives and either are leaking now or soon will be leaking. The RCRA-UST regulations introduced by the U.S. EPA to protect human health and the environment from contamination are summarized in this paper. In addition, various leak detection and monitoring techniques to avoid groundwater contamination also have been reviewed.

The details of codes and standards for steel and fiberglass tanks have been presented. However, most of these are consensus standards and may not ensure structural design adequacy for all anticipated loading and operating conditions. It is necessary to analyze and design these storage tanks using proper analysis techniques and procedures of state-of-the-art design practices.

The most important design considerations also were discussed. The design principles applied for large diameter buried pipelines during the last decade provide additional useful information for the designers of new tanks. The new tanks should be designed with appropriate leak detection and secondary containments. They should further have provisions for testing the integrity in place. Proper tank management and operation procedure are required to ensure long life for these potentially hazardous underground storage structures.

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Performance Evaluation of Commercial Hazardous Waste Treatment Facility Operations

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ABSTRACT

A number of the management processes employed by commercial hazardous waste treatment facilities were evaluated under a U.S. EPA research program. This program and the results of process monitoring at two facilities are discussed.

TEST PROGRAM BACKGROUND AND OBJECTIVES

In support of RCRA and the Hazardous and Solid Waste Amendments of 1984 (HSWA), the U.S. EPA Office of Research and Development (ORD) is seeking information on the applicability, effectiveness, capacity, cost and environmental impact of existing hazardous waste treatment technologies which are alternatives to land disposal.

The general waste types included in this study are several which were identified for priority action inthe HSWA legislation: solvents, cyanides, metals, corrosives and halogenated organics. For solvents, the HSWA states that, effective 24 months after the date of enactment, further land disposal is prohibited unless the U.S. EPA determines that such prohibition is not required in order to protect human health and the environment. If the Agency fails to meet this deadline, these wastes will be banned automatically from further land disposal.

The HSWA specifically addresses the spent solvents listed under F001, F002, F003, F004 and F005. Some examples of other waste types which are candidates for land disposal restrictions are F006 through F012 (metals and cyanides), D002 (corrosives) and K015, K016 and K029 (halogenated organics).

A wide variety of established treatment processes, combinations of processes and waste streams are being considered for evaluation under this phase of the ORD program which involves commercial off-site hazardous waste treatment facilities. There will be emphasis on the chemical and physical treatment methods including cyanide oxidation, chromate reduction, neutralization of corrosive wastes, heavy metal precipitation, evaporation, steam stripping and various forms of solvent distillation. Incineration and other thermal treatment processes and the waste categories for dioxins (F020 to F023) and PCBs are being investigated by others and are not included in this discussion.

APPROACH

The primary criteria used to select commercial facilities for evaluation under this program are:

- Ability to treat hazardous wastes scheduled to be banned or restricted from land disposal
- Well run facilities employing proven technology that could be representative of best demonstrated available technology

A number of sources were used to develop a list of candidate facilities, including the following:

- 1985 Industrial and Hazardous Waste Management Firms Directory
- RCRA Part B computer listing
- State agencies
- Trade associations
- Equipment vendors
- Conferences and seminars

Once identified, the candidate facilities were contacted about the waste types they treated and the treatment methods used; we also attempted to ascertain whether their company would be interested in participating in the program. With the cooperation of the companies, arrangements were made to visit each site and to discuss testing of specific operations. Based on these visits, several facilities were selected for one week of sampling and monitoring. The results of the first two field tests are the subject of this paper.

PROCESS EVALUATIONS

The treatment processes and waste types of interest at two of the hazardous waste treatment facilities are given in Table 1.

Table 1
Waste Treatment Processes and Waste Types

Facility	Process	Waste Type (RCRA Codes)
A	Distillation	Organic Solvents (F001, F002, F003, F005)
B	Fuel Blending	Organic Liquids and Sludges (D001, F003)
B	Alkaline Chlorination	Cyanide Liquids and Sludges (F007, F008, F009, F010, F011, F012 and F019)
B	Aqueous Waste Treatment Lime Precipitation Pressure Filtration Carbon Adsorption	Metal-laden and Organics (D002, D007)

Both facilities accept and treat corrosives, metal-laden aqueous wastes, aqueous cyanide wastes, halogenated and non-halogenated spent solvents. The waste treatment processes are described briefly and analytical results are presented.

Batch Distillation

As illustrated in Table 2, Facility A processed several types of waste solvents from one or more generators during the test program. Wastes containing less than 40% of the major solvent component are not accepted by this facility due to unfavorable economics for reclamation. Facility A places an upper limit on suspended solids content of the waste solvents of about 10 to 15%. Solvent wastes with higher solids content may be accepted, but the generator would be charged a premium for disposal of the excess solids.

Table 2
Generator's Manifest Data for Waste Solvents, Facility A

Day	Batch	Generator Industry Type	Major Components	Waste Code
1	1	Electronics	1,1,1 trichloroethane freon 113 isopropanol	F001
2	1	Electronics	isopropanol	D001
3	1	Biotechnology Research	methylene chloride	F002
3	2	Electronics Plating Specialty Chemical Manufacturer Motor Rebuilder	methyl ethyl ketone	F005

Figure 1 is a simple flow diagram for the batch distillation process. The feed is charged to the still pot and steam, in an internal coil, is applied to heat the liquid to boiling. Vapors rising from the still pot are condensed by cooling, and collected. Figure 2 illustrates the fate of the waste solvents processed during the test period. The major limitation on batch distillation was the 140°C maximum temperature achievable due to the capacity of the site's steam boiler. The facility plans to install a vacuum system to overcome this limitation.

Data on the still bottoms from four batches of waste solvents are presented in Table 3. The gas chromatograph data for the F001 waste was discounted because of the large discrepancy between the reported Freon 113 concentration of the bottoms, the percent chlorine and the process conditions. The principal organic components analysis for the second waste (D001) accounted for only 36% of the total mass as isopropanol, xylene and ethanol. However, the organic analyses accounted for 98% of the F002 batch and 70% of the F005 batch.

Fuel Blending

Organic waste blending operations constitute about 40% of Facility B's business. Incoming wastes for the process are segregated according to chlorine and moisture content, ground to particle sizes of less than 3 mm and placed in agitated storage tanks. The final blend is homogeneous, easily pumpable and suitable for burning in a liquid injection incinerator. The high chlorine waste blends (up to 45% chlorine and free of PCBs) are used by a manufacturer of low alkali cement. The low chlorine fuel blends (less than 6% chlorine) are sold to operators of kilns or furnaces that are permitted to store and burn U.S. EPA-listed hazardous wastes. Figure 3 depicts the organic waste blending operation.

Two batches of organic wastes were processed during the test period. The first waste was a low chlorine content waste drawn by vacuum from drums of paint sludges (waste code D001). The second waste was a mixture of varnish, paints, alcohols and xylene (D001 and F003). As a result of the grinding process, the suspended solids content of the treated organic wastes increased, the viscosity improved and a homogeneous material was produced. Table 4 presents the results of tests on the two fuel blends. Approximately 80% of the low chlorine waste included in the first blend was pumpable. The remainder of the material was solidified with lime and transported to a land disposal facility.

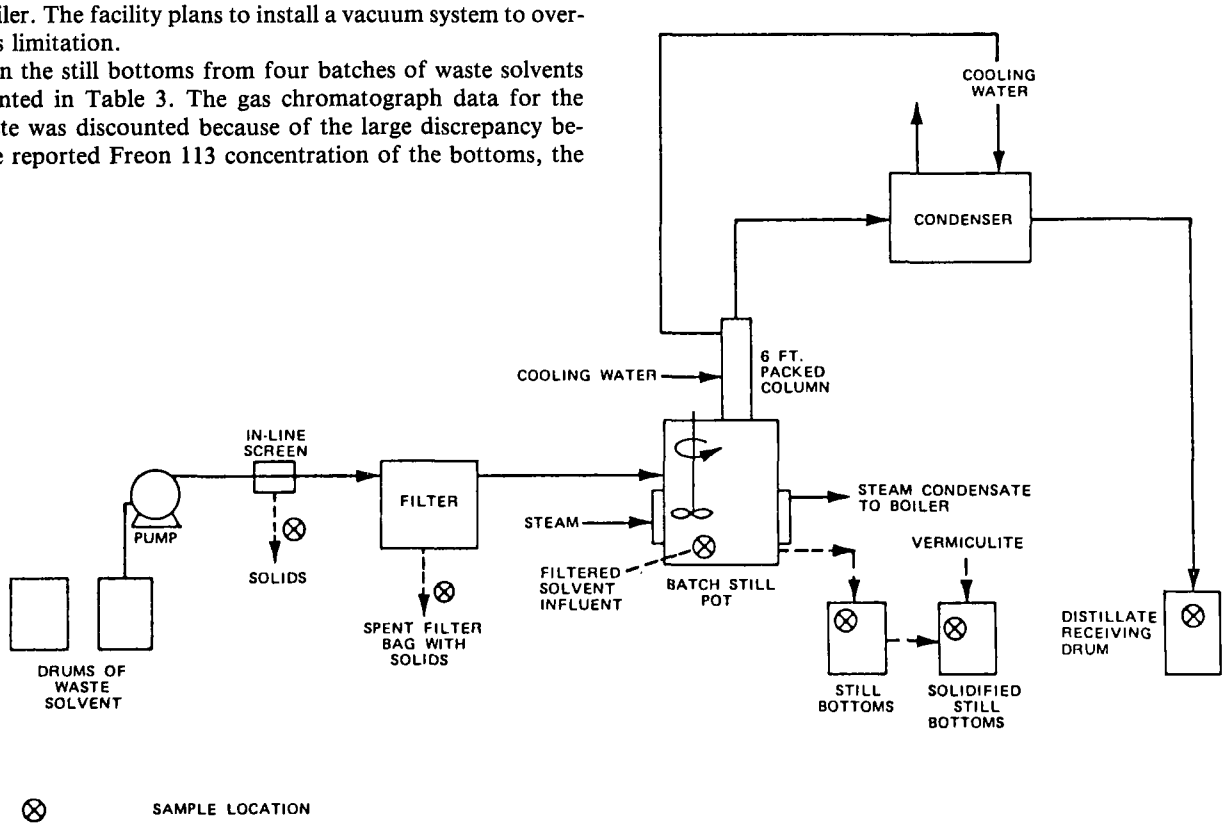

Figure 1
Flow Diagram/Sample Points for Batch Distillation

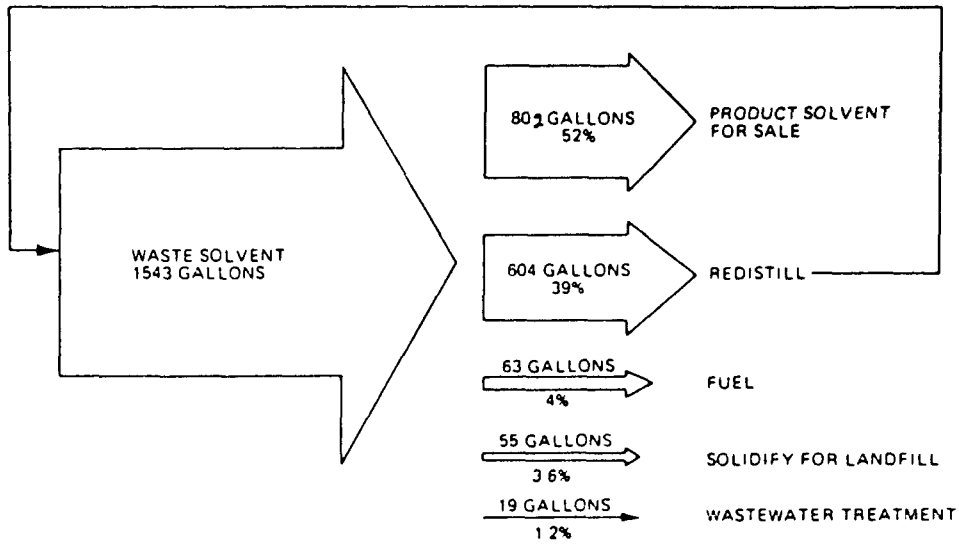

Figure 2
Fate of Waste Solvent

Table 3
Still Bottoms Characterization, Facility A

Parameter	Units	Batch 1 Day 1 (F001)	Batch 1 Day 2 (D001)	Batch 1 Day 3 (F002)	Batch 2 Day 3 (F005)
Viscosity (@25 C)	cSt	4.55	--	--	--
Paint Filter Test	--	Fail	Fail	Fail	Fail
Density	g/ml	0.952	0.789	0.856	0.858
COD	mg/l	I	I	I	I
Total Solids	%	71	10	0.63	6.7
Total Volatile Solids	% of TS	100	100	82	98
Total Suspended Solids	mg/l	5700	14	170	1400
Total Vol Sus Solids	mg/l	5600	12	160	860
Total Vol Dis Solids	mg/l	560000	100000	4100	66000
Total Dissolved Solids	mg/l	560000	100000	4800	66000
Silica	wt%	NA	NA	LT 0.005	0.01
Metals					
Copper	mg/kg	NA	NA	2.3	2.5
Lead	mg/kg	NA	NA	NS	NS
Chromium	mg/kg	NA	NA	0.096	0.65
Silver	mg/kg	NA	NA	LT 0.05	0.052
Iron	mg/kg	NA	NA	1.4	44
Nickel	mg/kg	NA	NA	NS	NS
POC					
Acetone	mg/l	ND	ND	1300	LT 500
Butanol	mg/l	ND	ND	7500	11000
Iso-Butanol	mg/l	ND	ND	640	LT 500
Dioxane	mg/l	150000	ND	4000	6400
Ethanol	mg/l	ND	2100	14000	34000
Freon 113	mg/l	ND	NM	NM	NM
Isopropanol	mg/l	ND	350000	98000	56000
Methanol	mg/l	ND	ND	230000	14000
Methylene Chloride	mg/l	ND	ND	ND	ND
Methyl Ethyl Ketone	mg/l	ND	ND	370000	530000
1,1,1-Trichloroethane	mg/l	370000	ND	NM	NM
Toluene	mg/l	ND	ND	110000	18000
P-xylene, M-Xylene	mg/l	ND	ND	3100	23000
O-xylene	mg/l	ND	10000	LT 500	4300
TOX	wt% Cl	8.85	0.071	1.07	1.11
EP TOX		X	X	X	X
TCLP		X	X	X	X
% Carbon	wt%	73.33	65.73	57.81	52.29
% Hydrogen	wt%	11.82	13.98	11.41	11.48
% Water	wt%	0.04	2.86	7.13	13.79
BTU Content	Btu/lb	15722	15244	12339	11555

Symbols:
LT Less Than
GT Greater Than
NS = Not Sampled
ND = Not Detected
NM Not Measured
NA = Not Applicable Under the Circumstances
I Interference Prevented Quantitation
X = Analytical Results Are Not Yet Available

Alkaline Chlorination

Alkaline chlorination is a well-established technology for the destruction of simple aqueous cyanide mixtures. Typically, cyanide oxidation is achieved by raising the pH of the wastewater to 8.5-9.0 and adding chlorine. In practice, many of the spent metal cyanide compounds require additional amounts of time and chlorine to complete the conversion of the complex cyanides to cyanates or to carbon dioxide, nitrogen and water.

At Facility B, cyanide-containing aqueous wastes are segregated and treated in a single-stage process. Sodium hydroxide is used for pH adjustment if necessary, and sodium hypochlorite is used as the source of chlorine. Wastes containing more than 4% cyanide are diluted to this level before treatment to minimize the temperature effects on the reinforced fiberglas reaction vessels. Following the reaction, the waste is mixed with other aqueous wastes for further treatment (described in next section).

The cyanide wastes treated during the sampling program at Facility B included cyanide rinse waters (F007-F012) and cyanide sludges (F019). Table 5 presents the results of the analytical tests performed on these wastes. Based on the data obtained during this test, the alkaline chlorination process effluent concentrations were less than 5 mg/l.

Aqueous Waste Treatment

The aqueous waste treatment system at Facility B is comprised of a number of major unit processes arranged in a series: pH adjustment, chemical reduction, lime precipitation, pressure filtration, neutralization and granular activated carbon adsorption (Fig. 4). The aqueous wastes were characterized as D002. However, they originated from several generators and some had received some previous treatment within Facility B.

The effluent from the alkaline chlorination process (75%) and non-cyanide aqueous wastes received at the site (25%) are pumped to equalization tanks. The blended wastewaters then are pumped to pH adjustment tanks for the addition of waste acid to pH 2. This acidification serves to break some metal-organic chelate complexes, but primarily introduces metal wastes for removal in the next process, lime addition and precipitation of metal hydroxides. The resulting hydroxide slurry is dewatered by a plate-and-frame filter press to approximately 45% solids. The sludge filter cake is trucked off-site for land disposal.

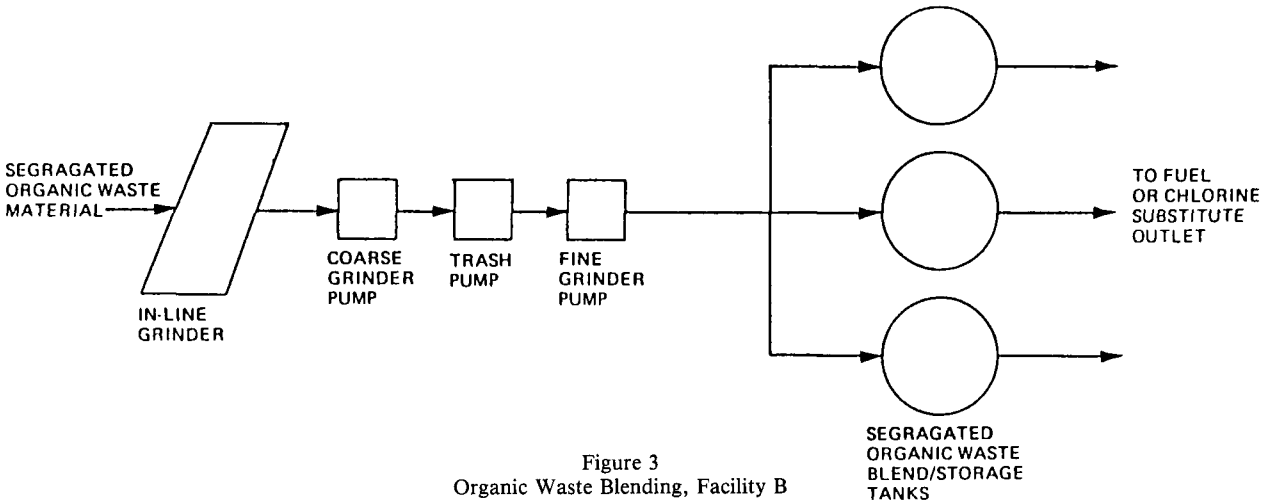

Figure 3
Organic Waste Blending, Facility B

Table 4
Analytical Results for the Fuel Blending Process, Facility B

		Sample Period One			Sample Period Two					
Pollutant	Units	Low Cl_2 Organic Liquid	Composite Influent Blend	Treated Fuel Blend	Organic Liquid	Organic Sludge Non-Pumpable	Organic Sludge Non-Pumpable	Organic Sludge Non-Pumpable	Organic Sludge Non-Pumpable	Treated Fuel Blend
Toxic Metals										
Cadmium	mg/kg	NS	NS	NS	NS	220	3,400	5,000	30,000	NS
Total Chromium	mg/kg	NS	NS	NS	NS	390	260	170	1,400	NS
Copper	mg/kg	NS	NS	NS	NS	3,900	5,100	510	800	NS
Lead	mg/kg	NS	NS	NS	NS	36,000	70,000	8,600	5,900	NS
Nickel	mg/kg	NS	NS	NS	NS	62	260	31	650	NS
Zinc	mg/kg	NS	NS	NS	NS	1,300	8,500	610	14,000	NS
Other Analysis										
Total Organic Halide	weight %	0.074	0.26	0.78	2.32	NS	NS	NS	NS	0.79
Total Solids	ppm	69,000	130,000	120,000	NS	410,000	560,000	530,000	690,000	390,000
Total Volatile Solids	ppm	58,000	110,000	100,000	NS	240,000	540,000	260,000	620,000	350,000
Total Suspended Solids	ppm	26,000	46,000	70,000	NS	NS	NS	NS	NS	330,000
Total Dissolved Solids	ppm	43,000	84,000	50,000	NS	NS	NS	NS	NS	60,000
Total Volatile Suspended Solids	ppm	21,000	37,000	55,000	NS	NS	NS	NS	NS	280,000
Total Volatile Dissolved Solids	ppm	37,000	73,000	45,000	NS	NS	NS	NS	NS	70,000
EP Toxocity		NS	NS	NS	NS	X	X	X	X	NS
TCLP		NS	NS	NS	NS	X	X	X	X	NS
% Carbon	weight %	NS	NS	23.13	NS	40.45	59.15	40.75	64.85	58.17
% Hydrogen	weight %	NS	NS	10.71	NS	7.94	10.33	6.94	10.91	10.15
BTU Content	BTU/lb	2,472	786	2,179	NS	5,217	15,350	8,443	14,765	11,601
% Water	weight %	NS	NS	80.56	NS	NS	NS	NS	NS	11.14

NS = Not Suspended
X = Analytical Results Are Not Available Yet

Table 5
Analytical Results for the Cyanide Treatment Process at Facility B (F007-F012, F019)

		Sample Period One			Sample Period Two							
Pollutant	Units	Cyanide Treatment Influent	Cyanide Treatment Effluent	Cyanide Containing Sludge	Cyanide Treatment Influent	Cyanide Treatment Effluent	Cyanide Containing Sludge	Cyanide Containing Sludge	Cyanide Containing Sludge	Cyanide Containing Sludge	Cyanide Containing Sludge	Cyanide Containing Sludge
Toxic Metals												
Cadmium	mg/l	45	3.5	# 11,000	230	160	# 1,500	# 1,300	# 24	# 120	# 2,400	# 7,200
Total Chromium	mg/l	2.3	12	# 180	24	19	# 54	# 14,000	# 26,000	# 73	# 15,000	# 250
Copper	mg/l	1,300	42	# 34,000	6,200	3,300	# 150	# 15,000	# 15,000	# 720	# 21,000	# 600
Lead	mg/l	2.8	1.9	# 36	21	8.5	# 67	# 1,900	# 8,500	# 130	# 2,600	# 1,700
Nickel	mg/l	450	6.2	# 750	1,400	730	# 280	# 490	# 270	# 1,300	# 430	# 200
Zinc	mg/l	3,200	1,000	# 750	1,500	920	# 1,200	# 13,000	# 4,700	# 9,700	# 46,000	# 480
Other Analysis												
Total Organic Carbon	mg/l	20,000	5,700	NS	20,000	6,900	NS	NS	NS	NS	NS	NS
Total Organic Halide	weight %	0.30	0.68	NS	10.19	LT 0.6	NS	NS	NS	NS	NS	NS
Cyanide	mg/l	5,800	LT 5	# 96,000	11,000	LT 5	# 87,000	# 9,000	# 8,000	# 1,900	# I	# 69,000

NS = Not Sampled
I = Interference
# = mg/kg
X = Analytical Results Are Not Available Yet

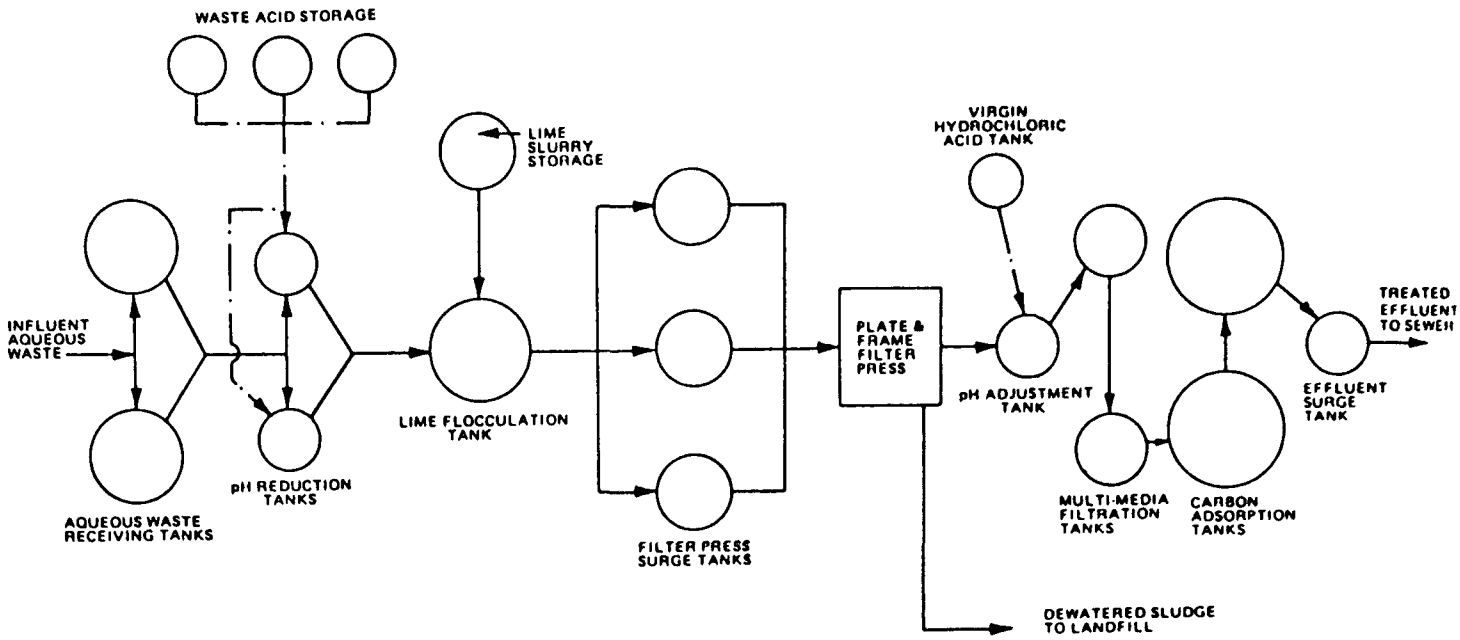

Figure 4
Aqueous Waste Treatment Facility

Filtrate from the press is neutralized with hydrochloric acid and passed through two multi-media filters in series followed by two beds of granular activated carbon (9100 kg each) before discharging into the public sewer collection system. Facility B's effluent discharge permit contains limits on heavy metals, chlorinated compounds, phenol and total organic carbon. Phenol breakthrough is monitored as an indicator of carbon exhaustion. Breakthrough typically occurs after about 20 to 25 days of operation.

The analytical results for the principal components found in 3 days of sampling the filtrate, filter press sludge and carbon column effluent are given in Table 6. Heavy metal concentrations in the final effluent were acceptable for discharge. The carbon columns removed the organic compounds amenable to adsorption (trichloroethane, toluene, total xylenes and phenol), but moderately high concentrations of acetone were present in the GAC column effluent. The TOC concentrations were reduced by an average of 90%.

Table 6
Analytical Results for Aqueous Waste Treatment, Facility B

Pollutants	Units	Discharge Permit Limits	Filtrate	Filter Press Sludge	GAC Effluent
Methylene Chloride	ug/l	21,400	220,000; 43,000; 130,000	ND; 61,000; 79,000	ND; ND; 30,000
Acetone	ug/l	--	68,000; 61,000; 69,000	260,000; ND; ND	140,000; 160,00; 55,000
Trichloroethane	ug/l	5,160	4200; 2500; 1600	400,000; 160,000; 110,000	ND; ND; 1600
Toluene	ug/l	765	13,000; 7700; 3900	1,400,000; 580,000; 290,000	ND; ND; ND
Chlorobenzene	ug/l	765	ND; ND; ND	15,000; 34,000; 11,000	ND; ND; ND
Ethyl Benzene	ug/l	--	ND; ND; ND	110,000; 73,000; 55,000	ND; ND; ND
Total Xylenes	ug/l	--	ND; 8,000; ND	57,000; 720,000; 300,000	ND; ND; ND
Phenol	ug/l	6160	19,000; 4,200; 5100	ND; ND; ND	ND; ND; ND
Cadmium	mg/l	1.1	1.2; 7.9; 50	12,000; 6,700; 2900	0.15; 1.5; 1.4
Total Chromium	mg/l	2.16	2.1; 1.9; 0.7	10,000; 23,000; 2200	0.1; 0.12; 0.09
Copper	mg/l	4.8	160; 170; 380	50,000; 43,000; 25,000	0.32; 0.9; 0.6
Lead	mg/l	3.43	1.4; 0.8; 0.6	1,300; 790; 830	0.56; 0.7; 0.6
Nickel	mg/l	11.48	2.2; 2.3; 22	9,300; 6,400; 1400	2.2; 2.0; 1.8
Zinc	mg/l	4.26	24; 16; 46	35,000; 14,000; 4000	1.4; 1.6; 0.7
Cyanide	mg/l	1.33	NS	900; 400; 650	NS
TOC	mg/l	1500	2500; 2400; 5000	NS	1200; 1500 1400

CONCLUSIONS

The treatment technologies evaluated at Facility A or Facility B were batch distillations, fuel blending and alkaline chlorination/aqueous waste treatment. If simple batch distillation is the sole waste solvent treatment process, the recovered solvent must be acceptable for use either as recycled to the process which originally generated the waste solvent or in some other application. This limits the types and concentrations of impurities that can be accepted in the influent and this limitation is specific to the end use.

The waste segregation, blending and grinding operation appears to be a practical approach to management of organic solids such as resins, latex, paint sludges and distillation bottoms for ultimate disposal as a fuel or chlorine substitute suspension.

Finally, the alkaline chlorination/aqueous waste treatment system was effective in treating cyanide and metal-laden wastes, producing an effluent suitable for discharge to a publicly owned treatment works.

The data from these two facilities and other locations will provide process and residual characterization information that will contribute to the determination of the adequacy of available treatment options.

DISCLAIMER

Although the research described in this article has been funded wholly or in part by the U.S. EPA, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

An Examination of Siting Problems for Off-Site TSDFs

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ABSTRACT

The number of off-site Treatment Storage and Disposal Facilities (TSDFs) in the United States is decreasing. Because of the social stigma associated with a facility which manages hazardous waste and the high public visibility of an off-site facility, proposed commercial TSDFs are finding it increasingly difficult to get approval to operate. Meanwhile, several factors are working to close currently existing facilities. This decrease in TSDFs is going to lead to an increasing problem for waste generators—how to manage their waste.

The Solid and Hazardous Waste Management Committee of the ASCE has been researching this problem over the last year. A previous study confirmed that a decrease in sites has occurred in the period 1980-1985. In addition, the revisions to RCRA have forced many land disposal facilities to close and may have a similar impact on other types of facilities in the next 3 years. Additional work has been done to evaluate the reasons for the overall decline. Specifically, a state survey is being conducted to identify: (1) why existing facilities have shut down during 1980-1986 and (2) what has caused the denial of permits for most of the proposed new sites during the same period.

INTRODUCTION

The siting of new off-site Treatment, Storage and Disposal Facilities (TSDFs) for hazardous waste management has become increasingly difficult over the past several years. In addition, existing facilities across the country are feeling increased pressures to cease operations. Such pressures are being exerted by various organizations: local citizens who fear the long- and short-term health effects of a TSDF in their town; regulatory groups who identify technical design or operational problems which violate existing regulations; and insurance brokers and company management who see long-term financial risks.

Off-site facilities are defined in this paper as TSDFs which accept waste from generators who pay the facility to handle the waste for them. Most clients of off-site facilities are small generators for whom a dedicated on-site TSDF is not economically feasible. In many cases, the clients include federal, state and local governments. Because an off-site TSDF is a commercial enterprise, it is highly visible and thus subject to close public scrutiny. Off-site facilities that are hazardous waste landfills particularly attract attention.

Much of the opposition to off-site hazardous waste management derives from poor public relations. No number of logical technical discussions can overcome past horror stories. The mere mention of any hazardous waste facility causes an immediate public outcry in opposition.

Many engineers and scientists who work in the hazardous waste management field are concerned that the country will soon face a crisis in the effective management of hazardous waste. All three types of facilities are being affected: (1) treatment, (2) storage and (3) disposal. Land disposal is being phased out out as a result of the RCRA amendments passed in 1984 (however, off-site disposal usually is considered as a cleanup method at every uncontrolled waste site).

Treatment technology has not advanced far enough so that: (1) absolute destruction of the waste can be assured and (2) process upsets will not occur. As a result, a release is possible and the public does not want to take that chance in their towns.

Storage facilities for hazardous waste are only a temporary measure and do nothing to solve the real problem. Storage merely serves as an intermediary step. Long-term storage is nothing more than aboveground landfilling before disposal or treatment. As a result of these technical and public relations problems, it is difficult to open or continue operation of an off-site TSDF.

PREVIOUS WORK

The Solid and Hazardous Waste Management Committee (SHWMC) of the American Society of Civil Engineers has been investigating the problems of siting off-site TSDFs. A survey of states was conducted from January through April of 1985 to determine the status of new facility siting. In May of 1985 the results of the SHWMC survey were presented at the Hazardous Material Control Research Institute's (HMCRI) Hazardous Waste and Environmental Emergencies Conference. That paper, "The Status of Off-Site TSDF Siting," provided information on the then current number of TSDFs operating, the change since 1980 (RCRA implementation) and the success rates of proposed facilities.[1] The results of that survey are summarized below:

- As of May 1985, 566 off-site TSDFs operated in this country. Approximately 50 of these sites were disposal. Ten states had no TSDFs; California had 133.
- A total of 118 facilities were closed between November 1980 and May 1985. (No reasons were given.)
- A total of 119 facilities were proposed in that same period.
- Of the 119 proposed TSDFs, only 33 began operations (five disposal facilities).
- The number of off-site TSDFs decreased by about 13% from 1980 to 1985. In that same period, only 28% of proposed sites have been approved.

The SHWMC study was done prior to the Nov. 8, 1985 deadline for land disposal facilities to submit a Part B application. That deadline has had the impact of further reducing the num-

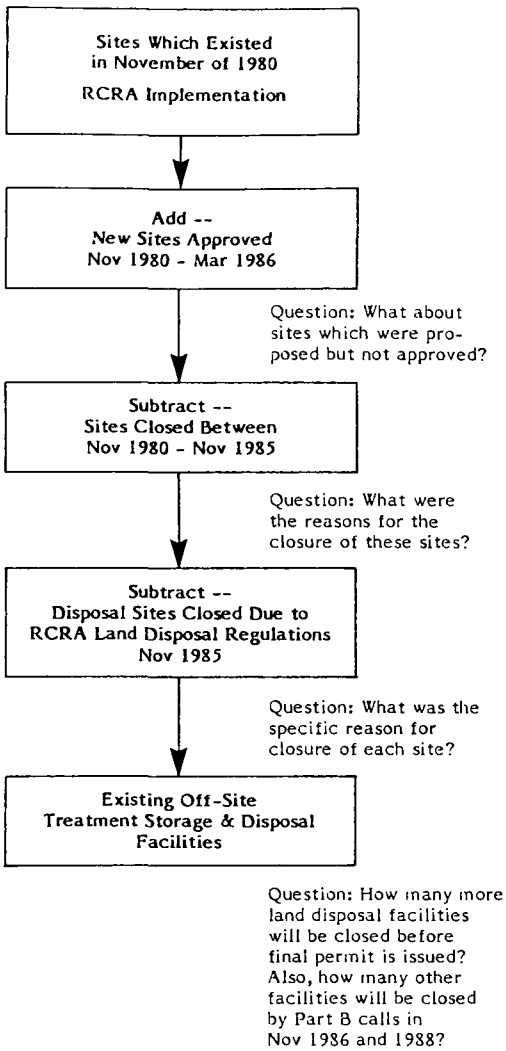

Figure 1
Summary of Change in the Number of TSDFs

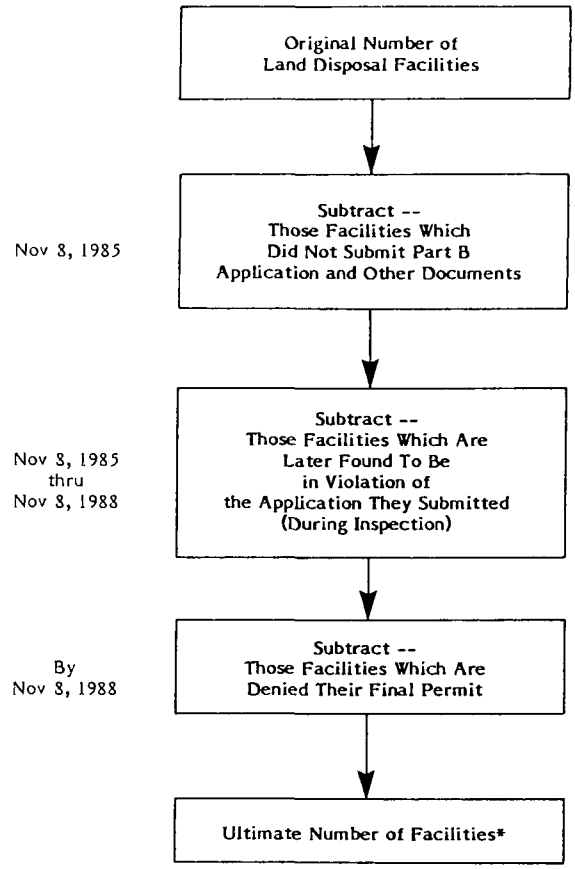

Figure 2
Effects of Part B Deadline on Land Disposal Facilities

ber of disposal facilities. The specific impact of this deadline is not yet known (Fig. 1). A certain number of facilities have not submitted a Part B application and have stopped operation. Undoubtedly, some percentage of those who submitted certifications in November ultimately will be found to be out of compliance. This decrease in facilities only adds to the problems of commercial sites still available for hazardous waste management (throughout our work we do not discriminate "good" sites from "bad" sites and we do not wish to imply that a reduction in sites is a bad change).

The problems with opening or keeping open a TSDF apply both on-site and off-site. However, SHWMC selected to study off-site facilities in particular because of the direct impact off-site TSDFs have on the majority of generators. Generators who use off-site facilities have very limited options if their TSDF is closed.

The results of SHWMC's study are being used as a basis for further work. This will include an assessment of the impact of the land disposal permit deadline. Our followup study is described below.

METHODS

The followup study being conducted by the SHWMC is using information provided by state contact people responsible for permitting TSDFs. This list was provided by the U.S. EPA and has been updated during previous contacts. The states will be asked to provide information about the up-to-date number of facilities operating in each state and the problems TSDFs are experiencing. The following questions will be asked:

- How many off-site TSDFs currently operate (accept waste) in your state? If possible, break this number down into treatment, storage and disposal.
- What were the reasons for the closure of off-site facilities which were reported in the 1985 survey? The reasons will be grouped into general categories: technical, financial, political, capacity.
- How many off-site disposal facilities did not submit their Part B application in November 1985? Do you suspect that more will be closed after permit review?
- What were the reasons for the rejection of off-site facilities which were reported in the 1985 survey?

Written responses are being requested, and the responses will be verified and/or clarified by telephone contact.

After responses are received from each of the states, they will be tabulated. The summary table will show the current number of sites, the number of closed sites, the number of new sites and the reasons for site closure and application rejection. The results of

the state survey will be presented in the table just as they are presented. Only the responses related to the reasons will be interpreted. As mentioned, this information will be grouped into categories which best describe the specific situation at each site.

The results of this followup survey are intended to provide information to SHWMC and other interested members of the scientific community on the current status of TSDFs throughout the United States and on the problems which are causing the recent decline in the number of facilities. The previous paper served as a basis for establishing that the number of sites has been decreasing in the past 5 years. This survey will both update the information generated one year ago and explore more fully the reasons for this decline.

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Spatial Data Research for Hazardous Waste Sites

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ABSTRACT

Analytical and numerical models are used throughout the hazardous waste site industry to assist managers investingating groundwater conditions. An investigation based on geographic information systems (GIS) was initiated in the San Gabriel Basin in Los Angeles County, California. The objective of the pilot project is to determine operational capabilities of a spatial-based system to enhance management of the hazardous waste site data. An initial goal of the research is to demonstrate feasibility of using the GIS to run various groundwater flow and transport models. A project design is presented which describes the hazardous waste spatial data research processes leading to input into two classes of groundwater models. Anticipated strength of the GIS approach is in the management of the spatial site data for multiple modeling interfaces to offer increased analytical options for the U.S. EPA Site Offices.

INTRODUCTION

Numerous analytical and numeric models are being used to provide imput for engineering and management decisions at hazardous waste sites. Groundwater models require significant resources to build data sets, often taking months or years to assemble. Resources in time and money once expended should not require wasteful repetition due to phase changes or management adjustments of a site study. The ability to switch or choose among different models is important to the success of a site evaluation. However, the availability of data may curtail the use of some models. Efforts to satisfy the data requirements of multiple models easily can surpass the resources allocated for a site. Geographic Information Systems (GIS) have demonstrated robustness and flexibility in natural resource applications over the past few years. In particular, GISs permit maintenance of spatial data sets and preparation of these data for multiple use analysis programs.

A research program was initiated by the U.S. EPA's Environmental Monitoring Systems Laboratory (EMSL) in 1985 to assess the utility of GIS technology in providing an interface capability between input data and standard groundwater models for hazardous waste sites. The primary benefit to be gained for an enhanced interface capability is the multidisciplary use of the multiple types of hazardous waste site data. Such a trend in capabilities would provide cost sharing of data and enhance uses of the data sets. To investigate these issues in a real world context, the San Gabriel Basin Superfund site was selected for this pilot study.

SITE HISTORY

The San Gabriel Groundwater Basin is comprised of approximately 444 km² (165 miles²) of groundwater bearing, urbanized land in east Los Angeles County (Fig. 1). Groundwater in this basin is used extensively for public water supply with over 400 known public and private wells. Approximately 47 water purveyors supply drinking water to over 400,000 residents in over 33 communities.[1] The geologic structure is composed primarily of coarse alluvium lying along the southern base of the San Gabriel Mountains; aptly described as a large "sand box." This area is almost completely urbanized.

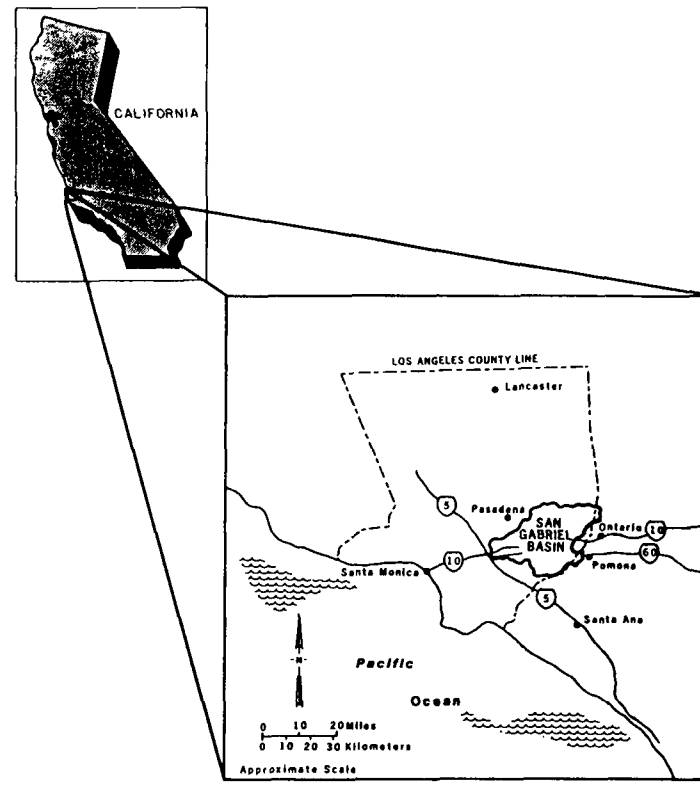

Figure 1
San Gabriel Basin Geographic Information System Pilot Study

In 1979, the first incident of groundwater contaminated by chlorinated hydrocarbons was reported. A concentration of 1800 µg/l trichloroethylene (TCE) was discovered in the central portion of the basin. The state and federal standard for safe drinking water is 5 µg/l TCE. Further sampling by the California Department of Health Services revealed a widespread situation of contaminated groundwater which included unsafe levels of carbon tetrachloride (CTC) and perchloroethylne (PCE). The U.S.

EPA became involved because of the toxicity of the contaminants and the magnitude of resources required to mitigate and manage this hazardous waste problem.[2]

The San Gabriel Basin is atypical of CERCLA sites by virtue of its geographic range. It is, in fact, a groundwater basin impacted by numerous contaminant sources, some of which probably were originated decades ago by post World War II industries.[3] The complexity and size of this site demands the examination of approaches oriented toward large, spatial data base management systems. Spatial management tools with the flexibility to potentially interfere with existing groundwater models were selected for examination in this study.

RESEARCH APPROACH

An important value of managing hazardous waste site data using spatially-based information systems lies in the organization and storage of the disparate types of information or data. These data are the essential descriptors of a site's physical, chemical and biological characteristics. By examining steps leading up to the processing of groundwater models, other uses of these processing capabilities for site operations should become evident.

A flow diagram of the processing steps for this project is presented in Figure 2. Most technically mature GIS packages will have similar programming capabilities. This research used programs or algorithms developed for the ARC/INFO GIS package and will be noted by parentheses in the following descriptive text.[4] The reader is referred to references[5-7] for a more thorough description of GIS components and capabilities.

DATA COLLECTION

Data collection was based on a thorough review of existing data from the San Gabriel area. Emphasis then was placed on defining appropriate data to be used as source input to transport and flow models. Use of transport and flow models was based on an assessment of operational U.S. EPA and contractor practices.

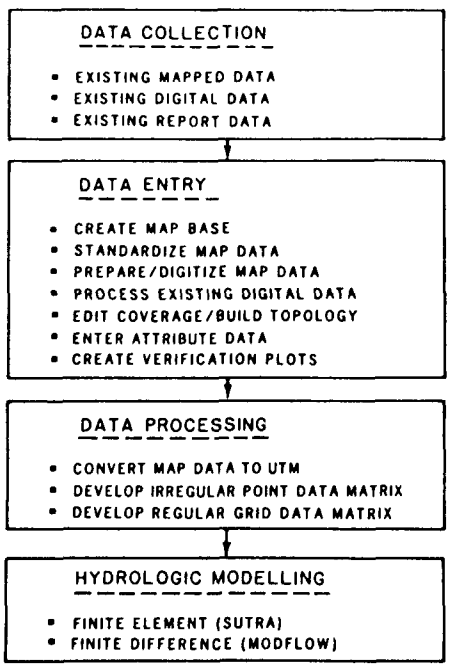

Figure 2
Processing Flow Chart

Additional data collection incorporated information necessary to define: (1) the extent and characteristics of the aquifer; (2) the extent of contamination by various chemicals; (3) spatial distribution of pumpage and water levels over time; (4) hazardous substance activities within a given area; and (5) population serviced by water supply wells. Data were obtained from engineering contractors, local and state water agencies and several federal agencies. To spatially integrate all of the data sets into the GIS, a base map at 1:62,500 scale was created. The data then were entered as either point, line or polygon (area) information. Attribute data, such as well water quality, were then recorded and referenced to a correlated point or area.

DATA ENTRY

Data entry of the data sets required the steps depicted in Figure 2. These steps were required to establish and maintain quality control standards for automating the data in terms of precision and accuracy consistent with National Mapping Standards. Fifteen U.S. Geological Survey 7.5-min quadrangle maps were required for a base scale of 1:62,500. Standardizing the map data entailed the precise integration of common boundaries between map themes such as geology, streams and soil using DIGITIZE. This standardization eliminated the artificially created phenomenon of boundary slivers. Preparation and digitization of map data required the careful transfer of data from templates of existing mapped data, such as potentiometric surfaces and annual precipitation, into computer files with the use of digitizing tables. Careful attention to ambiguities during this stage can eliminate erroneous output in later site analysis. Existing digital data on pumpage, water levels, chemical analysis and elevation data then were integrated into the GIS (GENERATE).

To remove numerous input errors, editing was performed and all data sets were attached to the proper spatial coordinates to provide correct topologic structuring. All supporting file information was entered to these data sets (ADDITEM, DROPITEM, JOINITEM). These attribute data are descriptive files, such as the chemical analysis of wellwater over time, which relate spatial coordinates to data base information. Displays then were produced for the different information themes (for example, groundwater boundary, population service areas, soil types and precipitation) to use in the determination of the accuracies of these verification plots.

DATA PROCESSING

Once all the base map coverages and attribute data were coded and verified, processing, analysis and creation of higher order or derived information proceeded. The analytical processes required to prepare data for hydrologic models are presented in Figure 3.

Well locations were recorded in Universal Transverse Mecator (UTM) coordinates, while other data sets were in units defined by the digitizing process. To relate or match well information to other data sets, a coordinate transformation algorithm was required (ARC TRANSFORM).

The next analysis step entailed the linkage of water service areas as defined by the water purveyors to specific well locations and attribute data. This step allowed further correlation of population data with water service and site-specific well information.

The capability of the GIS includes the manipulation of both vector and raster (grid) data formats. These formats have specific limitations and uses in cartographic processing, storage and retrieval. The reader again is referred to references[5-7] for detailed information on uses of the two formats.

A standard grid spacing and point of origin were required to establish the location and relationship of cells in advanced spatial processing stages. Grid spacing was designed at 0.25 mile cell size.

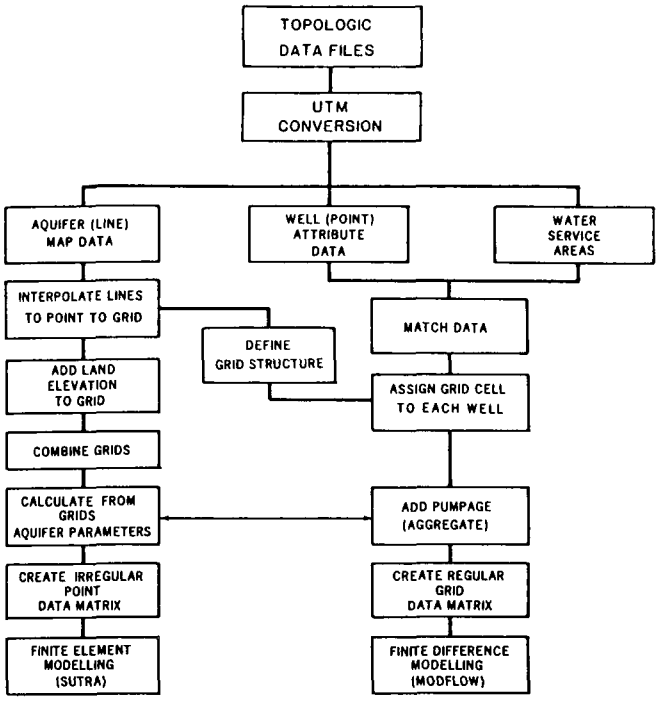

Figure 3
Groundwater Data Flow for Hydrologic Models

The grid structure then was used to assign reference cells to both line and point data sets. Topographic data defined by elevation points were registered on this grid structure. These grid registration steps enable analysis of aquifer parameters, such as calculating aquifer thickness and effective porosity. Pumpage rates could be assigned as aggregates within cells and used in further modeling efforts. The aquifer parameters data sets (e.g., hydraulic conductivity and potentiometric surface) were then available through various GIS algorithms in both grid data matrix (GRID TOPO) and point data matrix formats (TIN and TIN GRID). At this stage of analysis, the hazardous waste site parameters could be filed, reformatted if necessary and input to groundwater models.

GROUNDWATER MODELING

Testing the effectiveness of the GIS for support data input to groundwater models has to be completed. Two types of standard categories of models were selected for the modeling analysis: finite difference (MODFLOW) and finite element (SUTRA). Finite difference models use hydraulic parameters structured in a grid base format, both regular grid and irregular grid. Finite element models use these same parameters but as discretely spaced points, as in the location of wells in the San Gabriel Basin.

Application of algorithms for establishing gridded and discrete point networks are major contributions of the GIS's flexibility for model interfaces (GRID TOPO and TIN). These algorithms soon will be used to prepare irregular point data into finite element format to run the USGS. SUTRA groundwater transport model.[8] The algorithms also will be used to prepare grid data for a finite difference format to run the USGS MODFLOW groundwater flow model.[9]

DISCUSSION

The use of a GIS provides potential improvements over conventional approaches in three general areas. These are: (1) data management and storage; (2) identification of site data spatial relationships; and (3) data interface options for models and users. While these areas presently are difficult to quantitatively compare in any formal analysis, results of user oriented pilot studies demonstrate GIS strength for these areas.[10-12] The San Gabriel Basin GIS demonstration should help focus these strengths for hazardous waste management. Operational use of GIS for hazardous waste studies over the next few years should provide the necessary technology experience base to validate and quantify the system's value to federal, state and private sector users.

Central collection and spatial formatting of voluminous site data is of high functional value to hazardous waste site management. A site can be probed and analyzed by various teams of federal, state and contractor personnel and can experience major changes in chemical or physical states. A spatial data management system to handle dynamic inputs and facilitate the automation of analysis can save time for data aquisition, data analysis and data update functions. These improvements also should have significant economic benefits.

Site data spatial relationships are important to proper environmental assessments. The ability to correlate text information to points, lines and areas of a hazardous waste site is mandatory. GISs are the only data base management systems built on a spatial architecture which enables an automated capability to perform spatial assessments and proximity analyses. As a built-in function, topology or spatial structure is significantly better adapted to toxic transport and fate issues than systems which must add on such capabilities.

Communication of site data to multiple users for multiple analyses is a key aspect of efficient site management. Final results of the pilot studies' hydrologic groundwater modeling interface tasks should verify the design hypothesis that enhanced communication amongst industry, public and federal agencies is dependent upon spatial data management. Capabilities of the GIS could be used to develop internal groundwater modeling routines. However, the anticipated strength of the GIS is in the management of the spatial site data for multiple modeling interfaces, thereby relieving the U.S. EPA Site Officers from restrictive analytical options.

There always will be limits for many models in using parameters and variables existing at a site. This limitation will not be overcome by any single system. However, basic hydraulic parameters should be usable on a majority of industry approved flow, transport and particle tracking models. This interface management ability in data systems communications is within the technical range of current state-of-the-practice GISs. The U.S. EPA's research effort will continue to assess the issue of range and applicability of a GIS approach to hazardous waste site management.

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Sensitivity Analysis of Remedial Action Alternatives for Hazardous Waste Sites

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ABSTRACT

This paper presents the sensitivity analysis methodology used in the economic evaluation of remedial action alternatives at hazardous waste sites. The authors base their presentation on actual experience in conducting sensitivity analyses in the economic evaluation of alternatives for such sites. The paper recognizes that in the evaluation of remedial action alternatives, certain technologies have a larger degree of sensitivity than others and establishes procedures for the evaluation of possible sensitivity factors. The methodology gives decision-makers a range of unit costs and statistically calculated levels of confidence associated with each alternative.

The objective of the costing exercise is to develop criteria for obtaining a range of probable project costs. Once the range of possible project costs is obtained, basic statistical principles are incorporated to obtain levels of confidence of the cost estimates.

The authors establish a baseline (present worth) cost for each alternative, including the following components:

- Mobilization and startup
- General site work
- Off-site hauling
- Contractor's labor, overhead and profit
- Equipment and materials
- Energy
- Monitoring and safety
- Legal, license and permits
- Engineering and administrative costs
- Post-closure costs (present worth)

Sensitivity factors for each of the above categories are established and present worth costs are calculated for each case using a computer program. Combinations of sensitivity factors of the principal cost component are added to establish the possible project costs.

A statistical analysis is incorporated to determine the baseline price (mean) and other parameters, including the level of confidence.

INTRODUCTION

There is a degree of uncertainty in costs for remedial action alternatives at hazardous waste sites. It is important to recognize and evaluate this uncertainty in selecting the alternatives on a cost-effective basis. This evaluation is known as a sensitivity analysis.

This paper presents a methodology for doing a sensitivity analysis. The methodology focuses on presenting the decision-makers with a range of unit costs and statistically calculated levels of confidence associated with each alternative.

Factors basic to a sensitivity analysis, such as discount rate in a present value analysis, are straight forward and are not discussed.

REASONS FOR SENSITIVITY ANALYSIS

Not only is there a wide range of alternatives for remedial action, but also within each alternative the actual costs may differ significantly from the costs estimated in the feasibility study. Not considering the potential difference in costs could result in the selection of an alternative with actual costs more than estimated. Moreover, the selected system could have ended up with a cost higher than the actual costs of other alternatives even though their estimated study costs were higher.

The sensitivity analysis gives the decision-maker an opportunity to judge the possible range of costs for a certain alternative and to decide whether to accept this range or select another alternative, with an upper range of costs less than the first, but a greater calculated "best estimate" cost.

In doing the sensitivity analysis for an alternative, each cost component must be carefully evaluated with respect to magnitude and degree of certainty. A cost component with a high uncertainty but with a very small range of possible costs compared to total costs may not need to undergo sensitivity analysis. Similarly, a cost component with a relative high proportionate cost of the alternative may have little or no uncertainty and, hence, may not need a sensitivity analysis.

Examples of cost components and related factors that may be subject to a sensitivity analysis are set forth below.

Project Schedule

The actual project schedule can affect several items in the project cost including: energy, materials, resources and labor. An early project finish may result in significant savings. However, a late finish (due to weather delays, equipment malfunctions, unexpected site problems, etc.) can increase the project cost significantly.

Unexpected Site Complications

Cleanup of hazardous waste sites containing buried toxic materials that have not been qualified or quantified in detail may present unexpected project expenses or savings during remedial action implementation. For example, during a remedial investigation (RI) phase at a hazardous waste site, heavy metals are detected with no documentation of waste disposal activities. Electromagnetometer (EM) studies reveal the presence of metals; in addition, the groundwater is contaminated with metals and volatile organics (VO). The remedial action decision consists of excavating the site, removing the metals and treating the groundwater. During excavation, buried drums with unclassified solvents are unearthed. This situation will cause additional expenses for: monitoring and analysis, added personnel safety equipment, time delays and an overall increment in the excavation and disposal costs. On the contrary, another possible scenario may present no complications and reduce the actual cost of excavation.

Off-site Disposal

There are only a few off-site RCRA-approved disposal facilities in the continental United States. A cleanup remedy may consist of disposal of hazardous wastes at a chemical landfill. Due to uncontrolled conditions, the facility planned for waste disposal may not be available at the time of cleanup. This change in disposal plans may result in hauling the material to another facility located several hundred miles further than originally planned. In addition, this new facility may have higher tipping fees, require new transportation permits and demand other disposal taxes which may (depending on the waste quantities and material to be disposed of) increase the off-site disposal costs significantly.

Research and Development

A feasibility study (FS) recommendation could be based on the satisfactory performance of pilot testing of waste treatment units. The apparent preferred technology identified in the FS phase may not prove technically feasible when site-specific conditions are tested. Therefore, another option must be evaluated and researched, resulting in a significant increase in the engineering, administrative and capital expenditures.

Legal Fees and Permits

Unknown situations during implementation of a remedy may result in an increment of legal fees and permit application and approval costs. This condition may affect the project cost significantly.

Post-closure Activities

After implementation of a remedy, the post-closure monitoring may be scheduled and budgeted for several years. However, site cleanup probably will exceed the cleanup goals and, after consistent verification, the site may be determined clean and require no additional monitoring. This positive development may result in significant savings in present worth costs for post-closure monitoring and analysis.

STATISTICAL ANALYSIS

The sensitivity analysis methodology used in assessing the possible cost variations of remedial action alternatives uses the principles of the "Central Limit Theorem" to calculate the confidence limits that can be attributed to a range of probable project costs. The "Central Limit Theorem," first stated by Laplace in 1812[1], formulates that:

"For almost all populations the sampling distribution of the mean derived from the universe will be approximately normally distributed provided that the associated sample size is sufficiently large."[2]

In other terms, this theorem states that if a random sample of size n is drawn from a population with mean μ and variance σ^2, then as n increases, the distribution of $\frac{\bar{x} - \mu}{\sigma \cdot n}$ approaches the standard normal distribution. It has been demonstrated empirically[2] that a sample size with 30 or more observations will be "sufficiently large" to produce an approximately normally distributed sample mean.

Based on previous experience in performing sensitivity analyses of remedial action alternatives, it is estimated that the number of "what ifs" or uncertainties of different cost estimate components may generate combinations and permutations of possible project costs exceeding 30 or more probable cost products. Therefore, it is reasonable to presume that if the possible project costs may exceed 30 or more products, the analyst can evaluate the confidence level of the data using the normal distribution equations. The normal distribution formulas for unclassified (not grouped in cost class intervals) and classified data are presented below.

Normal distribution formulas for unclassified data

$$\bar{X} = X/n \tag{1}$$

and

$$s = \left[\frac{1}{n-1} \sum_{i=1}^{n} (X-\bar{X})^2\right]^{\frac{1}{2}} \tag{2}$$

where:

$\bar{X}$ = mean project cost or base cost
X = variable project cost obtained from one or more possible variations of cost components of the sampling population
n = number of possible project costs (30), and
s = standard deviation

Normal distribution formulas for classified data

If the data have been classified into k classes, then by definition:

$$Si \quad \left[\frac{1}{n-1}\left(\sum_{i=o}^{k} fi\, Xi^2 - \frac{1}{n}\left(\sum_{i=o}^{k} fi\, Xi\right)^2\right)\right]^{\frac{1}{2}} \tag{3}$$

where:

Si = standard deviation for the classified data
Xi = the midpoint (class mark) of the ith class
fi = the number of observations in the ith class
w = incremental value of the class interval
n = the normal number of observations

$$Xi = Xo + w\left(\frac{\sum_{i=o}^{k} (fi\, Xi)}{\sum_{i=o}^{k} fi}\right) \tag{4}$$

where:

Xi = the sample mean
Xo = value of the midpoint class mark at i = 0

Confidence Limits

The confidence limits of the confidence interval of unclassified or classified data evaluation are obtained as follows:

$$X_1 \leq \bar{X} \leq X_2 \quad \text{or} \quad X_1 \leq \bar{X}i \leq X_2 \tag{5}$$

where:

X and Xi are the unclassified and classified means, respectively, and s and si are the unclassified and classified standard deviation, respectively
X_1 = lower confidence interval = X − zs or $\bar{X}i$ − zsi
X_2 = upper confidence interval = X + zs or $\bar{X}i$ + zsi
z = one-half the area under the normal curve within a specified confidence interval

The value of z can be obtained from integration of the area under the normal curve or from normal curve areas tables available in most statistics books. Common z values used in the sensitivity analysis are shown in Table 1.

APPLICATION

As previously discussed, the purpose of the sensitivity analysis is to assess the effect of variations in specific assumptions associated with the cost estimates of remedial action alternatives. The sensitivity analysis is specifically concerned with those factors that could bring significant changes in the overall costs with only a small variation in value. In addition, factors with the most uncertain values are chosen for the analysis.

Table 1
Normal Curve Areas for Certain Confidence Intervals

Confidence Interval (%)	z
95	1.960
90	1.645
50	0.675
30	0.385

Taken from Wine[4]

An actual study of a hazardous waste site in Florida is used as an example to illustrate the application of sensitivity analysis methodology. This study involved a site located over a sole source drinking water aquifer. Heavy metals and PCBs were the basic contaminants. Possible remedial alternatives included solidification, solidification/stabilization, solidification/containment, partial off-site hauling/stabilization/solidification, extraction/solidification, extraction/containment and incineration/solidification. A sensitivity analysis example performed on the incineration/solidification alternative is presented in this paper.

The preferred remedial action identified in the feasibility study consists of incineration of about 2,400 yd^3 of soils with 50 ppm or higher of PCBs and solidification/stabilization of approximately 44,000 yd^3 of soils with PCB concentrations below 50 ppm and heavy metals. Cost estimates for this alternative include the following components.

- Mobilization and startup
- General site work
- Off-site hauling
- Contractor's labor, overhead and profit
- Equipment and materials
- Energy
- Monitoring and safety
- Legal, license and permits
- Engineering and administrative costs
- Post-closure costs (present worth)

Once the base costs are estimated for each component, the analyst evaluated the assumptions made to establish the base costs and asks "what if" the presumed cost estimating conditions

Table 2
Possible Sensitivity Factors for Remedial Action Alternative

Sensitivity Factor	Probable Cost, $1,000	Difference from Base $1,000	Justification for Cost
1. PROJECT SCHEDULE			
1.1 Early Finish			
• Site Work	821	-341	Unit cost of $9/$yd^3$ instead of $16.5 $/yd^3$
• Energy	12.2	-1.4	Facilities used less than estimated
• Labor	800	-500	Work done with 60 percent of estimate
• Equipment	1,100	-742	Less cost of rental equipment
• Engineering & Admin.	6% a	-4% a	No research needed; Pre-assembled equipment
• Monitoring & Safety	283	-67	Good post closure results
1.2 Late Finish			
• Energy	18	+4.4	Use 257,000 kwh @ $0.07
• Labor	1,396	+280	Labor hours increased by 20%
• Equipment	2,300	+458	Higher cost for use of incinerator
• Engineering & Admin.	17% a	+7% a	Extensive research and complicated design
• Monitoring	200	+22	20% more time at $1,000/week
• Permits and Legal	13	+3	Extension of temporary permit
2. SITE COMPLICATIONS			
• Site Work	2,000	+500	Site excavation cost of $21.50 $/$yd^3$
• Engineering & Admin.	17% a	+7% a	Redesign based on actual site conditions
• Monitoring	500	+150	Unexpected sources are discovered
• Labor	1,500	+200	Additional cost due to unexpected situations
3. RESEARCH & DEVELOPMENT			
• Engineering & Admin.	10% a	-0% a	No complications during design
• Engineering & Admin.	20% a	+10% a	Preferred alternative is not implementable
4. LEGAL FEES & PERMITS			
• Legal	5% a	-5% a	No need for litigation
• Permits and Legal	15% a	+5% a	Litigation and unexpected permits
5. POST CLOSURE			
• Monitoring	150	-108	5 years monitoring
	258	0	30 years monitoring
	458	+200	30 years with more intensive monitoring

a % of capital cost

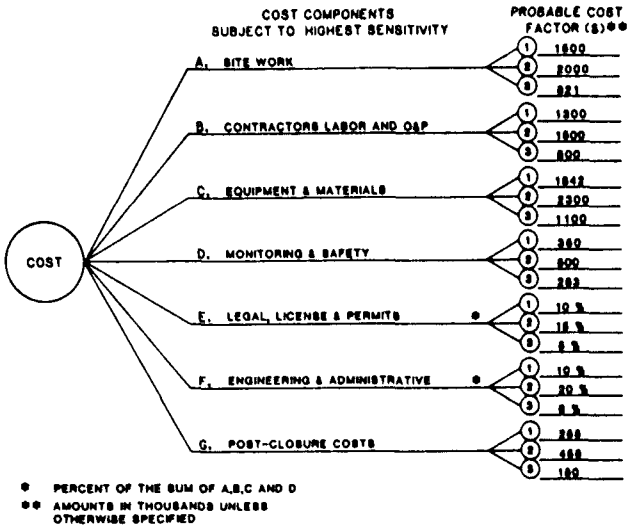

Figure 1
Cost Components Subject to Highest Sensitivity

change due to justifiable reasons. In addition, the lower and higher possible costs are established based on possible or expected conditions. Table 2 summarizes the possible sensitivity factors established for the case study analysis. These possible sensitivity factors are screened, and those that have the highest possibility of influencing significant cost changes are selected for the analysis (as shown in Fig. 1). In this particular case, it is determined that possible mobilization, off-site hauling and energy cost variations will not influence significant total project cost variations (less than 2% of the cost). The remaining cost components, judged to yield significant changes, are selected.

This arrangement can product 210 cost permutations [n!/(n-r)! or 7!/4!]. However, this analysis will generate many repeated combinations of cost products, and for practical purposes the overall normal distribution parameters may not have significant difference if a smaller sample size (larger than 30) is used. Therefore, the cost combination pattern shown in Table 3 was used in this case study. This pattern produced a sample size of 39 possible project costs summarized in Table 4.

These data are evaluated by either the classified or unclassified methods previously stated.

Table 4
Possible Project Costs for Remedial Action Alternatives

Costs in Thousand Dollars					
1.	6,515	14.	8,412	27.	4,486
2.	9,264	15.	9,064	28.	5,040
3.	3,748	16.	5,701	29.	5,595
4.	6,716	17.	5,101	30.	6,419
5.	7,238	18.	4,211	31.	6,660
6.	7,498	19.	4,129	32.	7,247
7.	7,701	20.	4,033	33.	8,068
8.	8,319	21.	3,904	34.	4,040
9.	8,589	22.	6,408	35.	4,105
10.	7,115	23.	6,199	36.	4,814
11.	7,356	24.	5,939	37.	5,107
12.	7,905	25.	5,864	38.	6,727
13.	7,433	26.	5,263	39.	7,672

RESULTS

The 39 possible cost products were classified in seven $1 million class intervals ranging from $3 to $9 million, as shown in Table 5, and the frequency histogram is presented in Figure 2. The calculated mean and standard deviations for the classified cost data are $6.37 million and $1.59 million, respectively. Likewise, the sample mean and standard deviations for the unclassified data are $6.30 million and $1.58 million, respectively. The results of the evaluation and pertinent statistical parameters are summarized in Table 6.

Table 5
Analysis of Classified Data

Class Interval	Class Midpoint	fi Frequency	Fractional Frequency	Cumulative Frequency	xi Deviation From the Origin	fi.xi	fi.xi
3,000-4,000	3,500	2	0.0513	0.0513	0	0	0
4,001-5,000	4,500	7	0.1795	0.2308	1	7	7
5,001-6,000	5,500	8	0.2051	0.4359	2	16	32
6,001-7,000	6,500	7	0.1795	0.6154	3	21	63
7,001-8,000	7,500	9	0.2308	0.8462	4	36	144
8,001-9,000	8,500	4	1.1026	0.9487	5	20	100
9,001-10,000	9,500	2	0.0513	1.0000	6	12	72
TOTAL	—	39	1		21	112	418

Table 3
Project Cost Combinations Used in the Analysis

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
A	1	2	3	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3
B	1	2	3	1	1	1	1	1	2	1	2	2	2	2	2	1	3	3	3	3	3	1	1	1	1	1	3	3	2	2	2	2	2	3	3	3	3	3	2
C	1	2	3	1	1	1	1	2	2	1	1	2	2	2	2	1	1	3	3	3	3	1	1	1	1	3	3	3	3	2	2	2	2	3	3	3	3	2	2
D	1	2	3	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1	3	3	3	1	1	1	3	3	3	3	3	3	2	2	2	3	3	3	2	2	2
E	1	2	3	1	1	2	2	2	2	1	1	1	1	2	2	1	1	1	1	3	3	1	1	3	3	3	3	3	3	3	3	2	2	3	3	2	2	2	2
F	1	2	3	1	2	2	2	2	2	1	1	1	1	1	2	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	2	3	2	2	2	2	2
G	1	2	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2

Note: Refer to Fig. 1 for actual values of A, B, C, D, E, F and G
Numbers 1 through 39 are probable project costs.

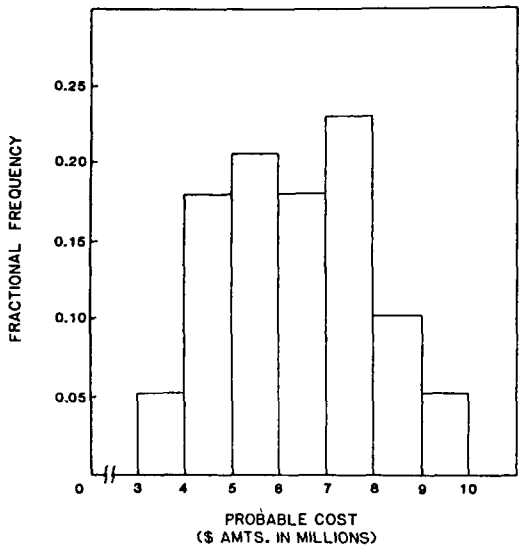

Figure 2
Histogram of Probable Project Costs

CONCLUSIONS

The alternative of incineration-solidification/stabilization of a hazardous waste site shows that there is a place in the decision-making process for sensitivity analysis of remedial action alternatives.

The economic impact of various cleanup methods can be compared in terms of levels of confidence of cost estimates using this methodology. By establishing possible variations of cost components for each alternative, the analyst can obtain a range of probable overall project costs. This range of project costs can be statistically analyzed to determine levels of confidence associated with each alternative. The end results show that the apparent lowest cost alternative may not necessarily be the one with the least economic risk.

Table 6
Summary of Results for Economic Sensitivity Analysis of Remedial Action Alternatives

Statistical Parameters	Values for Classified Data[a]	Values for Unclassified Data[a]
Mean	6.37	6.30
Standard Deviation	1.59	1.58
Coefficient of Variance[b]	0.25[c]	0.25[c]
Confidence Intervals		
-90%	3.74	3.70
+90%	9.00	8.90
-50%	5.30	5.23
+50%	7.45	7.37

a In millions of dollars unless specified otherwise.

b Coefficient of variance is defined as the ratio of the standard deviation(s) over the population mean (x).

c Unitless.

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Design of a Lateral and Vertical Expansion at an Existing Interim Status Landfill

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ABSTRACT

The Hazardous and Solid Waste Amendments of 1984 (HSWA) have resulted in changes to the U.S. EPA's existing hazardous waste management program. Final rules have impacted lateral and vertical expansions of existing interim status landfills. According to HSWA, the landfill expansion area must comply with minimum technological requirements of RCRA even if the facility no longer accepts or intends to accept hazardous waste. An exception to the minimum technological requirements would be possible if the expansion area were constructed and maintained as a separate and discrete unit. Within the framework of the new rules, proposed remedial work and horizontal and vertical expansion at an existing zone of saturation interim status landfill site have been complicated.

Control of seepage from in-place hazardous and solid waste utilizing a groundwater containment structure was mandated by the state regulatory agency (Wisconsin Department of Natural Resources) as part of the existing solid waste landfill permit. A program was developed and implemented to generate information regarding containment design criteria and to define the presence of leachate at the site perimeter as well as the off-site migration potential of the leachate. The recommended design also is impacted by the HSWA; the potential exists that the recommended containment structure meets minimum technological RCRA requirements.

The proposed vertical and horizontal expansion design options may have to be modified due to required separation of the existing hazardous waste unit from the proposed solid waste landfill unit unless costly minimum technology RCRA designs, such as double liner and separate leachate collection systems, are proposed. The design is further complicated by the lack of guidance from the U.S. EPA as to what is an acceptable design for separation of solid and hazardous waste units.

INTRODUCTION

The desire of the site operator was to obtain a preliminary indication from the state regulatory agency as to the potential suitability of a lateral and vertical expansion to this existing interim status landfill. The site operator desires an expansion that will maximize refuse volume while producing final grades which will conform with the intended final use. In addition, a condition of the existing landfill operation permit requires the construction of a groundwater containment structure along two sides of the existing site.

Recent state and federal statutes have impacted the design of landfill expansions by limiting or complicating design options. Presently, state statutes and guidelines are being revised.

According to the U.S. EPA[1], a lateral expansion to an existing interim status landfill must comply with the double liner and leachate collection requirements. However, this rule may only apply to sites that continue to receive hazardous wastes.

SITE HISTORY

The southwest portion of the existing landfill site (Fig. 1) was used as a municipal dump in the early 1970s. Foundry sand and municipal wastes fill this approximately 10-acre area. There are no documented base grades or leachate collection systems. According to a local contractor, a clay cutoff wall was constructed along the western edge of the site. However, based upon incomplete construction documentation, the cutoff wall apparently did not extend through a shallow sand seam.[2]

The facility commenced operations as a sanitary landfill in the mid-1970s. Four areas were filled in a sequential manner. However, corridor 3 was constructed between corridors 1 and 2 by excavating until the collapse of corridor 1 and 2 sidewalls precluded further digging. These three corridors were constructed without leachate collection systems and documented base grades. Corridor 4 was excavated to a greater depth than the earlier disposal areas. Documentation of ultimate base grades or liner construction was not performed. Installation of a partial leachate collection system was undertaken, but the system did not extend to the base of corridor 4, and construction of the system was only partially documented.[2]

Corridor 5 was overexcavated by 5 to 10 ft. This excavation resulted in backfilling the corridor with clay up to the approved base grade. Documentation of the recompacted clay base and the installation of the leachate collection system was performed.[2]

The area between the old municipal site and corridors 1 through 4 has been partially filled with primarily foundry waste. Again, the base grade was not documented nor was a leachate collection system installed.[2]

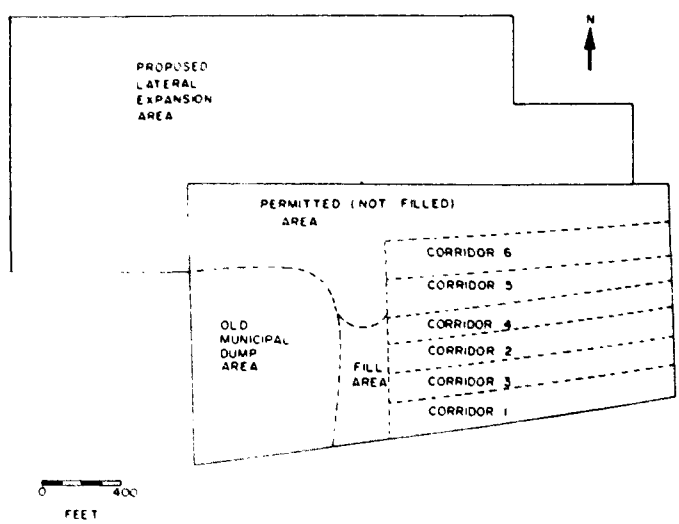

Figure 1
Plan View Map of Landfill

Presently, corridor 6 has been constructed with documented base grades, 5 ft of documented compacted clay liner and a leachate collection system. Approved for filling this corridor with solid waste has been received from the state regulatory agency.

The site operator was licensed by the Wisconsin Department of Natural Resources (DNR) to receive hazardous waste from 1975 through 1982. On Nov. 19, 1980, Part A of the RCRA hazardous waste facility permitting process was submitted to the U.S. EPA. As a result of submitting Part A and the Preliminary Notification on Aug. 18, 1980, the site received "Interim Status" and was allowed by the U.S. EPA to continue to accept hazardous wastes. Since Nov. 19, 1980, various types of hazardous wastes have been disposed with municipal solid waste in corridors 3 and 4. The hazardous wastes which have been approved for receipt and disposal under the federal Interim Status requirements include spent halogenated solvents, spent non-halogenated solvents and spent plating bath solutions and wastewater treatment plant sludges from electroplating operations.[3] Hazardous wastes have not been accepted at the site since Jan. 1, 1983.

SITE GEOLOGY

The positions of the various strata in the subsurface stratigraphy are illustrated in the generalized geologic cross-section in Figure 2. The strata are comprised of till and proglacial fluvial and lacustrine sediments of the Oak Creek Formation.[4]

The existing landfill and the proposed expansion area are located in front of and on the distal slope of the inner Lake Border moraine. The moraine represents a standstill position of the ice margin. During glaciation, drainage to the east was blocked by the ice and the north-south trending morainal deposits and produced glacial ponding. These sedimentary units are more likely to be continuous parallel to the former ice margin (north-south orientation) rather than in an east-west direction. The western part of the site area is dominated by lacustrine and fluvial sediments while glacial and ice-marginal deposits are more dominant in the eastern part of the site.[4]

Redisposition of till and sorted sediment by mass-flow processes is common in ice-marginal environments, and some of the sediments in the geologic section at the site probably resulted from mass-flow. Mass-flow at a ponded ice-margin would result in mass-flow deposits interbedded with fluvial or lacustrine sediment.[4] Because of the variety of processes involved in the deposition of sediments at the site area, the general geologic cross-section (Fig. 2) may not be indicative of true conditions (i.e., the layers are probably not as interconnected or laterally extensive).

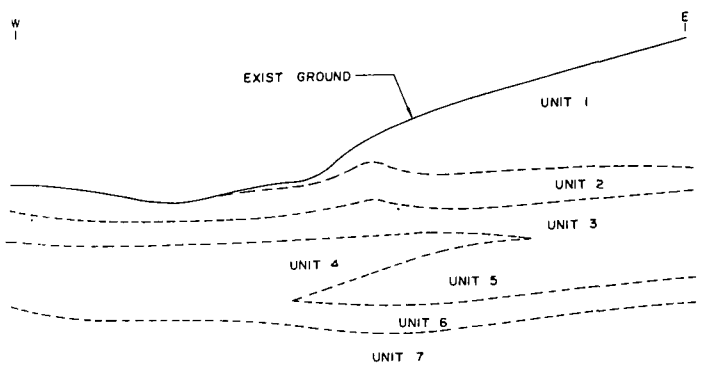

Figure 2
Typical Geologic Cross-Section of Landfill Area

The upper unit is composed of till. The lower units appear to consist primarily of proglacial fluvial and/or lacustrine materials with the exceptions of units 3 and 7, which may be in part till, and unit 5, which may be a mass-flow deposit.[4]

Based upon regional data and nearby water supply well records, the bedrock is at a depth of approximately 150 ft and is composed of Silurian dolomite at the bedrock surface.[4]

In summary, the soils beneath the site are layered and nonhomogeneous. The geologic environment is quite complex and needs to be defined in greater detail.

SITE HYDROGEOLOGY

The top of the zone of saturation (water table) exists generally between 3 and 10 ft below the ground surface. The general trend of groundwater flow is toward the west, although the water table has been distorted by excavation and filling within the existing site. The excavation within the present site has created a depression in the water table and an inward gradient toward the excavation. However, along the south side and southwest corner of the existing site, there is some question as to whether these inward gradients are being maintained due to possible leachate mounding within the filled areas.

The shallow groundwater aquifers do not appear to be interconnected. The hydraulic conductivity of the most shallow silt and sand zone (unit 2) has a horizontal permeability range of several orders of magnitude (10^{-3} to 10^{-6} cm/sec). The grain size, as measured by P2000 values, varies between 17 and 97%.[4] The fourth and sixth units also exhibit similar grain size and horizontal permeability variations.

CONTAINMENT STRUCTURE

As indicated previously in this paper, the NDR is requiring the landfill owner to design and construct a containment structure around the south and west sides of the existing landfill site. The purpose for requiring the containment structure is to ensure that inward groundwater gradients are maintained into the landfill site area. This design will be intended to prevent the outward migration of any contaminated water from the documented base areas of the site.

Three design options were developed for consideration by the landfill owner for construction of the containment structure. The first design option included the excavation of a trench to construct a soil/bentonite slurry wall. As part of the design of the slurry wall, the appropriate mixture of native soils and commercially available bentonite and the compatibility of the soil/bentonite slurry wall to leachate-contaminated groundwater would be determined. The leachate compatibility and soil/bentonite mixture specifications would be determined in a series of laboratory tests and also would be based on the experience of the geotechnical contractor in similar applications. This option would include, in addition to the soil/bentonite slurry wall, a second trench constructed on the landfill side of the slurry wall to contain a perforated groundwater collection pipe, which the state regulatory agency requires to be installed. A possible restriction with this design is the sidewall stability of a narrow trench excavated to a depth of approximately 45 ft. The possibility would exist for the collapse of sidewall soils into the trench because of high groundwater conditions and layers of sandy and silty soils. This option would require all pipe placement, bedding placement and backfill to be accomplished by the contractor from the ground surface.

The second design option recommended a partial excavation using scrapers along the slurry wall followed by construction of a soil/bentonite slurry wall and gravel filled trench similar to Option 1. The advantage of excavation along the containment struc-

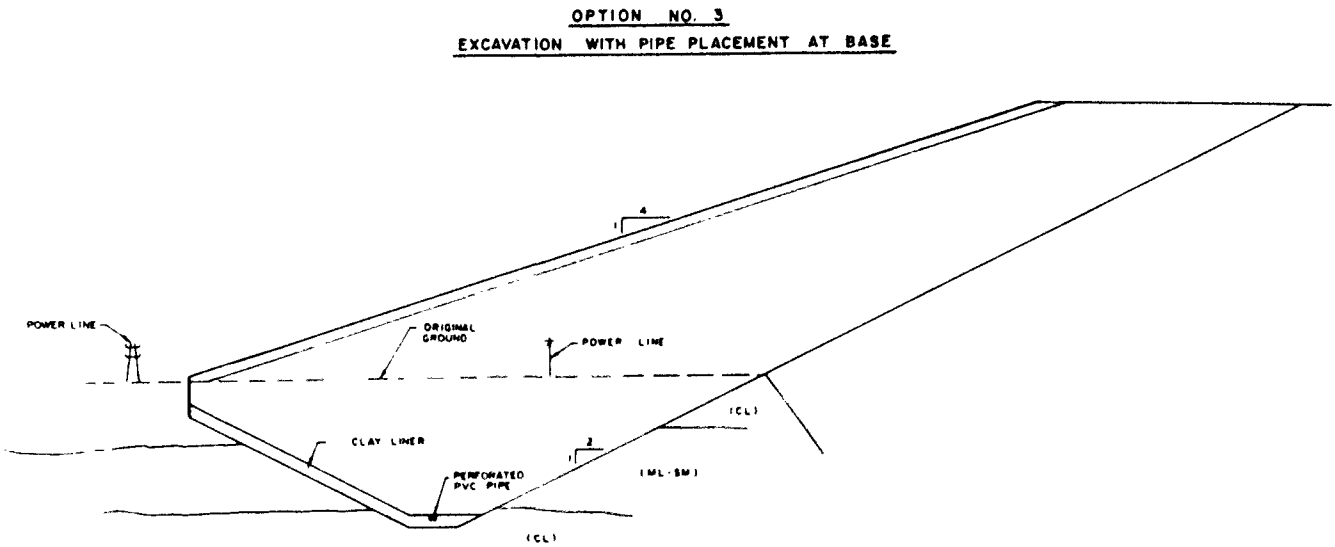

Figure 3
Design Option—Containment Structure

ture to provide a workable base area for the slurry wall and pipe trenching contractor would be to reduce the total depth of slurry wall and trench excavation required. This design concept would include the placement of a synthetic flexible membrane liner and/or clay liner along the outward slope of the scraper excavation to ensure that groundwater flow from the landfill would be intercepted by the containment structure and routed to the collection pipe. The remainder of the excavated area would be filled with earth material or with approved solid waste to the original ground surface.

The third design option includes scraper excavation along the containment structure extending to the design depth to install the perforated groundwater collection pipe. A cross-section view of this option is shown in Figure 3. The excavation would be an average of 45 ft deep over the 3700-ft long containment structure. Similar to option 2, a flexible synthetic liner or clay liner would be constructed along the outward slope of the excavation to provide a low permeability barrier to seepage from the landfill area. The landfill owner desires that the air space created by soil excavation along the containment structure be approved for filling with solid waste materials. In addition, solid wastes would be filled above existing ground surface over this area, which would result in a modified final grade for the landfill.

The design concept of a refuse filled containment structure would result in revenue to the landfill operator due to the increased waste disposal capacity provided by the containment structure and would modify the final side slopes on the south and west sides of the site from an approximate 2:1 slope to a final slope of 4:1. The landfill owner presently is under administrative orders by the DNR to modify the south and west slopes. Therefore, option 3 would provide a solution to issues associated with the present 2:1 slope along the borders of the site and would provide additional refuse fill capacity for the landfill owner. After evaluating the advantages and disadvantages of each option, the landfill owner has decided to prepare detailed plans and specifications for option 3 and to conduct the DNR relative to approval of this design concept for the containment structure.

The issue of minimum technical compliance with hazardous waste regulations for a vertical and horizontal landfill expansion also will be addressed relative to the proposed design of the containment structure. It is possible that the NDR may determine that the proposed containment structure constitutes a lateral expansion to a hazardous waste landfill. The NDR also may determine that previously filled hazardous waste areas, due to the nature of closure and lack of documented base areas or leachate collection systems, do not constitute a separate and discrete hazardous waste unit. If such a determination is made, it is possible that the landfill owner may be required to comply with the minimum technology standards for a hazardous waste landfill for the containment structure area. This decision would require that a double liner, equal to or equivalent with guidelines promulgated in the HSWA, be compiled with for the design of the containment structure. If this determination is made, approval for the containment structure design would have to be obtained from the hazardous waste section of DNR as well as the U.S. EPA. In addition, it is probably that the DNR will require the landfill owner to prepare the necessary feasibility reports, engineering plans and specifications for the landfill licensing process for the containment structure. In the State of Wisconsin, the landfill regulatory process can take from 3 to 5 years to complete. The landfill owner intends to prepare the necessary feasibility reports and engineering plans to fulfill state licensing requirements for an expansion to an existing landfill site.

SITE EXPANSION

Initial DNR reaction[3] to the lateral solid waste site expansion centered around the issue of separation of solid and hazardous waste units. According to the State of Wisconsin regulatory agency interpretation, the proposed lateral expansion (solid waste disposal) must be physically and hydraulically separated from the existing hazardous waste unit. Hydraulic separation is required due to the U.S. EPA mixture rule which specifies that all leachate from the existing site would be considered hazardous. Therefore, a separate leachate collection system is recommended by DNR for both the vertical and lateral expansion areas.

There are six corridors remaining to be constructed and filled in the existing landfill. A determination is needed as to whether or not these corridors are considered to be part of the hazardous waste unit under the HSWA. The remaining corridors have DNR solid waste approval but have not been reviewed by the hazardous

waste permit section. It was suggested by DNR that a clay wall of "scraper width" may be needed for physical separation of the solid and hazardous waste units. However, redesign of the remaining corridors within the existing permitted landfill area may be required by DNR.

A second possible alternative was suggested by DNR—delisting the site as a hazardous waste unit. This procedure would involve obtaining certification from the U.S. EPA that the hazardous wastes accepted at the site from 1975 through 1982 should not have been characterized as hazardous. Based on the waste types disposed at the site, it is unlikely that the recommended certification could be made.

Since the DNR is not fully authorized under RCRA, the U.S. EPA must determine what part(s) of the existing landfill is the hazardous waste unit and what engineering design options are recommended to satisfy the separate and discrete unit issue.

According to U.S. EPA guidance,[1,6] a new unit or lateral expansion of an existing unit operating under interim status may continue to receive non-hazardous wastes without complying with the minimum technological RCRA requirements. Apparently, the minimum technological RCRA requirements apply to those interim status landfills that receive hazardous wastes after May 8, 1986.[6] In regard to placing waste over a partially or finally capped hazardous waste unit without complying with minimum technological RCRA requirements, the guidance[6] suggests that if the new waste is effectively isolated from the waste within the capped unit, the new waste area will be considered as a new unit. In addition, the U.S. EPA is concerned with closure of hazardous waste units that no longer accept hazardous wastes. Solid waste disposal over such a closed unit would constitute a modification of the closure plan and would require U.S. EPA review and approval.

CONCLUSIONS

A solid waste landfill adjacent to and over an existing hazardous waste landfill can be engineered in an environmentally sound manner. A containment structure can be designed to provide environmental protection along an existing hazardous waste unit and also be a source of revenue to the landfill owner.

The U.S. EPA and NDR must determine the applicability of minimum technological RCRA requirements to solid waste landfill expansions at interim status landfill facilities. Until this determination is made, it will be difficult and perhaps costly to develop acceptable design concepts.

The containment structure design issue also is complicated by the recent HSWA due to possible limitations on design concepts.

Environmentally sound designs presently are available for landfill expansions and containment structures. However, compliance with the recent HSWA may be expensive.

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Cost Estimating for RCRA/CERCLA Remedial Actions

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ABSTRACT

Developing cost estimates for hazardous waste remedial actions is an integral part of the process of designing the remedial facility. This paper details the content of screening and feasibility cost estimates and their use in feasibility studies for remedial actions. Estimating terminology is defined, and key differences between "traditional" estimating and estimating hazardous waste projects are discussed.

INTRODUCTION

Estimates of the costs for remedial actions at hazardous waste sites are an essential, and often required, part of the feasibility study and the process of determining the most cost-effective method for site cleanup. During the feasibility process, technological and cost criteria are weighed and compared several times during the process of refining alternative remedial actions (Fig. 1).

Initially, comparative screening costs are generated to screen out disproportionately expensive alternatives. Subsequently, feasibility costs are developed and used in the selection of the most cost-effective alternative. The basic procedures for generating these two cost estimates are essentially identical, although greater accuracy is achieved for the feasibility costs through a more detailed evaluation of the alternatives and their related cost components.

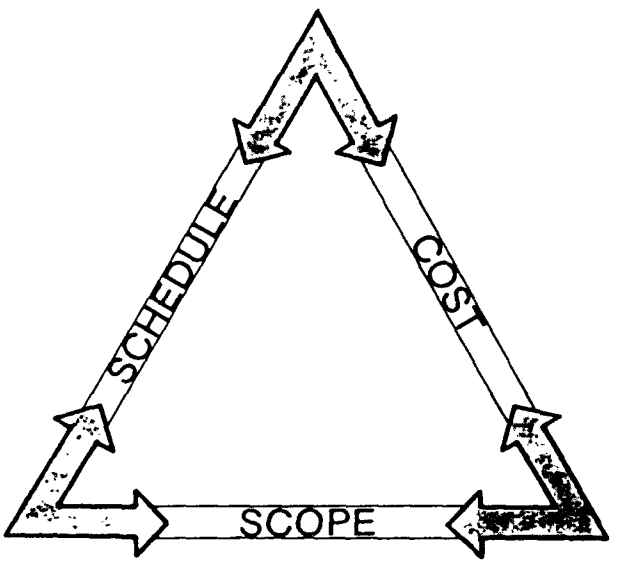

Figure 1
Project Interrelationships
This Figure Diagrams the Inseparability of Scope, Schedule, and Cost.

ESTIMATING DESIGN AND CONSTRUCTION COSTS

The American Association of Cost Engineers (AACE) lists three levels of cost estimating accuracy to reflect the increasing definition of a remedy at three points in a project. These three levels are: order of magnitude, budget and definitive. Feasibility studies are always order-of-magnitude estimates because of the limited scope of work available at this stage in the project. AACE defines order-of-magnitude estimates as approximate estimates made without detailed engineering data. Some examples would be: an estimate from cost capacity curves, an estimate using scaleup or down factors and an approximate ratio estimate. Order-of-magnitude estimates normally are accurate within plus 50% or minus 30%.

Estimating ranges are not meant to be absolute limits, but instead imply that there is a high probability that the final project costs will fall within a range. Contractors' bids often fall outside of these ranges, but cost estimates focus on predicting the selected low bid.

When using cost estimating terminology, it is important to discriminate between the terms "allowance" and "contingency." The AACE defines allowances as incremental resources included in estimates to cover known but as yet undefined requirements for individual accounts or subaccounts. An example of an allowance would be the inclusion of pipe supports and freeze protection for a 3-in. above-ground pipe, estimated at $15/ft. The pipe supports and freeze protection are neither designed nor quantified in the feasibility study; however, since good designers would include them in the completed design, an allowance of 70% could be included in the estimate for these items.

Contingencies are defined as specific provisions for unforeseeable elements of cost within the defined project scope; particularly important where previous experience has shown that unforeseeable events which will increase costs are likely to occur. If escalation is included in the contingency, it should be a separate item, determined to fit expected escalation conditions of the project.

HAZARDOUS WASTE ESTIMATING VS. TRADITIONAL ESTIMATING

A defined scope of work is the first requirement for developing a cost estimate in the traditional manner. However, at the feasibility stage, hazardous waste remedial actions do not have defined scopes and the site often is incompletely characterized.

The feasibility analysis consists of comparing a number of options. These options may reflect different assumptions about the characteristics of the site and a range of possible designs and project scopes. For example, suppose a hazardous liquid is leaching out of a municipal landfill. Remedial action options may include excavating a range of soil volumes for disposal at one of several licensed disposal sites; a range of groundwater pumping and treatment rates; and a range of on-site containment options. The geology, geohydrology and many other factors may be only partially explored.

There are two basic steps that can be taken to narrow this large range of unknowns: (1) collect more data or (2) rely on the use of good engineering judgment to make the necessary assumptions to help quantify each alternative. In hazardous waste remedial work, the collection of additional data can reduce the range of unknowns but never will replace the use of good engineering judgment in identifying a reasonable estimating scope. Since many of the elements of a remedial action involve subsurface conditions and/or new waste technology, a conservative viewpoint is essential for cost estimating.

Furthermore, projects involving hazardous waste have certain unique features that affect cost estimates. These may include:

- Reduced productivity due to personal protective gear
- Purchase and disposal cost of protective equipment
- Decontamination facilities
- Worker physical examinations and training
- Seasonal weather effects on construction costs
- Freeze protection for on-site facilities
- Nonconventional, multi-unit process treatment trains
- Extraordinary ancillary items
- High redundancy or conservative loads
- Disposal of treatment sludges and residues

It is very important that all parties understand the inherent uncertainty in feasibility cost estimates. The estimated costs should be used only in the light of the accuracy, context and scope under which they were prepared. It is therefore necessary that all the assumptions about the scope be documented. This documentation, or at least the summary of it, should be included in any report, along with cautions about the limitations associated with using any of the costs out of context.

FEASIBILITY STUDY COSTING

Feasibility studies make use of screening costs and the somewhat more accurate feasibility costs. Screening costs are used to compare alternatives in order to eliminate those with higher costs but no significantly greater environmental or public health benefits. Prior estimates, site cost experience and good engineering judgment are needed to identify those unique items in each alternative which will control these screening estimates. Items common to all alternatives do not warrant substantial effort at the screening stage.

For alternatives that survive screening, feasibility costs are developed. The feasibility cost estimates are more detailed than the screening cost estimates and include both capital and annual operating costs. The annual operating costs are viewed over a predicted life and converted to life-cycle costs. A sensitivity analysis also can be done on the key items in the alternatives. The latter steps are discussed later in this paper.

Capital and Annual Operating Costs

Capital costs include only those expenditures that are initially incurred to develop and install a remedial action and major capital expenditures anticipated in future years. Both direct and indirect costs are included.

Direct Capital Costs

The four types of direct capital costs discussed briefly below should be line items in the estimate. These four line items may include a number of other items, some of which are listed.

Construction costs cover equipment, labor and materials required to install a remedial action. They also include site modifications, process equipment, testing and monitoring equipment, health and safety monitoring and site closure costs. Construction costs available from nonhazardous waste sites should be used with care. Normally, considerable modification of any of these costs is necessary. Labor costs will include all fringe benefits, workman's compensation and contractor fees.

Land and site development expenses include easements, development of access roads, access control (e.g., gates, fences) and site preparation for equipment and buildings.

Buildings and services costs cover construction of temporary and permanent buildings and establishing utilities.

Construction of a hazardous waste remedial facility also may require relocating affected populations. This may involve temporary or permanent accommodations for nearby residents, moving allocations, temporary wage settlements and other associated costs, as necessary. Guidance for relocation costs is available from the Federal Emergency Management Administration (FEMA).

Indirect Capital Costs

Indirect capital costs consist of engineering, financial, supervision and other services necessary to carry out a remedial action. They are not incurred as part of actual remedial actions but are ancillary to direct or construction costs. Indirect capital costs include allowances for design and engineering and contingency.

All other costs, for example, monitoring and sampling, data collection, pilot testing, startup and shakedown, "debugging," operator training and initial field monitoring, should be listed separately in the estimate. For remedial actions involving an extended (more than 6 months) construction schedule, an adjustment can be made for interest and inflation during construction. The assumed schedule and cost index date should be stated.

Allowances and Contingencies for Capital Costs

Two categories of contingencies can be added to total capital costs for unforeseen circumstances which may result in additional costs. Bid contingencies cover unknown costs associated with constructing a given project scope such as adverse weather conditions, strikes by material suppliers, geotechnical unknowns and unfavorable market conditions for a particular project scope. Bid contingencies may vary between 10 and 20% and are applied against the construction subtotal for each alternative.

Scope contingencies cover scope changes that invariably occur during final design and implementation. They are intended to adjust the estimate so it can be used for budgetary purposes. Since the site characterization is often incomplete and volume estimates rudimentary, the scope contingency enables the use of engineering judgment to establish a reserve for project scope modifications. Scope contingencies will vary between alternatives. They may be 10 to 25% of the total capital costs for known technologies and sites with minimum elements of risk; they can be much more for state-of-the-art technologies at sites with higher elements of risk. Even on well-defined conventional projects, order-of-magnitude cost estimates tend to be 10 to 30% below the actual bid price. Below are some of the factors that determine the magnitude of the scope contingency:

- A reserve of 6 to 8% of the total construction cost is desirable for change orders.
- Scope changes during design and/or construction may be needed to meet performance-based criteria.

- Bidding competitiveness may be low; this, in turn, increases the bids.
- Vendors may provide over-optimistic performance data.
- Quantities may be inaccurately defined and listed.
- Performance histories for developing performance specifications may be lacking.
- Regulatory or policy changes may impact basic study assumptions.
- Different firms and agencies, with different operating procedures, can be involved from concept to cleanup.

Presentation of Total Capital Cost

Superfund site cleanup activities are classified by the U.S. EPA as either planning costs (remedial investigation, feasibility study and design) or implementation costs (construction, construction management and startup). Since funding for site cleanup can come from more than one source, it is important to format the presentation of the estimate to facilitate any cost sharing that may occur. For example, the cost estimate required for the Record of Decision and the fraction of the cost that the state shares, is a part of the implementation cost.

Capital cost estimates for feasibility studies should be structured as shown in Table 1, below. Note the compounding effect of the calculation. If all calculated costs shown were a percentage of Item A only, a lower total would be calculated.

Table 1
Format and Method for Calculating Total Capital Costs

Items	Name	Method of Calc.
A.	Construction Subtotal	From estimate details
B.	Bid Contingencies	% of Item A
C.	Scope Contingencies	% of Item A
D.	CONSTRUCTION TOTAL	Sum of Items A B & C
E.	Permitting and Legal	% of Item D
F.	Services During Construction	% of Item D
G.	Other Costs	Varies with estimate
H.	TOTAL IMPLEMENTATION COST	Sum of Items D E F & G
I.	Engineering Design Costs	Usually % of D
J.	TOTAL CAPITAL COST	Sum if Items H & I

Annual Costs

Annual operating costs for a remedial action include the operating and maintenance (O&M) costs incurred following its construction and/or installation, and, where applicable, annualized capital costs. Screening level annual costs may be obtained from such references as the *Compendium of Cost of Remedial Technologies at Hazardous Waste Sites*[1] or from prior estimates. For the detailed feasibility analysis, O&M cost estimates must be based on site-specific information. Equipment vendors, similar estimates or standard costing guidance references may be consulted. All estimates a year or more old should be updated with current labor rates and price quotes.

O&M Costs

The post-construction/installation activities necessary to provide continued effectiveness of a remedial action may involve the following cost components:

- Operating labor—all wages, salaries, overhead (which includes payroll taxes, salaries, etc.) and fringe benefits. Nonproductive labor for vacations, sick leave, holidays and H&S training sessions can consume 16 to 18% of the standard 2,080-hr work year.
- Maintenance materials and labor—the costs for labor, parts and other materials required to perform routine maintenance of facilities and equipment.
- Auxiliary materials and energy—such items as chemicals and electricity needed for plant operations, water and sewer service and fuel costs.
- Purchased services—such items as sampling costs, laboratory fees and other professional services for which the need can be predicted.
- Disposal—transportation and disposal of any waste materials, such as treatment plant residues, generated during the course of a remedial action.
- Administrative costs—all costs associated with administration of operation and maintenance not included under other categories such as labor overhead. This item can be 10 to 15% of the operating labor cost.
- Insurance, taxes and license—such items as: liability and sudden and accidental insurance; real estate taxes on purchased land or right-of-way; licensing fees for certain technologies; and permit renewal and reporting costs.
- Maintenance reserve and contingency costs—annual payments into escrow funds to cover anticipated replacement or rebuilding of equipment and any large unanticipated O&M costs, respectively.

Life-Cycle Costs

Present-worth analysis is a method of evaluating and comparing costs that occur during different time periods by discounting all future expenditures (i.e., replacement of worn parts) to a common base year. The result is the total cost, in today's dollars, of the remedial action alternative. The U.S. EPA has indicated that the current Office of Management and Budget (OMB) guidance should be followed for calculating life cycle costs. Many engineers are familiar with life-cycle cost calculations, or a firm may employ economists or statisticians to help with these calculations.

Sensitivity Analysis

Errors in estimating key variables may have a large effect on the accuracy of the overall cost estimate. A sensitivity analysis can assess the effect on the cost of varying specific assumptions associated with economic conditions or with the design, implementation, operation and effective life of the remedial action strategy.

Through good engineering judgment, one should be able to identify those items that could bring about a significant change in overall costs with only a small change in the value of the item. Results of the analysis can be used to identify "worst case" scenarios and to revise estimates of contingency or reserve funds.

In addition, sensitivity analysis can be used to optimize the final design of a remedial action alternative. This analysis is particularly useful where design parameters are interdependent, such as for treatment plant capacity versus time for treating contaminated groundwater.

The following factors are primary candidates for consideration in conducting sensitivity analyses:

- The effective life of the remedial action. In estimating replacement costs, use base period dollars; do not adjust for inflation.
- How clean is clean? The public health assessment normally provides a range of cleanup criteria dependent on variation between the different health standards and cancer risks. There often can be a 10- or 100-fold difference between alternate criteria.
- O&M costs
- Duration of cleanup activities
- Availability of off-site treatment, storage and disposal facilities

- Uncertainty regarding site conditions. This item includes the volume to be treated, materials present and treatment used.

CONCLUSIONS

If there is one message to be gained from this paper, it is that in the development of remedial actions for hazardous waste contamination, perhaps more than for any other type of engineering, cost and scope (and, of course, schedule) are interdependent and inseparable. This paper outlines some procedures for developing feasibility costs, including discussions of line items peculiar to hazardous waste work.

Estimating costs for hazardous waste facilities has many intrinsic risks. The authors' experience in defusing some of these risks has been included where possible. However, in the space permitted here, there is no way to cover all of the problems the cost engineer may encounter in estimating hazardous waste remedial action designs.

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A Modular Computerized Cost Model for Remedial Technologies at Superfund Sites

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ABSTRACT

The purpose of the research reported in this paper was to develop prototype cost estimation models for response technologies at uncontrolled hazardous waste sites. This research was conducted for the U.S. EPA, Hazardous Waste Engineering Research Laboratory in cooperation with the Office of Emergency and Remedial Response.

The model is designed for operation on a personal computer and can provide levels of detail in the estimate as a function of input parameters available. The cost estimation model takes into account site, waste, workers safety and regional variations. Output formats and types of cost calculations are consistent with the U.S. EPA Remedial Action Costing Procedures Manual. Default values for interest rates, discount rates, planned life, contingency allowances, etc., are consistent with the costing procedures manual.

The model can be used by U.S. EPA Headquarters and Regional Staff, State personnel and contractors (REM/FIT Contractors, cleanup contractors, etc.) for quick, easy and effective calculations of costs for evaluating and comparing a variety of different remedial measures.

INTRODUCTION

Computerized cost estimating models are finding widespread use in the building and construction fields because of the advantages of uniform procedures and access to cost data bases they provide. The U.S. Army Corps of Engineers has perhaps the best established program, i.e., the Computer Assisted Cost Estimating system (CACES). The Corps requires that this program be used by architects and engineers to generate cost estimates on Corps projects. Other government entities (U.S. DOE, VA, Air Force, Navy, etc.) and private firms have computerized systems and data bases for various applications.

Remedial action technologies at Superfund sites employ many conventional civil engineering elements with well-documented costs as well as completely new technologies for which little or no cost data exist. Both construction and chemical process components are involved in cleanup technologies. This is a unique requirement not encountered in other computerized models.

With the huge backlog of Superfund site work and the complexity of cleanup technology, it was apparent that some form of computer-assisted estimating was needed by the U.S. EPA for use by both contractors and Agency personnel.

The Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory contracted with PEI to develop such a system. The project is being done in phases. This paper presents the results of Phase I; the development of the overall design and objectives of the computerized system and development of several cost modules. Work is currently underway to expand the cost data base and algorithms. The system is designed to be flexible and dynamic; it is anticipated that new data continually will be used to update the cost data base.

The system is designed to operate as an interaction program on an IBM PC/XT or AT. The intended users include:

- U.S. EPA research personnel
- U.S. EPA policy analysts
- Superfund Regional Office personnel
- Superfund contractors
- U.S. EPA enforcement personnel

The system is intended to be used to:

- Develop scoping costs for budget planning
- Calculate specific remedial site costs
- Check estimates performed by others
- Compare alternative technologies
- Evaluate costs proposed by potentially responsible parties
- Perform value engineering analysis

Costs can be calculated as specific estimates or include probability ranges based on uncertainty input by the user. Net present worth analysis also is included in the program.

The advantages of the system include:

- Detailed, documented cost elements consistent with the National Contingency Plan (NCP) and EPA Cost Guidelines
- Uniform and consistent format for costs
- Rapid calculation of cost and accommodation of changes in specifications
- Ability to consider uncertainty in estimates
- Ability to compare alternatives for a given site

PROGRAM STRUCTURE AND OPERATION

The program is structured to a level of detail based on the data available prior to detailed design specifications and drawings by a contractor. Generally, a line item approach is used for output specifying line item detail for those users interested in the detail level.

The program is designed to be flexible. Some of the flexibility features include:

- Ability to include specific values for input parameters or use default values in the data base
- Ability to add write-ins for unusual items
- Ability to use adjustment factors for such things as inflation, geographic location, job difficulty, labor productivity due to health and safety requirements, geological effects, etc.

- Ability to have various levels of printouts with more or less detail
- Ability to override individual computed items of cost
- Ability to store partial or complete runs for recall and modification at a later date

The system is designed to separate the data base from the calculation requirements as much as possible. The data base includes room for expansion and the ability to add or update data items without affecting the program. This enables expansion and updating by personnel who are only casually familiar with computers.

The costing system requires the user to understand the technologies being used because relatively detailed design input data are required. Unlike some other approaches, this system does not rely on historical costs of previous remedial actions. Rather, the remedial technologies are broken down to levels of detail which can be costed based on sound engineering cost data.

The program is designed to be transportable and operate on an IBM PC/XT or AT or equivalent with at least 5 Mb of available hard disk storage capacity and 256K RAM. The operating system is MS DOS 2.0 or higher. The program is written in Microsoft FORTRAN. LOTUS 1-2-3 spreadsheet software is an option to enable users to change values on intermediate output. The data base is structured using dBASE III.

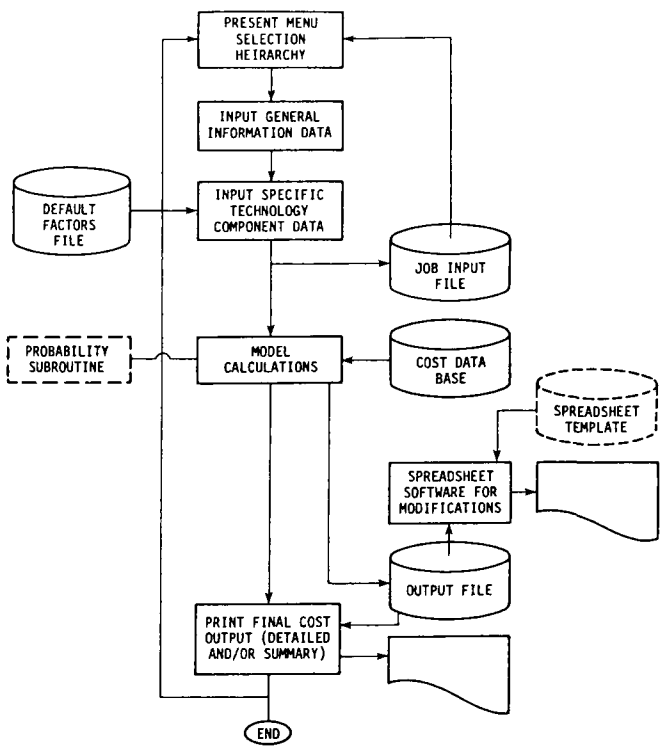


Figure 1
Overall System Flow Diagram for the Computerized Cost Model

Overall system structure and flow are shown in Figure 1. The program is designed around a series of menus used to select specific technologies and components. The general program control menu is shown in Figure 2. The user is guided through the menus in a logical fashion; experienced users can access a specific component directly without stepping through the menu hierarchy by entering the component I.D. Once at a component level, the user enters the design parameters which determine the cost of each subassembly.

```
Current Data File in use : NO FILE IN USE
-------------------------------------------------------------

                        Main Menu

-------------------------------------------------------------

     1) Begin a New Data File
     2) Edit Current Data File
     3) Save Current Data File to Disk for Future Use
     4) Load in Previously Saved Data File from Disk
     5) Calculate Costs from Current Data File and
        Print Report
     6) Exit Program

Enter your selection (1-6)
```

Figure 2
General Program Control Menu

Two general input screens are used to enter information such as date of run, title and various cost adjustment factors. Figures 3a and 3b are example general input screens.

The unit cost data base contains the unit costs or cost equation coefficients for each line item. The data base consists of two files: one for linear cost relationships (i.e., line item extensions) and one for exponential cost relationships (i.e., cost estimating relationships for process equipment). Many conventional construction line item costs are excerpted from references 1 and 2. The default factors file contains default values for items such as interest rate, contractor overhead, etc. If values are not specified for these parameters by the user, the default factors are used.

A job input file contains the input data for a past run and enables the user to recall and adjust past runs without reentering all the data.

```
                    |=================================|
                    |REMEDIAL  RESPONSE  CONSTRUCTION |
                    |   COST  ESTIMATING  SYSTEM      |
                    |=================================|
 DATE-------------)12-17-85(--|   ANALYSIS NO.-----)12-333  (--|

 ESTIMATOR--------)JOHN DOE            (--|

 SITE NAME--------)GENERIC SITE ONE                          (--|

 SITE LOCATION----)ANYWHERE, USA                  (--|
                  --)                             (--|
 ZIPCODE----------)12345(--|

 CONTRACT NO.-----)12-0356KDFA-45NMK4  (--|

 CONTRACTOR-------)ACME COMPANY                   (--|

 COMMENTS/SCOPE OF WORK :
)EXAMPLE OF SUBSURFACE DRAIN MODULE CALCULATION FOR A        (--|
)HYPOTHETICAL SITE.                                          (--|
)                                                            (--|

 IS THE INFORMATION CORRECT ? (Y/N)   Y
```

Figure 3a
General Input Screen

```
                    GENERAL  PROJECT  COST DATA

 GENERAL CONDITIONS     .0%                      GENERAL CONTRACTOR:
GEOGRAPHIC LOCATION FACTOR :                      OVERHEAD   10.0 %
 LABOR & EQUIPMENT   10.0 %                       PROFIT     10.0 %
 MATERIAL             5.0 %                       E,D & I    15.0 %
ESCALATION :                                  PERMIT/LICENSE FEE   1.0  %
  LABOR               .0 %                       BOND       1.0 %
  EQUIPMENT          5.0 %                       INSURANCE  5.0 %
  MATERIAL           3.0 %            ADDITIONAL LAND COST $      25000
SALES TAX            5.0  %

          ARE THESE CORRECT ? (Y/N)   Y
```

Figure 3 b
General Project Cost Data Screen

```
Current Data File in use : FILE3.BIN
-------------------------------------------------------------

                    Major Program Subdivisions          0

Technology                                          Modules
Level              Technology Categories            Chosen
-------------------------------------------------------------

1.0.0.0.0   Control Technologies                        0
2.0.0.0.0   Treatment Technologies                      0
3.0.0.0.0   Excavation                                  0
4.0.0.0.0   Transportation (Off Site),                  0
5.0.0.0.0   Disposal                                    0
6.0.0.0.0   Alternative Water Supplies                  0
7.0.0.0.0   Relocation                                  0
8.0.0.0.0   General Site Work                           0
9.0.0.0.0   Building/Structure Decontamination          0

Enter --> 99 to return to the Main Menu

Input a Technology Level 1
```

Figure 4
Major Program Subdivision

The technology-specific data entry is based on the "menu" approach because this is a proven approach which works well from a programming and organization standpoint and has found wide acceptance by noncomputer-oriented personnel.

The hierarchy of menus is organized by a numbering system and proceeds from broad categories of technologies to greater levels of detail in specification of individual components. Once the finest level of detail menu is reached, the user is prompted for the specific design parameters required to estimate the cost of that component. Following the design data, general cost information is required from the user such as contingency, subcontractor overhead and profit and adjustment factors. Defaults are provided wherever feasible.

The menu hierarchy is summarized below:

X.	Major Program subdivisions
X.X.	Technology categories
X.X.X.	Specific technologies
X.X.X.X.	Technology subcategories
Data input within X.X.X.X.	Subcategory modules and subassemblies

Figure 4 describes the major program subdivisions and is the highest level of the menu hierarchy. Figures 5 and 6 are examples of menus progressing through finer levels of detail for technology selection.

```
Current Data File in use : FILE3.BIN
-------------------------------------------------------------

1.0.0.0.0   Control Technologies                        0

Technology                                          Modules
Level              Technology Categories            Chosen
-------------------------------------------------------------

1.1.0.0.0   Air Emissions Controls                      0
1.2.0.0.0   Surface Water Controls                      0
1.3.0.0.0   Ground Water Controls                       0
1.4.0.0.0   Contaminated Water and Sewer Lines          0

Enter --) 0.  to return to the Main Technology Menu.
Enter --) 99  to return to the Main Menu

Input a Technology Level .3
```

Figure 5
Technology Category Menu

```
Current Data File in use : FILE3.BIN
-------------------------------------------------------------

1.3.4.0.0   Leachate Control                           0

Technology                                          Modules
Level              Technology Categories            Chosen
-------------------------------------------------------------

1.3.4.1.0   Subsurface Drains (T)                       0
1.3.4.2.0   Drainage Ditches (T)                       0
1.3.4.3.0   Liners (T)                                 0

Enter --) 0.  to return to the Main Technology Menu.
Enter --) 99  to return to the Main Menu

Input a Technology Level .1
```

Figure 6
Detail Technology Category Menu

```
1.3.4.1.0    Subsurface Drains (T)
   1         MODULE NUMBER 1

1            Drain Pipe size & material

                              Material
                              --------
| Size  | Asbestos | Porous   | Vitrified | PVC |
|       | Cement   | Concrete | Clay      |     |
|-------+----------+----------+-----------+-----|
|  4 in |    1     |    6     |    11     |  16 |
|  6 in |    2     |    7     |    12     |  17 |
|  8 in |    3     |    8     |    13     |  18 |
| 10 in |    4     |    -     |    14     |  19 |
| 12 in |    5     |    9     |    15     |  20 |
| 18 in |    -     |   10     |    --     |  -- |

Enter Drain Pipe choice (1-20)? 14

Is this screen O.K. (Y/N)?  Y
```

Figure 7a
Input Data Screen

```
1.3.4.1.0    Subsurface Drains (T)
   1         MODULE NUMBER 1

2        Non-perforated Pipe size & material

                              Material
                              --------
| Size  | Asbestos | Porous   | Vitrified | PVC |
|       | Cement   | Concrete | Clay      |     |
|-------+----------+----------+-----------+-----|
|  4 in |    --    |    --    |    30     |  36 |
|  6 in |    21    |    25    |    31     |  37 |
|  8 in |    22    |    26    |    32     |  38 |
| 10 in |    23    |    27    |    33     |  39 |
| 12 in |    24    |    28    |    34     |  40 |
| 18 in |    --    |    29    |    35     |  -- |

Enter Non-perforated Pipe choice (21-40)? 33

Is this screen O.K. (Y/N)? Y
```

Figure 7b
Input Data Screen

Items marked with "(T)" (for technology component) are at the lowest level of the menu hierarchy. Selection of one of these leads to a data input screen for user input of design parameters for that technology component. Menu selection can be bypassed

at any level by the experienced user selecting the specific menu I.D. number; e.g., 1.3.4.1 will take the user directly to the input screen for that particular subcategory component. Numerical design data are not required until the user reaches the technology level. At this point, the specific input varies depending on the component as illustrated in Figures 7a through 7f.

```
 1.3.4.1.0    Subsurface Drains (T)
    1         MODULE NUMBER 1

3
                        Pipe & Trench depth

   1)  3 feet    3)  6 feet    5) 10 feet    7) 14 feet    9) 18 feet
   2)  5 feet    4)  8 feet    6) 12 feet    8) 16 feet   10) 20 feet

                Enter Pipe & Trench choice (1-10)?  7

4     Total length of drainage pipe trench, (feet)    214.00

5     Total length of Non-perforated pipe trenching, (feet)    900.00

6     Manholes or Junction boxes :  Number required?   3
                                 :  Interior coating required (Y/N)? Y

7     Wet Wells :  Number required?   4
                :  Interior coating required (Y/N)? N

                    Is this screen O.K. (Y/N)? Y
```

Figure 7c
Input Data Screen

```
 1.3.4.1.0    Subsurface Drains (T)
    1         MODULE NUMBER 1

8
                          Wet Well Pump(s)

   Pump Capacity, Gallons/Minute        |  25 |  50 | 100 | 200
   -------------------------------------+-----+-----+-----+-----
   Number of Pumps required             |   0 |   0 |   5 |   0
   -------------------------------------+-----+-----+-----+-----
   Stainless/Lined Pump necessary (Y/N) |  N  |  N  |  Y  |  N


9                 Leachate Holding Tank Capacity

      Tank Capacity, Gallons   | 1000 | 2000 | 10000 | 20000
      -------------------------+------+------+-------+-------
      Number of Tanks required |   0  |   0  |   0   |   2

                Is this screen O.K. (Y/N)? Y
```

Figure 7d
Input Data Screen

```
 1.3.4.1.0    Subsurface Drains (T)
    1         MODULE NUMBER 1

10              100 Gallon/Minute Capacity Pumps

            Distance from pump to leachate holding tank

           Pump # 1   500.00
           Pump # 2   700.00
           Pump # 3   400.00
           Pump # 4  1200.00
           Pump # 5  1400.00

                Is this screen O.K. (Y/N)? Y
```

Figure 7e
Input Data Screen

Table 1 is an example of the input (or cost factor) components for several example modules. Each component and subassembly shown in Table 1 and included in the cost file is referenced to a component "fact sheet" which documents the battery limits of that component, the design, cost data sources and all items included in the cost. An example fact sheet for 1.1.1-Pipe Vents is shown in Figure 8. The numerical data values used in this paper are for illustrative purposes only and are not necessarily final or accurate.

There are two levels of output: a detailed output by technology component and subassembly, and a summary output for the entire site scenario. The detailed output format for capital costs is illustrated by an example shown in Figure 9. This is an example for the subsurface drains module only and does not represent a complete remedial scenario. Using the spreadsheet software, the user will be able to change any output value. A Lotus 1-2-3 template is provided to do all necessary extensions. All output is designed to fit on 8.5-in. x 11-in. paper.

```
                REMEDIAL RESPONSE CONSTRUCTION
                  COST ESTIMATING SYSTEM

| 1.3.4.1.0    Subsurface Drains (T)                          |
|                                                             |
|              MODULE NUMBER 1                                |

                          COST DATA

 SUBCONTRACTOR:                        HEALTH & SAFETY FACTOR  55.00%
   OVERHEAD   14.00%                   GEOLOGY FACTOR          22.50%
   PROFIT      7.50%                   DECONTAMINATION FACTOR   5.00%
                                       CONTINGENCY             18.25%
 GENERAL CONTRACTOR MARKUP             START-UP                  .00%
  ON SUBCONTRACTED WORK:               NET PRESENT WORTH:
   OVERHEAD    4.00%                     INSTALLATION PERIOD(X)   1  YRS
   PROFIT      5.50%                     OPERATING LIFETIME(X)   20  YRS
                                         DISCOUNT RATE(X)        10.00%

                ARE THE VALUES CORRECT? (Y/N) Y
```

Figure 7f
Input Data Screen

The job input file contains all user input data. The cost data base and default factors files are created and maintained using dBASE III but are used by the program as ASCII files. Figure 10 contains an example record from the unit cost data base file.

Calculation of Capital Costs

Capital costs are calculated as the sum of labor, material and equipment costs. These are defined as follows:

Labor	Labor to install components at the site. Off-site labor involved in fabricating delivery material is included in the material cost.
Material	Material such as piping, concrete, etc., used to build a technology, and preconstructed items such as incinerators, clarifiers, etc. (Note the latter are usually referred to as "equipment" in typical process cost engineering).
Equipment	Construction equipment cost, typically rental of bulldozers, cranes, etc.

The general cost equation

$$y = (ax^b + c)d \quad (1)$$

where a, b, c are coefficients and d is the number of items, is used to calculate the component costs. This form of the equation can be used to represent many cost characteristics. For example, a simple line item cost such as 100 ft of 4-in. PVC pipe at $4.50/ft can be represented as $y = [4.50(1)^1 + 0](100)$. A more complex CER such as for a liquid injection incinerator with 50×10^6 Btu/hr capacity may be represented as $y = [1.6(50 \times 10^6)^{0.55}](1)$ where the coefficients 1.6 and 0.55 have been determined from a least squares fit of cost data.

For most components, additional calculations are required in the program to convert user-specified parameters into component cost drivers. For example, in excavation components, the cost driver is cubic yards. While some users could input this directly if known, it is easier to enter dimensions so the program can calculate volume.

Calculation of Operating and Maintenance Costs

Operating and maintenance costs include those costs required to operate and maintain the system after the initial installation is complete. The user specifies the time period over which O&M

Table 1
Cost Input Data Requirements by Subcategory Component and Subassembly

I.D.	Component	Subassembly	Data requirements 1	2	3	4	5	HF	GF	DF
1.1.1	Pipe vents	Backfill	Diameter (feet)	Depth (feet)			Number	X	X	
		Piping and laterals (includes elbows and tees)	Diameter (inches)	Depth (feet)	Cap type * Mushroom * U-top (not applic. if laterals are used)	Lat. length	Number	X		
		* PVC * Asbestos bonded * ABS * Galvanized iron * Other								
		Exhaust system (includes flow meters and butterfly valves)	Flow rate (scfm)	Pressure drop (8 in. used if not specified)			Number	X		
1.1.2	Trench vents	Excavation, backfill, spreading, sheet piling, worker connections and struts	Depth (feet)	Length (feet)	Width (feet)			X	X	
		Piping and laterals (includes elbows and tees)	Diameter (inches)	Length (feet)	Cap type * Mushrooms * U-top (not applic. if laterals are used)	Lat. length (feet)	Number	X		
		* PVC * Asbestos bonded * ABS * Galvanized iron * Corrugated polyethylene * (uses PVC risers)								
		Exhaust system (includes flow meters and butterfly valves)	Flow rate (scfm)	Pressure drop (8 in. used if not specified)				X		
		Liner	Thickness (mils)	(square feet of liner calculated from excavation sub-assembly data input)				X		
		* Hypalon * 4 in. gunite and mesh * Other								
		Cap	(Square feet of cap area calculated from excavation sub-assembly data input)					X		
		* 6 in. clay * Other								

Note: HF, GF, DF denote whether the adjustment factors are applied to this cost element; HF is health and safety factor, GF is geology factor, and DF is decontamination factor

costs are to be incurred. Uniform annual costs are assumed; i.e., no inflation and no increase due to deterioration of equipment. The expected useful life of equipment is included in the data base and printed out with the capital cost calculation. Salvage value is not considered in the net present worth calculation.

O&M costs include labor, electricity, service water, fuel, chemicals, maintenance materials, water treatment, area maintenance and similar items. Unit prices for these items are maintained in the default rates file which the user can update for each run if desired:

Net present worth is calculated from the formula:

$$NPW \quad \sum_{t=1}^{n} X_t/(1+i)^t \qquad (2)$$

where NPW = net present worth in dollars

X_t = expenditures in year t
i = discount rate (10% or entered by user)
t = year

Costs are not inflated beyond the base year.

For capital costs, the cost data base file is used to provide installation time. The longest duration item is used as total installation time. Alternatively, the user can input an installation time, in which case the total cost is equally divided by year. For O&M costs, the user provides the number of years the site is to be maintained.

ADJUSTMENT FACTORS

General Conditions Factor

This factor is used to adjust costs to account for qualitative factors related to job difficulty. This factor allows a user to account for such things as unusual or difficult site conditions, weather, local labor conditions, local economy, contractor competitiveness and other factors that cannot otherwise be accounted for quantitatively. The factor ranges from zero (no adjustment) to any percentage value the user thinks is reasonable. For example, a value of 10% will increase the cost by 1.1. The factor is applied to labor, material and equipment.

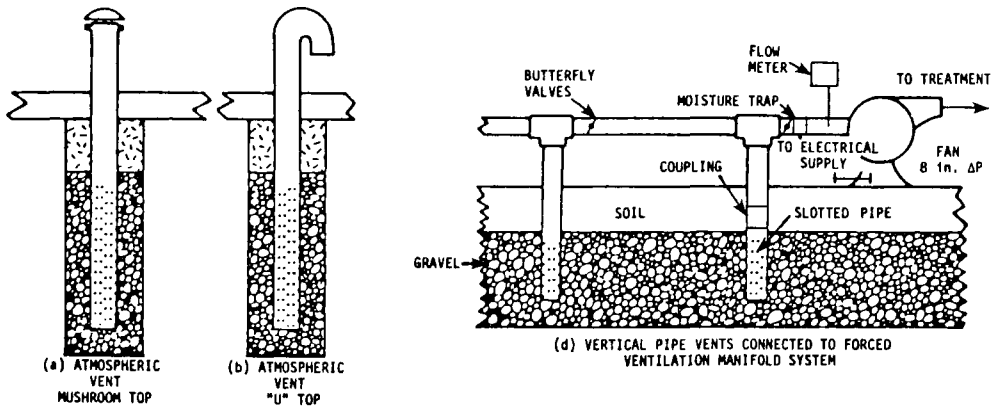
Geographic Location Factor

The geographic location of the Superfund site where the technology is to be implemented is another important consideration. Construction costs, material and labor vary by regions of the country. The variation can be significant, as much as 30% above or below an average national cost for the same category of items. Values for these geographic factors are available in various cost estimating publications such as R.S. Means and Dodge. The user can provide whatever adjustment is considered appropriate by entering a percentage to directly adjust costs upward or downward. If no factor is provided, costs are based on national average.

COMPONENT FACT SHEET

I.D.: 1.1.1 Title: Pipe vents

Subassemblies:
1 - Excavation
2 - Piping and materials
3 - Exhaust system



Exhaust System Subassembly Line items

Fan: Belt-driven, utility mount, weather cover, corrosion-resistant coating mounted on foundation/ready to connect to on-site electrical supply HP = 0.0001575 (ΔP)(SCFM)
Flow meter: Mounted on steel frame
Moisture trap: Trap and drain connection
Butterfly valves:

Piping and Laterals Subassembly Line Items

Slotted pipe
Coupling
Solid pipe (lateral piping diam. = riser diam. + 2 in.), 100 ft lateral added to user input from fan to treatment
Caps (mushroom or U-top), or tees

Excavation Subassembly Line Items

Excavate holes or trench
Spread burden
Backfill with gravel (nut size)
Cover with 6 in. dirt

Source: SCS, 1981 (Ref. 3), Modified by PEI for detail.

Figure 8
Pipe Vent Fact Sheet

Health and Safety Factor

This factor is applied to labor and equipment and represents increased costs because of decreased productivity due to personnel protection requirements in Superfund work as compared with conventional construction.

Worker health and safety considerations or precautions can significantly impact worker productivity and thus costs for some technologies at some remedial action sites. The impacts are expected to be more significant for control technologies than for treatment technologies. A literature review has revealed only one source of information that directly addresses the issue.[3]

The reported range of adjustments is extremely broad. For one technology, the reported percentage adjustment ranged from 58 to 1990%.

The user enters an adjustment percentage to increase labor and equipment costs based on judgment.

Users of the model will have to be somewhat familiar with the nature of the waste at the site to be remediated and with the defined levels of personnel protection. Four levels of protection are defined. Suggested values are as follows:

Personnel protection level	Adjustment factor
D	1.0
C	1.1
B	1.3
A	1.5

- Level A—Requires full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).
- 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).
- 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.
- Level D—No identified hazard present, but conditions are monitored and minimal safety equipment is available.

Geology Factor

This factor is applied to selected components (equipment and labor) which are affected by a site's geology. Example components affected are pipe vents, wells, trenches, etc. Base costs are calculated for "typical" geology. This is defined as unconsolidated silty sand with a water table 10 to 100 ft deep. The geology factor is a direct multiplier of the affected components; i.e., an input of 10% will increase costs by 1.1.

Decontamination Factor

This factor is applied to equipment and labor and represents increased cost due to the requirement to decontaminate equipment. The decontamination of buildings and structures is a sep-

12-17-85 U.S. ENVIRONMENTAL PROTECTION AGENCY FILE: FILE3.BIN

JOHN DOE REMEDIAL RESPONSE CONSTRUCTION COST ESTIMATING SYSTEM ANALYSIS NO. 12-333

GENERIC SITE ONE

CONTRACTOR:ACME COMPANY

ANYWHERE, USA

CONTRACT NO.12-0356KDFA-45NNK4

COMMENTS/ EXAMPLE OF SUBSURFACE DRAIN MODULE CALCULATION FOR A SCOPE OF WORK: HYPOTHETICAL SITE.

1.3.4.1 Subsurface Drains (T) MODULE NUMBER 1

ITEM ID	DESCRIPTION	QUANTITY	UN	•• CAPITAL COSTS •• LABOR	MATERIAL	EQUIPMENT	MF	OF	DF	TOTAL
0231001200	Trnch Excavtng 4Fwid bottm bank slpd .5-1 18Fdp 2CY Hyd Bckhoe	4217CY		1265	0	4807	3339	1335	303	11049
0230512020	Borrov,buy&load--pit Prcng Bethd Bank Run Gravel, Bank measure	2657CY		0	7306	0	0	0	0	7306
0230513000	Borrov, buy&load-pit Delivery Charge min. 14CY 1hr.round trip	2657CY		0	5978	0	0	0	0	5978
0230300100	Back Fill by hand no compaction light soil Heavy Soil	2657CY		27499	0	0	15124	6049	1374	50046
0230332020	Backfill,Dozer from exstng stckple no compcta common earth	1553CY		357	0	310	366	146	33	1212
0230817200	Compaction Walk behind vibrtng plate 12"lift 2 passes	1553CY		714	0	201	503	201	45	1664
0232202400	Grading Site excav.& fill 1/4 push dozer Hand grading, finish	1236SY		2039	0	0	1121	448	101	3709
0284602200	Seeding Fescue 5.5#/MSF Tall push spreader	1236MSF		15301	7848	4350	10006	4323	982	43612
0252953050	Piping, Subdrainage, Vtrfied Clay perf.2F lngths C-211 10"diam	214LF		387	1230	57	244	97	22	2037
0250214100	Catch Basins-Manhole Slab tops precast 8" thick 4Fdiam manhole	7Ea		349	525	133	265	106	24	1402
0250214200	Catch Basins-Manhole Sump 4ft. inside diameter	7Ea		1750	1400	665	1328	531	120	5794
0250020114C	Catch Basins-Manhole Precast 4FID riser @27.75 per VLF 14Fdp	7VLF		2468	4900	935	1871	748	170	11092
0980350040	Wall coating acrylic glazed coatings max. For confined space	75SF		161	67	18	98	39	8	391
1520540820C	Sump Pump Capacity 100GPM 15Fdeep well Trench Depth 12F,14F	5Ea		4375	21775	0	2406	962	218	29736
1520540860C	Pump cost addition Stnless stl or plstic 100GPM cap to15Fdpth	5Ea		0	29550	0	0	0	0	29550
1515002900B	Pipe plastic fitting 3 elbows 2"diameter	15Ea		630	120	0	346	138	31	1265
1518004450B	Piping Valves 2"diameter	5Ea		55	195	0	30	12	2	294
1514902000B	Pipe Fiberglass Reinforced 100Fpipe 2"diam	4200LF		226800	77279	0	124740	49895	11340	490054

Figure 9
Cost Output

1550890028	Tank Fbrglss Undgrnd 20000gal.cap. use050 manway fit.&holddvns	2Ea	5240	25440	0	2882	1152	262	34976
0231600200	Bulk Excavating Backhoe Hyd. crawler mtd. 1CY cap.=45CYhr	720CY	604	0	806	775	310	70	2565
0230030001	Backfill By hand no compaction Light soil	328CY	2902	0	0	1596	638	145	5281
0230030050	Backfill Air tamp, add	84CY	281	0	62	188	75	17	623
0232202400	Grading Site excav.& fill 1/4 push dozer Hand grading, finish	124SY	204	0	0	112	44	10	370
0284602200	Seeding Fescue 5.5#/MSF Tall push spreader	124MSF	1535	787	436	1084	433	98	4373
1510001000B	Totals for 100Fmain Includes disch. pipe elbows & tee 4"main	5Ea	2420	1525	0	1331	532	121	5929
1510002000B	Add or subtract for more or less than 100F 6"main	3700LF	5216	5365	0	2868	1147	260	14856
0230580001A	Trench & Backfill cost for trench 4.5F dpx100Flongx8"wide	42Ea	966	0	1260	1224	489	111	4050
0230580002A	Grade/Finish cost for trench 4.5F dpx100Flongx8"wide	42Ea	630	210	42	369	147	33	1431
SUBTOTAL			304148	191500	14082	175018	69997	15900	770645
HEALTH & SAFETY COSTS			167271		7739				
GEOLOGIC CONSIDERATIONS			66898		3091				
DECONTAMINATION COSTS			15197		698				
SUBTOTAL			553514	191500	25610				
GENERAL CONDITIONS			55351	19150	2561				77062
GEOGRAPHIC CONSIDERATIONS			55351	9575	2561				67487
SALES TAX				9575					9575
SUBTOTAL DIRECT COSTS			664216	229800	30732				924769
SUBCONTRACTOR OVERHEAD AND PROFIT									306506
GENERAL CONTRACTOR OH&P ON SUBCONTRACTOR									27585
GENERAL CONTRACTOR OH&P									0
SUBTOTAL									1258860
PERMIT/LICENSE									12588
INSURANCE									62943
BOND									12588
ENGINEERING									202046
STARTUP									0
SUBTOTAL									1549025
CONTINGENCY									278824
ESCALATION									54834
TOTAL CAPITAL COST - MODULE NUMBER 1									1882683

Figure 9 (continued)

CODE	0252933040	(CSI code)
UM	L.F.	(Unit of measure)
DESC_1	Piping, subdrainage,	(Description)
DESC_2	Concrete porous wall	(Description)
DESC_3	Conc. drain 8"diam	(Description)
UNIT_MAT	2.25	(Unit material cost)
UNIT_LAB	1.87	(Unit labor cost)
UNIT_EQP	0.28	(Unit equipment cost)
HEALTH_FLG	0	(Health factor flag)
GEOLGY_FLG	0	(Geology factor flag)
DECONT_FLG	0	(Decontamination factor flag)
REFERENCE	Means	(Cost reference)
COST_DATE	6/84	(Cost date)

(CSI Construction Standards Institute)

Figure 10
Example Record in Cost Data Base

arate component and is not covered by this factor. The base costs do not include any decontamination. The user can input a percentage that is directly applied to the appropriate components. Note that the above three factors are applied only to those items flagged in the data base (Fig. 10). A zero flag means the item cost is unaffected by the given factor.

Escalation Factor

Costs are calculated in mid-1985 dollars. An escalation factor is used to adjust costs for inflation. Separate factors are provided for labor (also used for equipment) and material if the user desires to use different factors. These values can be obtained from many references as the user desires. References include the CPI, CE Index, etc. The value is applied to total cost. An entry of 10% will increase costs by 1.1.

Contingency Factor

The contingency factor is a broad adjustment factor to increase costs for any aspects of the estimate the user believes are unaccounted for otherwise. In this program, the contingency factor can be used in the conventional manner (i.e., enter a percentage which will increase all costs accordingly) or to implement the more sophisticated probabilistic feature of the program. The latter is done by entering "P" in the contingency field. When this is done, an alternate series of input screens will be activated which require not only entry of a given data value, but also minimum and maximum values and selection of an appropriate frequency (probability) distribution for the data value.

PROBABILISTIC ESTIMATING

Uncertainty in the cost estimates for a given site can be due to several different factors:

- Uncertainty in the scope of the job
- Uncertainty in the technology
- Uncertainty in the cost model

Typically, cost models deal only with the last item, cost model uncertainty. Costs are loosely referred to as "budget estimates," "study estimates." "detail estimates," "site specific," etc. These items imply some level of certainty expressed as plus or minus some percent. In fact, the uncertainty is not really calculated, but an arbitrary error band is applied after a point estimate is calculated, for example, ±30%. This percent is applied as a qualitative indicator of the amount of detail considered in the estimate. An accurate estimate is obtained only after a specific job is engineered with design drawings, detailed takeoffs and vendor quotations to a bid specification.

At this writing, the probabilistic cost estimating feature has not been implemented. An option is being planned structured to accommodate the uncertainty of all three types referred to above. Furthermore, each element of the cost will have its own uncertainty in order to calculate a composite error range (i.e., a joint probability density function).

The probabilistic approach takes into account the fact that some elements of the estimate have much different uncertainty than others, and, simultaneously, each element does not have the same effect on the final estimate. Clearly, the objective is to identify what factors have the greatest impact and to obtain the most accurate estimate for those factors.

The greatest uncertainty in Superfund estimates usually is related to uncertainty in the scope of the job. The extent of contamination is really only defined after detailed site investigation and characterization. One advantage of the probabilistic approach is that it helps the user to organize the estimate and see where uncertainty has the greatest impact. Monte Carlo simulation of the cost estimating procedure can be used effectively in this application. This is superior to simply assuming all variables simultaneously are at their maximum or minimum, respectively.

Practical limitations to the application of this approach are:

- User sophistication in such an approach
- User knowledge of uncertainty in the data
- Execution time for the model, especially on a PC
- Storage requirements for the additional data and program subroutines

CONCLUSIONS

The large amount of resources committed to Superfund remedial actions make it very important that thoughtful and accurate cost estimates be performed. Cost-effectiveness decisions are an important aspect of resource allocation and budget policy analysis. Computerized cost estimation programs have a proven record in other areas (e.g., construction, process equipment) for improving the speed, accuracy and consistency of cost estimates. This program is designed to address the special problems associated with costing hazardous waste cleanup. These factors include special worker safety considerations, geological factors and various degrees of maturity of remedial action technology (e.g., drainage ditches vs. biological treatment).

It is hoped that this program will be a useful tool for U.S. EPA personnel and contractors through the detailed design stage of remedial actions. Strong emphasis was placed on the program's user interface. Experience with other programs has shown this to be essential in ensuring widespread usage. A minimum amount of computer knowledge is required to allow the user to concentrate on the application.

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Using Cost/Risk Analysis in Waste Planning: The New England Pilot Project

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ABSTRACT

In the fall of 1984, the Office of Policy Analysis at the U.S. EPA began a Pilot Project aimed at portraying the flows of hazardous wastes in and around one region of the country and at characterizing the impacts of future changes in that regional waste flow system. Selecting the New England six-state region as the subject of the Pilot Project, staff from the U.S. EPA's Integrated Analysis Branch and Temple, Barker and Sloane, Inc. developed a computerized model tying together data on the volumes and locations of industrial wastes in each state, estimates of the constituents present in each waste, the location and method of treatment, storage or disposal for each waste, representative exposure characteristics for each location and available health and ecological effects data.

Working with representatives from state, local, environmental and industry interests, a waste flow data base and computer model were developed—analysis of waste planning strategies is currently underway and a similar project is beginning in another region of the country. This paper describes the Project approach and Phase I findings.

INTRODUCTION

The Amendments to RCRA require that the United States move away from the practice of land disposal of hazardous wastes to alternatives that minimize present and future threats to human health and the environment and encourage the reduction of hazardous wastes at the point of generation. The New England Hazardous Waste Pilot Project is hopefully one way to assist regional and state decision-makers in implementing these broad goals by pulling together what is known about a particular "waste system" so that the best strategies for shifting to alternatives to land disposal and the best candidates for source reduction can be identified, given what we know now about potential risks to public health and the environment. Thus, the two major objectives of the Pilot Project are: (1) to paint a believable picture of a regional waste management system and (2) to use it, in conjunction with other information, to help point to the best waste management strategies given the particular mix and location of wastes in that region.

The paper is arranged in three sections; the first explains the nature of waste flow data base developed for the New England Pilot Project and, equally important, the process used to develop and refine that data base. The second highlights other critical data elements and methods that were tied together in Phase I of the Project. The third is an overview of the cost/risk model to be used in Phase II of the Project and of the kinds of scenarios to be evaluated.

In reading this paper, the reader should remember that, although there is little argument about the advantages of developing better information about the movement and effects of hazardous wastes, the acceptable and unacceptable uses for cost/risk analysis in waste planning still are being identified by Project participants. While the concepts of quantifying risks and focusing on exposures across all environmental medium are not new, to our knowledge this is the first attempt at applying these concepts to regional waste planning issues.

DEVELOPING THE WASTE FLOW DATA BASE

Our first steps in developing a waste flow data base for a region are to determine which wastes should and should not be counted and to set in place a series of data collection activities and data confirmation processes. Hazardous wastewater regulated by water permits, Superfund removals, waste oils, asbestos and PCB wastes are not included in the pilot analysis. These exclusions are made to realistically approximate the annual amount of waste to be managed in the region—or, the amount that might need to be managed differently if capacity shrinks due to facility closures.

Superfund and wastewater exclusions are made based on the assumption that their inclusion artificially inflates the amount of waste to be managed on an annual basis. In other words, for Superfund, removals conducted in 1 year might not occur on an annual basis and, for wastewater, there are few economic incentives for redirecting the large volumes of wastewater currently managed on-site to other types of treatment facilities. (The wastewater exclusion applied to wastewater that is treated in a treatment system permitted by the National Pollutant Discharge Elimination System but is reported as hazardous waste under the Resource Conservation and Recovery Act programs; in one of the states studied, inclusion of these wastes would have increased the volumes of hazardous waste to be managed by almost 80%.) Similarly, it is assumed that waste oils, PCBs and asbestos require specialized treatments and, hence, there are few alternative treatment options to explore. These assumptions are easily changed and some are changing in the second regional analysis.

The project team begins with the information that each state is required to submit reports to the federal government on a biennial basis and the annual reports required by some state governments. These reports, and the detailed data they are drawn from, often do not provide all the information needed to accurately reflect the flows of waste between generators and waste management facilities. Thus, meetings with various project participants, followup with state officials, generators, waste managers and, in some cases, the process of elimination play an essential role in creating the instant picture of the regional waste flow system.

Two groups of project participants assist the New England Pilot Project team by serving as reality checks on the data base as it develops. First, the Regional Coordinating Committee (RCC), includes a small group of representatives from regional, state, local, environmental and industry groups who have experience or strong interest in hazardous waste management issues. Individuals associated with the New England Council, the New England Environmental Network, the Vermonters Organized for Cleanup, the Tufts Center for Environmental Management, the New England Congressional Institute, the New England Governor's Conference, the New Hampshire Governor's Office, the Rhode Island League of Cities and Towns, the Connecticut Hazardous Waste Management Services, the Small Business Administration of New England are members of the RCC. Second, a hazardous waste staff in each of the states provides assistance by directing the project team to the best sources of data, reviewing the data base for their state and helping to reconcile differences between the Project data base and other data sources.

Much is learned in the process of confirming waste flow dates. For example, generator annual report information often is not appropriate for determining what types of treatments are being applied to shipped wastes once they reach their final destination. This is especially true where transfer stations arrange for landfilling or incineration is actually occurring at the transfer station. Review of facility annual reports or personal followup with waste management facilities is necessary to determine if, in fact, the reported treatment and disposal technologies exist at the facilities. Also, facility closures sometimes occur after annual or biennial reports are submitted. In these cases the team works with the states to determine, where possible, which facilities the affected generators are currently using.

Data Base Description

There are almost 15,000 computerized waste records describing the New England waste flow system. Each waste records contains types of waste generated by the U.S. EPA waste code, the U.S. EPA generator identification number, the Standard Industrial Classification (SIC) code for the generator, the amount of waste generated and treated on-site, the amount of waste generated and treated off-site, the U.S. EPA TSD number for treatment, storage and disposal facilities receiving the waste, the type of treatment (by U.S. EPA Appendix I Code) being performed at the facility and the community location for generators and receiving TSD facilities.

After exclusions, the current data base tracks 326 thousand metric tons generated by industrial sources across the six New England states. Since this figure is based on required reporting mechanisms, it does not pick up any generators who fail to report their wastes. Thirty thousand metric tons are generated from waste management facilities, including both wastes that pass through transfer stations and residuals from waste treatments such as solvent recovery.

The highest volumes of wastes tracked in New England are various wastes from electroplating operations, solvents and wastes reported as "otherwise unlisted corrosive or ignitable" wastes. One third of the waste is treated by chemical, physical or biological treatment processes located inside or outside the region, excluding solvent recovery operations which account for about 10% of the total waste treatment load.

Regionally, about one-half of the waste is treated on-site (including the amount in storage at the end of the year) and one-half is treated off-site, with a little less than 50% of the waste that is shipped to commercial facilities going outside of the region for treatment, most to facilities in New York and New Jersey. Figure 1 provides state-by-state summaries of the amounts of wastes

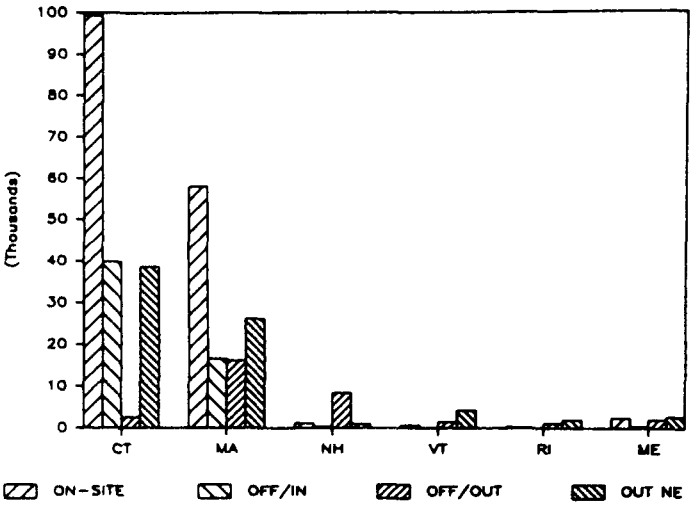

Figure 1
Waste Flows in New England
(1983 Metric Tons)

treated on-site and treated off-site in the same state, in one of the other states in the New England region and in other regions of the country.

PREPARING FOR STRATEGY ANALYSIS

A computer model, designed to analyze planning strategies in four ways, is developed to support the Hazardous Waste Pilot Project through the strategy analysis phase. The model calculates changes in the probability of health effects across the region as measured by potential changes in the concentrations of waste constituents transferred to air, surface water and groundwater; exposed populations; and dose-response information for various health effects. In separate modules, it relates the same changes in concentrations to environmental effects measures and relates the changes in the distances that waste is shipped to transportation risk measures. Finally, it calculates changes in regional costs. To perform these analyses, several data elements described below are assembled.

Constituents, Concentrations, Costs and Capacity

The constituents and concentrations of constituents present in each hazardous waste stream are estimated based on average or typical characterizations used in other projects conducted by the U.S. EPA. The certainty associated with each waste stream that is characterized varies.[1] For example, there is more certainty about the constituents and concentrations of discarded off-specification product wastes than with wastes that are reported as "ignitable, not otherwise listed."

Costs for on-site treatment, storage or disposal are, for the most part, based on the capital and operating costs developed for the various waste management methods in other studies conducted by the U.S. EPA.[1] They are annualized and divided by the annual operating volumes to determine cost per ton or cost per gallon for various waste types. Prices rather than operating costs are used for off-site facilities, generally based on Massachusetts cost data.[2]

A capacity file is assembled to help assure that strategies for redirecting waste flows are realistic. In other words, if we move something to another facility to reduce risk, is there really room for it? Most of the information gathered to date relates to larger commercial facilities.

Characterizing Potential Exposure

The exposure characteristics identified in the model are not based on site-specific data in the strictest sense. Rather, they are designed to eventually assist in pointing to large differences in exposures between areas. If and when significant differences are found, some check against real monitoring data will need to be made. Currently, the location of generators and handlers of hazardous waste is characterized according to the closest major community, the approximate latitude and longitude of the community, population and general air, surface water and groundwater conditions. These environmental factors are used with fate and transport models and waste volume data to calculate the changes in exposure (i.e., changes in concentrations) that may result under various waste management scenarios. Each waste handling method is assumed to have some potential route of environmental release and some probable amount of release. These potential releases may be routine (as in the case of air releases from incineration) or episodic (as in the case of spills around many types of treatment facilities).[1]

Specific release routes for storage technologies include volatilization into air routinely or as a result of spills, migration into surface water from overtopping or spilling, and seepage into groundwater from contaminated leachate or spilling. The routes for treatment and disposal technologies are similar, but also include for thermal treatment, consideration of residual organics and metals emitted into the air, scrubber discharge into surface water and potential leaching from residues. For chemical treatment, potential equipment failure is included; for biological treatment, effluent discharges to surface water are included.

Although disposal via underground injection or ocean disposal is not currently practiced in New England, these management methods are modeled for use in future studies. Possible well head, case or formation failure are considered for underground injection, as well as the obvious fate of ocean-disposed wastes.[5]

To convert mass air emissions into ambient concentrations, conversion factors for point sources and area sources are used for five concentric distances ranging from 1.05 km to 35 km.[4] Storage facilities, oxidation/reduction facilities, stabilization/fixation facilities, biological treatment and landfills are modeled as area sources while thermal treatment and solvent recovery are modeled as point sources. All communities in the study are assumed to have similar air environments described by an afternoon mixing height of 1200 m and an average ambient temperature of 7 °C. This assumption is made after reviewing data on mixing height, temperature, wind velocity and precipitation for New England weather star stations and finding insignificant differences.

For surface water, each community environment included in the analysis is assumed to contain one of three types of surface water environments: a small coldwater stream with low flow less than 3 m^3/sec and a maximum temperature less than 25 °C; a medium coldwater stream with a low flow between 3 and 30 m^3/sec and a maximum temperature less than 25 °C; or a large coldwater river with a low flow greater than 30 m^3/sec and a maximum temperature less than 25 °C. Mass loadings are converted to concentrations across five stream compartments for three categories of pollutants including metals, high transformation pollutants and low transformation pollutants.[6]

Groundwater environment characterization involves gathering and reviewing information on hydraulic conductivity, linear velocity and depth to groundwater. These data are matched to three representative flow field environments, all assuming a single shallow aquifer. The first flow field is characterized by an average linear groundwater velocity of 10 m/yr in the horizontal direction and 1 m/yr in the vertical direction, the second by a velocity of 100 m/yr in a horizontal direction and 10 m/yr in a vertical direction and the third by a velocity of 1000 m/yr in a horizontal direction and 100 m/yr in the vertical direction. The model used to convert loadings to concentrations in groundwater assumes that exposure points are directly downgradient of the source of contamination and that aquifer thickness is constant.[7] Concentrations are calculated at 600 m for total population exposure and at 60 m to calculate a maximum individual exposure.

The concentrations that are calculated represent an average over the first 70 years after initial contamination. This assumption is made to deal with the timing problem associated with comparing and summing potential risk across air, surface water and groundwater. Concentrations of substances in air and surface water occur within a short time-frame and thus can be measured using annual averages. However, concentrations of substances in groundwater may not appear for several years and, assuming that they occur in the first year, may lead to an over-estimation of potential risk given current monitoring and corrective action activities. Nevertheless, the current assumption and others easily can be changed to determine worst case or best case scenarios.

Finally, populations for each of the five distances used to calculate air concentrations are stored in the computer model for each community environment, as well as an estimate, based on the largest town in the 35-km area, of the percentage of the population drawing drinking water from groundwater sources.[8] These percentages are 100%, 75%, 50%, 25% or 5%, and the balance of the drinking water is assumed to be drawn from surface water sources.

Health Risk, Environmental Risk and Transportation Risk

Available data on potential health effects from exposure to various pollutants are obtained and used to define dose-response relationships. These relationships eventually are employed to estimate incidences of health effects given various exposure levels. Health effects are classified into seven broad categories—cancer, reproductive effects, liver effects, kidney effects, fetal development effects, neuro-behavioral effects and other effects. The sum of estimated incidences across effects and pollutants for each waste handling strategy is the health risk score for the strategy in the analysis phase. Currently, dose response curves are available for approximately 30 constituents of various hazardous wastes, and others are being researched on an ongoing basis.

The environmental effects component consists of an index of "ecological integrity" based on dose response information developed for aquatic populations only. These dose response relationships are constructed after review of available data on the effects of pollutants on aquatic organisms and are used to estimate potential impacts on finfish, vegetation zooplankton, macroinvertebrates and non-fish vertebrates resulting from increases or decreases in chemical discharge to surface water bodies.

For transportation risk, an average risk per km of 0.45 per million truck km for a releasing hazardous waste accident is used to assess changes in transportation risk.[9] This calculation is based on the probability of a releasing accident on a composite highway trip (interstate, state and urban).

ANALYSIS OF WASTE MANAGEMENT STRATEGIES

The project team has three objectives in Phase II of the Project. In the broadest sense, the team is trying to determine to what extent this type of approach can benefit waste planning decisions as measured by the reception of the analyses by project participants from local, state, regional, environmental and private concerns. Analytically, the team is trying to determine if measurable and significant changes occur when the waste system is

changed in a variety of ways given what we know now about the characteristics and effects of hazardous wastes in the environment. Finally, in tying together all available information, the team is trying to determine where the biggest data gaps are and how important or insignificant they are to waste management decisions.

The kinds of strategies that the project team currently is testing include a series of "what if" questions ranging from waste reduction queries to treatment capacity issues. For example, what if all electroplaters—identified by SIC code in the data base—could implement a particular waste reduction initiative? Or, what if the ratio of on-site versus off-site treatment changes? Will either of these scenarios show significant increases or decreases in potential risks and costs?

The kinds of strategies to be evaluated in the coming months depend largely on the interests of project participants. These strategies will be analyzed using the computer model.

The Computer Model

All data elements and exposure algorithms are linked in a fairly large but conceptually simple computer model. In the baseline analysis, the computer model relates volumes and locations of wastes (broken down by constituent concentrations) to the possible environmental releases and exposure conditions around waste management facilities and to the health and environmental effects associated with each waste constituent. Baseline transportation risk and baseline costs are computed in separate modules. Thus, the model works as shown in a simplified flow chart (Fig. 2).

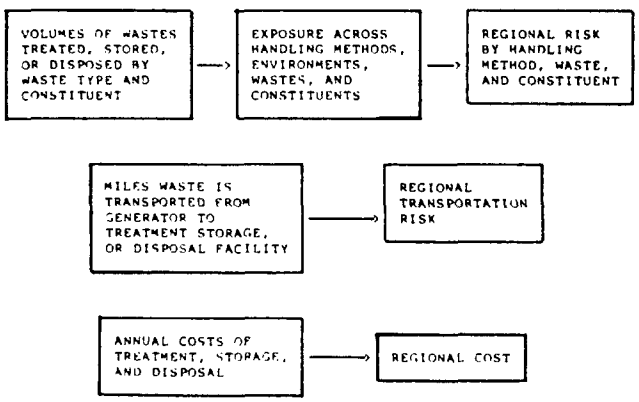

Figure 2
Flowchart Describing Baseline Transportation Risks and Costs

The first step in analyzing a strategy is to identify the key changes that need to be made to the baseline situation. For source reduction scenarios, this means the percentage of waste and kinds of waste that might be reduced on an annual basis. For shifting wastes to alternative facilities, either existing or new, the amounts and kinds of waste to be shifted and the alternative facilities, facility locations and treatment operations must be identified. These changes are entered into the model to compute new risk scores, costs and transportation accident probabilities. These results then are compared to the baseline results to determine if significant changes occur.

After the changes are calculated, the next step is to "dissect" strategies to determine why the changes occur. The purpose of this important step is to see to what extent general changes are driven by volumes of waste, waste characterizations, environmental settings and/or amounts of available effects information. In this way, we can begin to determine the relative importance of the many variables involved and to highlight critical uncertainties and data gaps.

There are some important questions that this kind of analysis cannot answer. While it provides a context for comparing, across environmental media, the risks and costs of a variety of waste management options at various locations, it does not compare the risks at waste handling operations to the risks associated with other industrial operations at the same locations. This is probably a valuable piece of information to communities which might be asked to accept risks associated with new waste treatment facilities, no matter how minimal they appear relative to other possible locations.

CONCLUSIONS

The New England Hazardous Waste Pilot Project is one way to assist in implementing the goals of federal and state legislation. In Phase I we've learned that there is, in particular, a need for better understanding of waste flow systems from a state, regional and possibly national perspective. We have learned that by resolving definitional issues and involving key interests in an attempt to quantify amounts of waste can dramatically change perceptions of the magnitude of a particular hazardous waste system.

In Phase II, the team will work to develop ways of maintaining waste flow information on an ongoing basis and continue to work with project participants to analyze waste planning strategies. By continuing to work with participants from the New England states and U.S. EPA officials, we hope to refine both the data and methods used in the approach and to determine acceptable and unacceptable uses for Project outputs.

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Assessment of Potential Public Health Impacts Associated with Predicted Emissions of Polychlorinated Dibenzo-Dioxins and Polychlorinated Dibenzo-Furans from a Resource Recovery Facility

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ABSTRACT

This paper provides summary results of a risk assessment performed by Fred C. Hart Associates for potential dioxin-related impacts associated with a proposed resource recovery facility to be constructed in New York City by the NYC Department of Sanitation.

With the assumptions used in this risk assessment, the maximum increased cancer risk due to the complex mixture of PCDDs and PCDFs present in the emissions ranges from less than 0.24 to an upper-bound limit of less than 5.9×10^{-6} for inhalation, ingestion and dermal absorption exposure pathways combined. In our opinion, within the context of the assumptions used in the risk assessment, the methods used to estimate risk and considering current regulatory practice regarding acceptable versus unacceptable health risks, a worst-case upper-bound excess cancer risk less than 5.9×10^{-6} is below levels found by many regulatory agencies to require additional review and probable action to reduce risk.

INTRODUCTION

The facility, known as the Brooklyn Navy Yard Resource Recovery Facility (BNYRRF), will be a 3,000 ton/day mass burn facility that will include four 750 ton/day combustion units and will incorporate the Martin stoker system. The BNYRRF will have natural gas auxiliary burners located at the point where secondary air will be injected to maintain a minimum secondary combustion temperature. Emission control systems will include a high-efficiency (greater than 99.5%) fabric filter to meet an outlet particular emission loading of 0.015 gr/dscf at 12% CO_2. This particular emission rate is well below the Federal New Source Performance Standard (40 CFR 60.52) and the New York State emission limitation (Part 222). Subsequent to our completion of this risk assessment, a dry acid gas scrubber system was added to the proposed pollution control ensemble.

The risk assessment was completed after an extensive examination of the literature focusing on the high temperature behavior of dioxins in incinerators. Reports of laboratory studies as well as sampling and analysis data on flue gases from actual incinerators were included. As part of the risk assessment, the predicted ambient air concentrations and daily intake of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) were compared to applicable standards and criteria and concentrations of PCDDs and PCDFs known or suspected to cause a toxic effect. As discussed below, a number of conservative assumptions were utilized in the risk assessment.

EXPOSURE ASSESSMENT

Emission test data from a number of incinerators have demonstrated a wide range of PCDF and PCDD emissions spanning several orders of magnitude. However, the lowest emissions were observed from incinerators with the same basic design as the BNYRRF. Actual emission data from operating municipal resource recovery facilities were used to predict PCDD and PCDF emission rates from the BNYRRF. In selecting the test data, the objective was to utilize data from facilities similar in design, operations and waste types to the BNYRRF. Furthermore, test data had to be obtained using sampling methods that are compatible with methods approved by the U.S. EPA for sampling organics in flue gases under rigorous quality control procedures. The emission data selected as the most representative were obtained fromthe Chicago Northwest facility[1] and the Zurich-Josefstrasse facility.[2] Both use a furnace design similar to that proposed for the BNYRRF; however, both use electrostatic precipitators rather than fabric filters for fly ash emission control.

If the PCDFs and PCDDs are emitted wholly in gaseous form, then the emission data obtained from similar systems could be applied to the BNYRRF, regardless of pollution control system dissimilarities. If the PCDF and PCDD materials are wholly absorbed onto particulate matter, more of these materials will be trapped in the fabric filter than in a comparably sized electrostatic precipitator. Measurement data show generally higher concentrations of PCDFs and PCDDs on emitted fly ash than on fly ash trapped in electrostatic precipitators, indicating a relationship that is influenced by particle surface area. By utilizing particle-size data and an assumption that PCDF and PCDD materials are absorbed onto fly ash in proportion to the available particle surface area, calculations were made concerning the amounts collected and emitted.

Since the partition between gas and solid forms is not known, emissions were calculated in two ways: (1) assuming all PCDF and PCDD materials observed at the test facilities are gaseous and (2) assuming all PCDF and PCDD emissions observed at the test facilities are particulate. If the emissions contain both gaseous and particulate PCDFs and PCDDs, then the emission rates will fall between these values. These emissions, corrected for the size of the BNYRRF, are shown in Table 1 as mass rates per unit time.

To assess the impact of the emissions from the proposed BNYRRF on the general population, computer modeling was performed on the emission data presented above to predict downwind concentrations of PCDFs and PCDDs in the ambient air, soil, dust and dirt. The predictions of ambient air concentrations

Table 1
Summary of Predicted PCDF and PCDD Emissions
Brooklyn Navy Yard Resource Recovery Facility
(Outlet of Fabric Filter)

	Case 1 All Gaseous Emissions (ug/sec)	Case 2 All Particulate Emissions (ug/sec)
Tri-CDF	51.18	23.95
Tetra-CDF	15.35	7.18
Penta-CDF	4.43	2.07
Hexa-CDF	10.58	4.94
Hepta-CDF	1.28	0.60
Octa-CDF	0.10	0.05
Total-CDF	82.92	38 79
Tri-CDD	2.22	1.03
Tetra-CDD	1.07	0.51
Penta-CDF	1.79	0.83
Hexa-CDD	2.73	1.28
Hepta-CDD	1.30	0.61
Octa-CDD	0.43	0.20
Total-CDD	9.54	4.46
2,3,7,8 Tetra-CDD		

Case 1: assumes all PCDF and PCDD materials are gaseous, therefore no additional collection occurs in fabric filter above that collected by an electrostatic precipitator.

Case 2: assumes all PCDF and PCDD materials are adsorbed on particulates, therefore additional fly ash collection in fabric filter reduces PCDF and PCDD emission.

The emission rates may vary between these values if there are gaseous and particulate fractions of PCDF and PCDD emissions.

of PCDFs and PCDDs quantify potential population exposure through the inhalation pathway, while the deposition analysis provides a quantification of potential human exposure through ingestion of contaminated dirt and dust as well as through dermal contact with these materials.

The model used for analyzing air quality impacts resulting from the BNYRRF stack emissions was the Multiple Point Source Gaussian Dispersion Algorithm with Optional Terrain Adjustment (MPTER) modified specifically for use in the urban environment. When using this dispersion analysis methodology and the PCDF and PCDD emission calculations from Case 1 and Case 2 of Table 1, it is assumed that all PCDFs and PCDDs are emitted and that they behave in the atmosphere as a gas. Application of these emission rates to the maximum normalized concentrations results in the maximum annual average concentrations shown in Table 2. Since these concentrations of PCDDs are extremely small, the units presented are picograms/m^3 (pg/m^3 or 10^{-12} g/m^3).

In Case 2, it was assumed that all dioxins entering the fabric filter enter attached to particulates. Those particulates that escape the fabric filter, if heavy enough, will deposit on ground surfaces, mixing with dust, dirt and soil for potential uptake through ingestion or dermal pathways. To determine the rate at which the particles settle to the ground, a computer model with specific capability to analyze particulate deposition rates was selected. This model is the Industrial Source Complex (ISC) model developed under the sponsorship of the U.S. EPA by a private contractor.[9]

The maximum concentration of PCDDs in soils was estimated by assuming a one centimeter mixing zone and a soil density of 1.6 g/cm^3 and estimating a build-up over a 20-year period. The estimate is clearly conservative, with no losses due to volatilization, degradation or physical clearing.

PCDD levels in home dust and street dirt on a surface area basis as opposed to a weight basis also were used in the estimate of risk. By comparing indoor deposition and accumulation to measured lead data, the maximum deposition on floors was estimated at 25% of the outdoor rate with a 30-day period of accumulation.[11]

There is some evidence to suggest that a 30-day accumulation period is overly conservative. The data provided by Solomon, *et al.*,[6] if extrapolated, indicates 0.6 to 1 g dust/m^2 in single family urban middle class homes (gas heated) in Champagne-Urbana, Illinois. His data, if applied to the PCDD and total particulate deposition rates, would indicate that steady state conditions for dust buildup in homes would be reached in 3 to 5 days.

For outdoor deposition, the accumulation period in urban streets is unknown. The Swiss EPS, in its assessment of dioxin emissions from incinerators, used an estimated half life equal to 14 days for rural environments.[2] Consistent with this Swiss EPA assessment, we have assumed a 30-day period of accumulation as a reasonable accumulation period.

Using the deposition model, the concentration of PCDDs in street dirt was determined by dividing the PCDD deposition rate by the average particulate deposition rate from non-dioxin sources. The deposition rate of non-dioxin particulates in Brook-

Table 2
Predicted Maximum Exposure Concentrations of PCDFs and PCDDs Due to Emissions from the Brooklyn Navy Yard Resource Recovery Facility

	Case 1: PCDF and PCDD Emissions Are Gaseous.	Case 2: All PCDF and PCDD Emissions Are Adsorbed on Particulate				
	Maximum Concentration in Air (pg/m^3)	Maximum Concentration in Air (pg/m^3)	Maximum Annual Deposition Rate (ng/m^2)	Concentrations in Soil After One Year (fg/g)	Concentrations in Street Dirt (pg/g)	30-Day Accumulation in House Dust (pg/m^2)
Tri-CDF	1.2283	0.5747	4.790	299	64	100
Tetra-CDF	0.3684	0.1723	1.436	90	19	30
Penta-CDF	0.1063	0.0497	0.414	26	6	9
Hexa-CDF	0.2539	0.1187	0.990	62	13	21
Hepta-CDF	0.0307	0.0144	0.120	8	2	2.5
Octa-CDF	0.0024	0.0011	0.009	0.6	0.1	0.2
Total-CDF	1.9900	0.9309	7.759	486	104	163
Tri-CDD	0.0533	0.0249	0.208	13	3	4
Tetra-CDD	0.0257	0.0012	0.101	6	1	2
Penta-CDD	0.0430	0.0120	0.167	10	2	3.5
Hexa-CDD	0.0655	0.0306	0.256	16	3	5
Hepta-CDD	0.0312	0.0146	0.122	8	2	2.5
Octa-CDD	0.0103	0.0049	0.041	3	0.6	0.9
Total-CDD	0.2290	0.0882	0.895	56	12	18
2,3,7,8 Tetra-CDD	0.00168	0.000782	0.0065	0.41	0.087	0.135

Notes: The concentrations presented in this table assume no chemical/biological degradation or transformation of PCDF and PCDD compounds.

pg/m^3 — picograms per cubic meter

ng/m^2 — nanograms per square meter

pg/g_2 — picograms per gram

fg/g — fentograms per gram

pg/m^2 — picograms per square meter

lyn was measured at 74 g/m^2/year.[4] Table 2 shows the average annual deposition rate for 2,3,7,8-TCDD equal to 0.0065 ng/m^2/year. At any point in time, this material is being diluted by 74 g/m^2/year of particulates from non-dioxin sources. Therefore, for the purpose of this assessment, we predict a maximum 2,3,7,8-TCDD concentration to equal 8.8×10^{-14} g/g of street dirt. This is a highly conservative estimate, since the dioxin containing fly ash will be diluted not only by other airborne particulate matter but also by lint, dirt, gravel, etc. already present on the surface. The estimates are particularly conservative in that no degradation, volatilization or physical cleaning (e.g., runoff to storm sewers) of TCDD is assumed.

On a weight to weight basis, TCDD concentrations in home dust were assumed to be equal to the concentration in street dirt, an assumption which is used by CDC in its risk assessment and supported by some studies of lead contamination in indoor versus outdoor environments.[3]

RISK ASSESSMENT

A risk assessment was performed to estimate the risks associated with predicted maximum PCDD and PCDF concentrations in ambient air, soil, dust and dirt downwind of the BNYRRF. The assessment compared the predicted ambient air concentrations and estimated daily intake levels for PCDDs and PCDFs with: (1) applicable standards and criteria; and (2) concentrations of PCDDs and PCDFs known or suspected to cause a toxic effect.

Several conservative assumptions were incorporated into our assessment. They include the following:

- Use of worst-case assumptions for three potential pathways of exposure: inhalation of gaseous or particulate emissions, ingestion and/or dermal absorption of particulates deposited on outdoor and indoor surfaces. Typically, risk assessments of point source emissions assess risks only for the inhalation pathway.
- Application of a toxic equivalency multiplier equal to 59. This number provides an estimate of the non-carcinogenic toxicity of the complex mixture of PCDDs and PCDFs compared with the concentration of 2,3,7,8-TCDD. This equivalency factor also was used to estimate carcinogenic equivalency as a worst-case assumption although such an application is speculative.
- Reductions in potential PCDD and PCDF concentrations in the environment due to volatilization or degradation or losses due to such actions as rainfall were not considered.
- Exposure assessments for ingestion and dermal pathways were done for both indoor and outdoor exposure; although buildings may have a filtering effect on airborne particles, indoor dioxin concentrations were assumed to be as high as outdoor ambient concentrations for the analysis by the weight approach.
- Risks were calculated based on exposure for 24 hours a day, over a 70-year lifetime, at the point of maximum impact.
- No threshold for a safe level of dioxin exposure was assumed; any exposure to dioxin was assumed to pose some health risk. Moreover, of the accepted models for extrapolating the potential risk of very low level exposure, the most conservative model factor was used.
- Conservative assumptions for bioavailability and rates of ingestions and dermal contact were included to estimate worst-case daily intakes of PCDDs and PCDFs.

The results of our risk analysis are summarized below. Maximum average annual ambient air concentrations (Table 2) were predicted for ground-level and elevated receptors assuming that all PCDDs and PCDFs are emitted as a gas. The maximum average annual ambient air concentrations are predicted to be well below existing standards and guidelines typically less than 1%. Only the NYSDEC performance guideline for evaluating combustion sources is approached but at only 28% of the guideline.

Risks associated with inhalation of PCDDs and PCDFs at the maximum average annual concentrations were determined by comparing a predicted maximum daily intake through inhalation (DI_{inh}) with Acceptable Daily Intakes (ADIs) and cancer dose/response extrapolations. The assumptions used to calculate DI_{inh} are provided in Table 3.

Table 3
Upper-Bound Estimated Percentage of Acceptable Daily Intake (ADI) Attributable to Inhalation of PCDD and PCDF Emissions from the BNYRRF at Ground Level and Elevated Receptors

	Acceptable Daily Intake (ADI)			
	Canada 10 pg/kg-day[8]	Netherlands 4pg/kg-day[9]	NYSDOH 2pg/kg-day[10]	CDC 1.8pg/kg-day[11]
Upper-bound Daily Intake-Inhalation Pathway				
2,3,7,8-TCDD[a] (2.7×10^{-4} pg/kg-day)	0.0027%	0.007%	0.014%	0.01%
TCDD[b] (4.2×10^{-3} pg/kg-day)	0.042%	0.11%	0.21%	0.23%
TCDD Toxic Equivalency[c] (1.6×10^{-2} pg/kg-day)	0.16%	0.40%	0.80%	0.89%

Assumes

DI_{inh} (g/day) = PCDD (g/m^3) × ventilation rate (m^3/day) × particulate retention (%) × bioavailability (%)

75% of the inhaled particles are retained by the body[12]

15 m^3 of air are exchanged in one day[11]

100% of the inhaled particles are bioavailable

Maximum ambient air concentration of 2,3,7,8-TCDD equals 0.00168 pg/m^3

70 kg/person inhaling .00168 pg/m^3 of 2,3,7,8-TCDD

(a) DI_{inh} (pg/kg-day) = DI_{inh} (g/day)/70kg = 1.9×10^{-2} pg/day/70 = 2.7×10^{-4} g/day

(b) DI_{inh} (TCDD) = DI_{inh} (2,3,7,8-TCDD × 15.5)

(c) DI_{inh} (Toxic Equivalents) = DI_{inh} (2,3,7,8-TCDD × 59)

As shown in Table 3, the maximum daily intake DI_{inh} of 2,3,7,8-TCDD, TCDD and TCDD toxic equivalents are predicted to be well below (less than 1%) any ADI promulgated by any regulatory agency. These ADIs provide a margin of safety and they identify a very safe dose, below which risks are insignificant for non-carcinogenic toxic effects.

An upper-bound to carcinogenicity risk was also determined by comparing DI_{inh} with three different cancer dose/response extrapolations. The most conservative dose/response extrapolation is that used by the U.S. EPA (unit risk estimate equal to 1.56×10^{-7}).[7] As shown in Table 4, the upper-bound excess risk due to exposure to 2,3,7,8-TCDD and HCDD, at the point of maximum impact, ranges from less than .0019 to less than 0.055×10^{-6} or less than six cases per 100 million people exposed to the maximum concentration over a 70-year lifetime.

The sensitivity of the risk estimates derived for the inhalation pathway to the additional risks that might be attributable to the ingestion and dermal pathways was tested. These two pathways were not considered in the initial risk assessment of the inhalation pathway due to the high degree of uncertainty in the estimates of ingestion, absorption and bioavailability rates and due to the difficulties in modeling PCDD concentrations in soil, dirt and dust.

Table 4
Upper-Bound Estimated Increased Cancer Risk for Population of One Million People Exposed for a 70-Year Period to the Maximum Daily Intake via the Inhalation Pathway

	Dose for 1 x 10-6 Excess Cancer Risk		
	Kimbrough (1.4 pg/kg-day)	Kimbrough (.028 pg/kg-day)	EPA (.0064 pg/kg-day)
	Upper Bound Excess Risk for 70 Kg man		
Daily Intake			
1.9 x 10^{-2} pg/day (2,3,7,8-TCDD)	.0019	.010	.042
0.15 pg/day (1,2,3,6,7,8 and 1,2,3,7,8,9-HCDD)	-----	-----	.013

A range of daily intake estimates was calculated (DI_{ing} and DI_{derm}). The assumptions used to calculate DI_{ing} and DI_{derm} are provided in Tables 5 and 6.

Table 5
Estimated Daily Intake of 2,3,7,8-TCDD through the Ingestion Pathway

	Source of Exposure		
	Home Dust[2]	Street Dirt	Soil[1]
A. Weight Approach			
Concentration of 2,3,7,8-TCDD	8.8x10^{-14} g/g	8.8x10^{-14} g/g	8.2x10^{-15} g/g
Mechanism		Daily Intake (g/day)	
Ingestion of:			
100 mg/day - 30% Bioavail	2.6x10^{-15}	2.6x10^{-15}	2.5x10^{-16}
410 mg/day - 80% Bioavail	2.9x10^{-14}	2.9x10^{-14}	2.7x10^{-15}
B. Surface Area Approach			
Concentration of 2,3,7,8 TCDD	1.3x10^{13} g/m^2	5.3x10^{-13} g/m^2	
Mechanism	Daily Intake (g/day)		
Contact with:			
0.0033 m^2/day - 30% Bioavail	1.3x10^{-16}	5.2x10^{-16}	5.2x10^{-16}
0.016 m^2/day - 80% Bioavail	1.7x10^{-15}	6.8x10^{-15}	6.8x10^{-15}

[1] 20-year accumulation period

[2] Assumes 30-day accumulation period at 25% of outdoor accumulation rate

As summarized in Table 7, for the low end of this range, the data indicate that the predicted additional 2,3,7,8-TCDD intake from ingestion or dermal absorption of particulate emissions from the BNYRRF would be negligible. Using worst-case assumptions regarding the maximum rates of exposure through ingestion or dermal in absorption, the total daily intake of 2,3,7,8-TCDD would increase by 2.4 times the amount from inhalation alone. Under this "worst-case" scenario, ingestion becomes the major pathway of exposure.

The general conclusions regarding the level of risk posed by the BNYRRF are not significantly altered if the maximum total daily intake of 2,3,7,8-TCDD increases 2.4 fold. This additional daily intake of 2,3,7,8-TCDD equals only 0.036% of the most conservative ADI (1.8 pg/kg-day) and a toxic equivalent daily intake which is only 2.1% of this ADI.

Table 6
Estimated Daily Intake of 2,3,7,8-TCDD from Dermal Absorption

	Source of Exposure		
	Home Dust	Street Dirt	Soil
A Weight Approach			
Concentration of 2,3,7,8-TCDD	8.8x10^{-14} g/g	8.8x10^{-14} g/g	8.2x10^{-15} g/g
		Daily Intake (g/day)	
0.55 g of dust - 1% Absorption	4.8x10^{-16}	4.8x10^{-16}	4.5x10^{-17}
0.55 g of dust - 10% Absorption	4.8x10^{-15}	4.8x10^{-15}	4.5x10^{-16}
	Source of Exposure		
	Home Dust	Street Dirt*	
B Surface Area Approach			
Concentration of 2,3,7,8-TCDD	1.3 x 10^{-13} g/m^2	5.3 x 10^{-13} g/m^2	
		Daily Intake (g/day)	
0.028 m^2 of surface area - 1% Absorption	3.6 x 10^{-17}	1.5 x 10^{-16}	
0.14 m^2 of surface area - 10% Absorption	1.8 x 10^{-15}	7.4 x 10^{-15}	

* PCDD concentrations in soils on a surface area basis are assumed to be identical with street dirt.

Table 7
Calculation of a Total Daily Intake of 2,3,7,8-TCDD for Inhalation, Ingestion and Dermal Absorption Pathway

Case 1 PCDDs and PCDFs Enter Fabric Filter in Gaseous Phase

$DI = DI_{inh} + DI_{ing} + DI_{derm}$

$DI = 1.9 \times 10^{-14} + 0 + 0$

$DI = 1.9 \times 10^{-14}$ g/day

Case 2 PCDDs and PCDFs Enter Fabric Filter Attached to Particulates

$DI = DI_{inh} + DI_{ing} + DI_{derm}$

$DI_{min} = 8.8 \times 10^{-15} + 1.3 \times 10^{-15} + 3.6 \times 10^{-17}$

$DI_{max} = 8.8 \times 10^{-15} + 2.9 \times 10^{-14} + 7.4 \times 10^{-15}$

$DI_{min} = 1.0 \times 10^{-14}$ g/day

$DI_{max} = 4.5 \times 10^{-14}$ g/day

The upper-bound carcinogenic risk estimates will also increase by a factor of 2.4 assuming the most conservative estimates for the ingestion and dermal absorption pathways. This would result in an upperbound increased cancer risk for a population exposed to the maximum 2,3,7,8-TCDD and HCDD concentrations over a 70-year lifetime ranging from 0.0046×10^{-6} to less than 0.13×10^{-6}.

As a further measure of conservatism, we examined the potential carcinogenic risks due to exposure to the complex mixture of PCDDs and PCDFs emitted from the BNYRRF for all three potential pathways of exposure. Because no actual animal studies have been conducted to assess the carcinogenicity of most of the individual PCDD/PCDF isomers on the complex mixtures present in fly ash emissions, another conservative assumption was made: that the carcinogenic effect of these compounds is equivalent to their toxic effect (i.e., that carcinogenic equivalency equals a toxic equivalency). However, this assumption is highly speculative. With these conservative assumptions, the maximum increased cancer risk due to the complex mixture of PCDDs and PCDFs present in the emissions ranges from less than 0.24 to an upper-bound limit of less than 5.9×10^{-6} for all these pathways combined.

In our opinion, within the context of the assumptions used in the risk assessment, the methods used to estimate risk and considering current regulatory practice regarding acceptable versus unacceptable health risks, a worst-case upper-bound excess

cancer risk less than 5.9×10^{-6} is below levels found by many regulatory agencies to require additional review and probable action to reduce risk.

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Improving the Risk Relevance of Systems for Assessing the Relative Hazard of Contaminated Sites[1]

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ABSTRACT

The ranking system (Hazard Assessment Ranking Methodology, or HARM) used to evaluate the relative hazard of contaminated sites during the records-search phase of the U.S. Air Force Installation Restoration Program (IRP) has been revised to priorities for later phases of the IRP. The resulting methodology, HARM II, is designed to use data obtained in preliminary site investigations and is expected to provide better approximations of relative site risk than could be obtained with the original HARM or with the U.S. EPA's Hazard Ranking System. This paper describes the methodological enhancements in HARM II and reports the results of preliminary testing of HARM II.

INTRODUCTION

The U.S. EPA "Superfund" program and other federal and state waste site remedial action programs set remedial action priorities using various methodologies that rank contaminated sites according to their relative hazard. Ideally, the site rankings produced by these methodologies would closely correlate with the actual health and ecological risks posed by individual sites; i.e., the relative scores would indicate relative potential for adverse effects, taking into account the relative probabilities of exposures to contaminants and the relative consequences of such exposures. We call this property "risk relevance."

While risk relevance was a critical consideration in the design of such widely used site-ranking systems as the U.S. EPA Hazard Ranking System (HRS)[1] used in the Superfund program, methodological simplifications needed to permit scoring of large numbers of sites in a short time with limited site-specific data often diminish the risk relevance of the resulting scores. Simplified ranking systems are appropriate for preliminary identification of sites where cleanup may be necessary, but final decisions on allocating remedial action resources among sites should use methods that relate more directly to actual health and ecological risks.

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In this paper, the authors describe a modification of the Hazard Assessment Rating Methodology (HARM), a site-screening system developed by the U.S. Air Force for use in the initial phase of its Installation Restoration Program (IRP). The Air Force used HARM to evaluate sites of suspected contamination based on information obtained from a records search. The new site-rating methodology (Hazard Assessment Rating Methodology II, or HARM II) is intended to set priorities for detailed site investigation and possible remedial action in later phases of the IRP. It uses data obtained from preliminary field surveys of sites identified during the records search as being potentially hazardous. The primary reasons for modifying HARM were to permit effective use of new field data and to improve the methodology's ability to discriminate between sites on the basis of actual risk. Although HARM is designed specifically to meet the needs of the Air Force, features incorporated in HARM II to improve its risk relevance may be useful in other decision-making problems involving hazardous materials and waste sites.

THE HAZARD ASSESSMENT RATING METHODOLOGY

The original HARM methodology is a close relative of the HRS.[1] As in the HRS, sites are scored on the basis of potential for contaminant transport ("Pathways"), contaminant characteristics ("Hazard") and potential receptors ("Receptors") along each of several possible exposure pathways. Subscores for these three risk categories are obtained by evaluating the sites with respect to several rating factors, multiplying factor scores by appropriate factor weights and summing the weighted factor scores. The resulting subscores then are averaged to arrive at a single overall site score.

Only hydrologic transport and exposure pathways are considered in HARM; air exposures are not included. Other differences between HARM and HRS include the use of standard four-point (i.e., 0-1-2-3) factor rating scales throughout HARM, inclusion of a few different rating factors (e.g., distance from the site to a facility boundary) appropriate to Air Force applications, assignment of different ranges of values (e.g., of local population

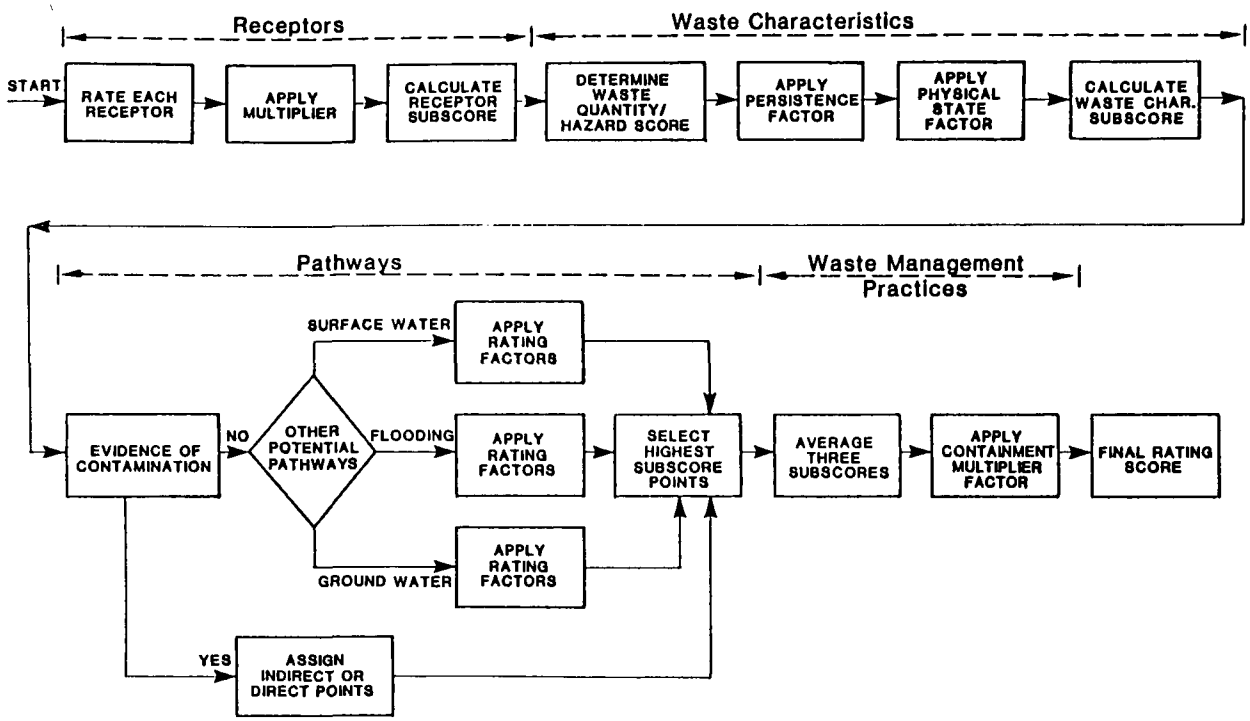

Figure 1
Hazardous Assessment Rating Methodology Flow Chart

and waste quantity) to individual factor scores and use of additive algorithms (instead of the multiplicative and root-mean-square algorithms employed in HRS) to combine subscores. Figure 1 illustrates the structure of the original HARM.[2]

The structure of HARM II (Fig. 2) is significantly different from that of the original HARM. In the original HARM (Fig. 1), three contaminant migration routes (Surface Water, Flooding and Groundwater) are evaluated in determining the subscore for the Pathways category, but a single subscore was determined for each of the three categories (i.e., Pathways, Hazard and Receptors) regardless of the mode of contaminant migration. To ensure that the factors considered in Receptors scoring are relevant to the expected mode(s) of contaminant migration and that Hazard scores reflect the sensitivity of the exposed populations, HARM II requires separate calculation of scores for each of four exposure pathways: (1) Surface Water Migration/Human Health Receptors, (2) Surface Water Migration/Ecological Receptors, (3) Groundwater Migration/Human Health Receptors, and (4) Groundwater Migration/Ecological Receptors. Subscores for each of the three rating categories are aggregated to arrive at an overall pathway score, and the four pathway scores then are combined to arrive at a single overall site score. In HARM II, the Flooding migration route from the original HARM has been incorporated into the Surface Water migration route, and the Waste Containment factor from the original HARM has been incorporated into the Pathways scoring category. Other features of HARM II intended to improve its risk relevance are described below.

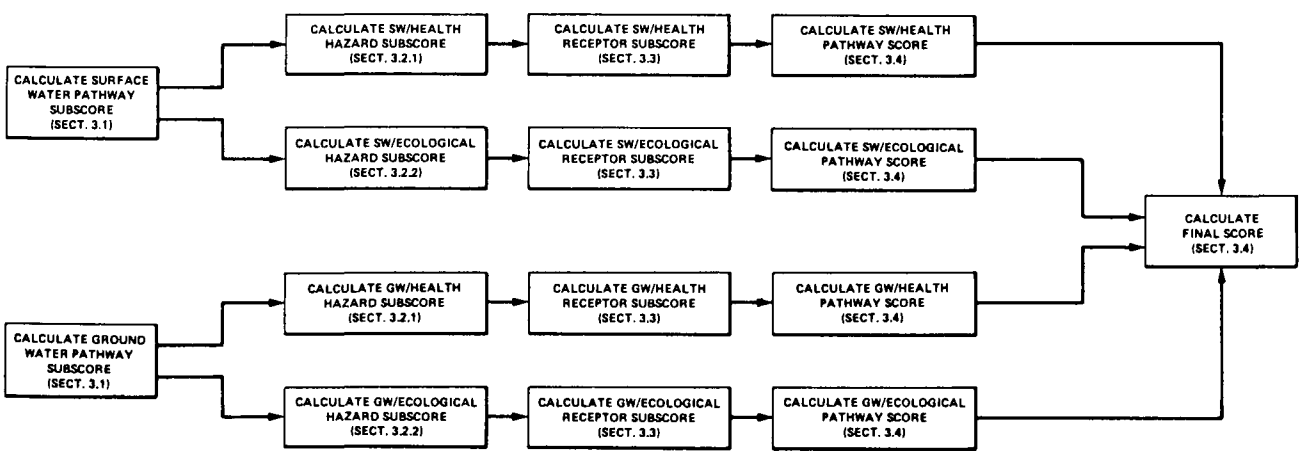

Figure 2
Flow Chart for HARM II Site Rating System

HARM II Contaminant Hazard Scoring

The most important limitation in the contaminant hazard scoring portion of the original HARM is the method's reliance on the Sax Toxicity Rating.[3] The Sax method, which is widely used in site-ranking methodologies such as the HRS, assigns toxicity scores on the basis of a substance's observed biological mechanism of action, independent of the dose level at which the substance is toxic. Also, Sax ratings do not indicate hazards to nonhuman ecological receptors and sometimes are not relevant to the modes of exposure that would be expected along environmental exposure pathways (e.g., a chemical whose fumes are highly toxic may not be very toxic when ingested in drinking water). A second problem with HARM that is common to most site-ranking methodologies is the use of only the most toxic chemical at a site to characterize the site hazard. When a site's hazard rating is based only on the most toxic chemical, it is possible to assign a high score to a site having a large quantity of low-hazard wastes solely due to the presence of a very small quantity of high-toxicity wastes.

The risk relevance of HARM II contaminant hazard scores has been enhanced by replacing the Sax rating with a set of toxicological benchmarks and by scoring hazard on the basis of comparisons between the benchmarks and measured contaminant levels. Separate sets of benchmarks are used, and separate scores are calculated for human-health hazards and ecological hazards. As in HARM, the score for site contaminant hazard is obtained after applying contaminant persistence and waste quantity multipliers to the toxicity score.

Human-health hazard scores are based on ingestion of contaminated water and consumption of fish that have accumulated waterborne contaminants. Ecological hazard scores are based on acute lethality to fish and aquatic invertebrates and effects on terrestrial plant production due to contamination of growth media. If data are available on contaminant concentrations in surface waters or groundwaters, these concentrations are used to calculate hazard quotients, which are ratios of the estimated intake rates of the detected contaminants to the toxicity benchmarks of the contaminants. The specific formula used depends on the existing or potential uses of the contaminated water; the human-health hazard contribution of a contaminant found in surface water that supplies drinking water would be calculated as follows:

$$Q = (C_w \times F_w + C_f \times F_f)/B_h \quad (1)$$

where:

- Q = human-health hazard quotient for the contaminant of interest
- C_w = contaminant concentration in surface water (μg/l)
- F_w = estimated individual drinking water intake (2 l/day)
- C_f = concentration in fish (μg/g) = $C_w \times B_b$, where B_b = bioaccumulation factor (l/g) for the contaminant of interest
- F_f = estimated mean daily individual fish consumption (6.5 g/day)
- B_h = health effects benchmark (μg/day) for the contaminant of interest

Where more than one contaminant has been detected, quotients for the individual contaminants are summed. Hazard scores are assigned on a scale of 0 to 6, based on the order of magnitude of the sum of quotients.

Procedures have been specified[4] for obtaining contaminant-specific benchmarks for effects on humans, effects on aquatic and terrestrial biota and potential bioaccumulation in fish. For regulated chemicals, the human-health toxicity benchmarks used in HARM II are based on the U.S. EPA's drinking water quality standards (40 CFR 141) or on the "permissible concentrations" promulgated by the National Institute for Occupational Safety and Health. For unregulated contaminants, benchmarks are obtained by evaluating test data available in such published compilations as the Registry of Toxic Effects of Chemical Substances (RTECS),[5] using the relative potency technique described by Jones, *et al.*[6] Similarly, benchmarks for ecological effects are obtained from U.S. EPA water quality criteria for protection of aquatic life or from the U.S. EPA's on-line data bases on toxicity to aquatic organisms (QUIRE) and terrestrial plants (PHYTOTOX). Bioaccumulation factors for estimating the contribution of contaminated food chains to human intake, are obtained from published compilations,[7-10] or estimated from structure-activity relationships, e.g., from the octanol-water partition coefficient.

If contaminant migration has not been detected along a particular migration route or if water concentration data are unavailable, hazard scores are based on the characteristics of the most toxic contaminant. A score from 0 to 6 is assigned, based on the toxicological benchmarks of the most toxic contaminant. For this case, the scale used in scoring human-health hazards is based on the range of potencies of 60 chemicals drawn at random from RTECS,[5] and the scale used in scoring ecological hazards is based on the range of toxicities for chemicals listed in the AQUIRE data base.

The calculations and data assessments required to implement this portion of HARM II are significantly more complex and time-consuming than those involved in either the original HARM or the HRS. However, because it is unlikely that HARM II users will have the expertise needed to determine appropriate contaminant benchmarks, Oak Ridge National Laboratory is determining benchmarks for all nonradioactive contaminants that have been found at Air Force facilities. Their results will be published in a user's manual for HARM II. Given this tabulated information, determination of HARM II contaminant hazard scores can become a routine microcomputer spreadsheet application.

HARM II Pathways Scoring

The "Pathways" portion of HARM II rates the potential for contaminants from a waste site to enter surface waters via overland flow routes or to enter groundwater. As in the HRS and the original HARM, if contaminants from a site have already been detected in water, the maximum possible pathway score is assigned. Thus, the Pathways scoring procedures are applied only if contamination has not yet been detected.

Factors in the Pathways scoring category in HARM II are listed in Table 1. The HARM II surface water pathways scoring system is very similar to that used in HARM, with the notable exception that the potential for floodwater transport of contaminants is included in the surface water pathway in HARM II. This change was made to reflect the fact that floodwater transport is only one of several routes for overland transport of contaminants to surface waters, and factors affecting risk from floodwater transport are similar to those affecting risk from other overland transport routes. A few factor weights were adjusted to better reflect their relative importance to overland transport or overflow from impoundments.

The scoring system for the groundwater pathway was modified slightly from HARM to make better use of the new data obtained in site investigations. The original HARM included two factors related to the length of the pathway between the waste and the groundwater: (1) depth to groundwater from the land surface and (2) potential for subsurface flows (i.e., the water table) to intersect the base of the waste. HARM II replaces these with a single new factor: depth to seasonal high groundwater from the base of the waste or contaminated zone. This new scoring factor

Table 1
Listing of HARM II Pathways and Receptors Scoring Factors

Category	Scoring Factors	
	Surface water migration	Groundwater migration
PATHWAYS	Distance to nearest surface water Net precipitation Surface erosion potential Rainfall intensity Surface permeability Flooding potential Containment effectiveness	Depth to groundwater from base of waste or contaminated zone Permeability of unsaturated zone Potential for discrete features to "short circuit" pathway to the water table Infiltration potential Containment effectiveness
RECEPTORS		
Human health	Population served by surface water supplies within 3 miles (4.8 km) downstream Water quality classification of nearest surface water Population within 1000 ft (305 m) of site Distance to nearest installation boundary Land use and zoning within 1 mile (1.6 km) of site	Mean groundwater travel time to nearest downgradient well Groundwater use of uppermost aquifer Population served by affected downgradient aquifers within 3 miles (4.8 km) Population served by affected aquifers not in downgradient direction within 3 miles (4.8 km) Mean groundwater travel time to downgradient surface waters that supply domestic uses or food-chain agriculture Population within 1000 ft (305 m) of site Distance to nearest installation boundary
Ecological	Importance/sensitivity of biota/habitats in potentially affected surface waters Presence of "critical environments" within 1 mile (1.6 km)	Mean groundwater travel time to downgradient habitat or natural area Importance/sensitivity of downgradient habitats/natural areas Presence of "critical environments" within 1 mile (1.6 km)

uses information that may not have been available before site investigation, and it should enhance the ability of the method to identify sites where there is a real potential for contamination of groundwater. Another feature of this portion of HARM II that represents a change from the original HARM is the addition of a factor called "infiltration potential," which is based on an estimate of the amount of water available to cause waste leaching or infiltration. Infiltration potential is determined as a function of net precipitation (a Pathways scoring factor included in the waste hazard score in the original HARM). This new scoring factor is expected to be a better indicator of the hydraulic potential for waste constituents to reach groundwater.

The waste containment effectiveness factor, which was applied to the overall site score in the original HARM, is applied only to the Pathways scores in HARM II, because effective waste containment reduces the potential for contaminants to enter water but does not affect the other major risk categories considered in HARM. HARM II includes separate rating scales for waste containment effectiveness for surface water and groundwater pathways, permitting separate evaluation of factors limiting surface water or groundwater transport. The HARM II rating scales for containment effectiveness were derived from the "waste management factors" in HARM[2] and the "containment values" in the HRS.[1]

HARM II Receptor Scoring

The "Receptors" portion of HARM II evaluates the potential for human populations and ecosystems to be exposed to contaminants present in surface waters or groundwaters. This portion of HARM II has been modified significantly from the original HARM, primarily to permit use of groundwater information obtained through site investigation.

Factors in the Receptors scoring category in HARM II are listed in Table 1. The scoring factors for human health receptors affected by surface water migration are essentially unchanged from HARM. The dominant factors in this category are those related to the potential for humans to ingest contaminated surface waters, either as drinking water or in foods. Three other factors related to the site's proximity to human populations (i.e., population within 1,000 ft [305 m], distance to installation boundary and land use and zoning) are included because they indicate a potential for humans to come into contact with contaminated waters through routes other than ingestion (e.g., direct contact by children playing near contaminated drainage ditches).

The scoring factors for human receptors affected by groundwater migration are significantly different from those used in the original HARM. This portion of HARM, like the analogous portion of HRS, is concerned primarily with distances to water supply wells and does not consider the direction or rate of groundwater flow. Initial field investigations should have supplied the information needed to estimate groundwater velocities and flow directions, so HARM II receptors scores can be based on estimates of the actual potential for contaminants to reach points of groundwater use. HARM II assigns more weight to receptors that are found to be hydraulically downgradient from the waste site and incorporates a measure of the urgency of a particular contamination problem by including scoring factors based on estimated groundwater travel times to sites of groundwater use. Also, because surface waters are often outlets for groundwater discharge, the human health receptors category for groundwater migration includes scoring factors related to the uses and susceptibility of surface waters hydraulically downgradient from contaminated sites. These features of HARM II are intended to ensure that scores are based on consideration of the populations that are actually at risk.

The groundwater travel time parameter in HARM II is similar to the travel time criterion adopted by federal regulators as a measure of the isolation of radioactive wastes in geologic repositories.[11, 12] Mean groundwater travel time is calculated from the estimated hydraulic conductivity of the affected aquifer (k), the hydraulic gradient in the affected aquifer (i), the distance to the well (d) and the effective porosity of the affected aquifer (n), using the following equation:

$$\text{Travel time} = dn/ki \qquad (2)$$

This calculation will provide an estimate of the mean travel time of a nonreactive contaminant, neglecting the effects of dispersion. It is recognized that the data needed for this calculation will not always be available. To promote consistency in evaluating this parameter, guidance has been developed[4] for estimating input values when appropriate data are unavailable. For consistency in applying HMAR II, "downgradient" is defined to mean a 90- to 120-degree arc containing the best estimate of the direction of groundwater flow at its center. Where the direction of groundwater flow is highly uncertain or indeterminate, all travel-time scoring is based on an estimated travel time to the nearest well or surface water in any direction.

The method for scoring the potential exposure of ecological receptors has been expanded from the original HARM and the HRS, both of which emphasize the proximity of the site to various critical environments. HARM II also considers the potential ecological importance or sensitivity or ecosystems likely to be exposed to a particular transport pathway but not necessarily "critical environments." These include all permanent streams, lakes, wetlands and irrigated land areas.

Aggregation of HARM II Subscores

In the original HARM (Fig. 1), the overall site score is obtained by simple arithmetic averaging of the Pathways, Hazard and Receptors subscores. This method of aggregating scores is simple to apply, but its results are not well correlated with actual risks of

toxic exposures. Three factors must be present to result in an exposure risk: toxic contaminants ("Hazard"), potential for migration ("Pathways") and a potentially exposed human population or ecological resource ("Receptors"). If an additive algorithm (such as arithmetic averaging) is used to combine subscores for an exposure pathway, it is possible to obtain a relatively high score for a pathway along which only two of these three factors are present and for which risk is therefore rather low. For example, a site with highly toxic contaminants and a large receptor population but very little potential for aqueous transport of contaminants poses relatively little risk, but could receive a high score. To avoid this outcome, HARM II uses a multiplicative algorithm similar to that in the HRS[1] to combine subscores into a single pathway score. The three subscores are multiplied together, and, to normalize to a 100-point scale, the product is divided by 10^6 (the product of the highest possible category scores). With this algorithm, an exposure pathway with a very low or zero subscore for Pathways, Receptors or Hazard will receive a very low or zero score, consistent with the low pathway risk.

Several different approaches were available for obtaining an overall site score from the four HARM II exposure pathway scores. Arithmetic averaging was not used for this purpose because this method assigns equal weight to high- and low-risk exposure pathways. A site with a high risk via one exposure pathway is a high-risk site even if it has a low risk via another exposure pathway. Although such a site should receive a higher score than a site with a moderate risk via both pathways, the two sites might receive the same score if the pathway scores were averaged arithmetically. The objective of assigning greater weight to high-risk pathways could be achieved by setting the overall site score equal to the single highest exposure pathway score, but this approach is inappropriate because it does not reflect the fact that a site with high risks along two or more exposure pathways presents greater risk than a site with high risk along only one pathway.

A weighted root-mean-square algorithm was selected for combining the four HARM II exposure pathway scores into a single overall site score. The HRS uses a root-mean-square algorithm for combining exposure pathway scores because this approach reflects the contributions of several pathways while it gives greater weight to pathways with higher scores.[13] Explicit factor weights are also applied in combining HARM II pathway scores in order to give human health risks greater weight than ecological risks. Thus, the following algorithm is used to obtain the final site score:

$$S_f = [5(S_{s,h})^2 + (S_{s,e})^2 + 5(S_{g,h})^2 + (S_{g,e})^2]^{1/2}/3.464 \quad (3)$$

where

S_f = final score
$S_{s,h}$ = score for human health risk via surface water pathway
$S_{s,e}$ = score for ecological risk via surface water pathway
$S_{g,h}$ = score for human health risk via groundwater pathway
$S_{g,e}$ = score for ecological risk via groundwater pathway

The weight of 5 for the human health scores was selected because the original HARM assigned factors related to human receptors 5 times the weight given to factors related to ecological receptors. The divisor 3.464 is the square root of 12, which is the sum of the weights assigned to individual pathway scores.

TESTING OF HARM II

As a preliminary test of the methodology, HARM II was applied to a representative Air Force facility that contained nine contaminated sites for which both preliminary site investigation data and original HARM scores were available.[4] The nine sites that were assessed represented a diverse range of waste characteristics, waste quantities and physical settings. As indicated by the scores in Table 2, HARM II produced a clear separation between a group of high-scoring sites (i.e., the 46-55 range) and a group of relatively low-scoring sites (i.e., the 15-30 range), whereas scores from the original HARM had been spread fairly evening over a range from 51 to 88. This improved score separation, which is largely due to the change from an additive to a multiplicative algorithm, should be helpful in setting and defending remedial action priorities. In general, scores assigned with HARM II were lower than those assigned with the original HARM, largely because the change to a multiplicative algorithm resulted in significantly lower overall scores for sites that had low subscores in one of the three rating categories. Since the HARM systems are tools for evaluating relative site hazards and are not correlated with absolute degrees of risk, the lower range of scores obtained with HARM II does not mean that the sites pose any less risk now than they did when the original HARM was applied.

HARM II also produced a different ranking of sites than the original HARM. The most dramatic changes in site rank were attributable to new information obtained during site investigations. For example, in applying the original HARM, the chrome waste pit (Table 2) had been scored as having a small quantity of waste and a low potential for contaminant migration, but it later was found to contain a large quantity of waste and to have caused significant groundwater contamination. A variety of smaller changes in scores and site ranks could be attributed to new data, changes in individual scoring factors and changes in scoring algorithms.[4]

Table 2
Comparison of Scores for Sites Evaluated With Both HARM and HARM II

Site	HARM score and rank		HARM II score and rank	
Landfill #1	88	(1)	47	(4)
Landfill #3	86	(2)	55	(1)
Waste oil pits	74	(3)	46	(5)
Old fuel storage tank site	73	(4)	27	(7)
Die yard chemical pits	64	(5)	54	(2)
Fire-training burn pit #6	58	(6)	15	(9)
Chrome waste pit	55	(8)	54	(2)
Two other fire-training burn pits[a]	51-58	(6-9)	22-30	(6-8)

[a] Individual burn pits rated with HARM II could not be directly correlated with specific burn pits rated with HARM.

This testing indicated that it is feasible to apply HARM II with the types of data available for contaminated sites on Air Force facilities and gave a preliminary indication that the method will provide meaningful distinctions between high- and low-risk sites. More extensive test applications and sensitivity analyses are now being performed to confirm these observations, to evaluate the methodology's effectiveness for comparing a wide variety of sites in different geographical areas and to identify any needed refinements in HARM II.

CONCLUSIONS

HARM II is expected to provide a better approximation of relative risk than has been available previously in scoring systems suitable for wide application in setting remedial action priorities. Although HARM II was designed specifically to meet the needs of the Air Force, the concepts employed in HARM II should find application in other decision-making problems involving hazardous materials and waste sites. Important innovations in HARM II include estimation of contaminant hazard using actual risk approximations and the use of field data in determining the actual susceptibility of groundwater receptors. Like the original HARM, the HRS and other similar systems, HARM II is not a formal risk-assessment methodology but is designed for routine application to

large numbers of sites. Although the method is expected to produce reasonable approximations of relative risks, it is not possible to objectively relate the numerical scores to absolute levels of potential health and environmental hazard.

Additional changes could be made in HARM II to produce scores that would more closely resemble risk-assessment results. For example, the Receptors scoring categories might be expanded to include factors related to surface water dilution, aquifer dispersion or contaminant sorption in aquifers. However, most such refinements would imply greater data availability and reliability than can be realistically expected, and any potential improvements in scores do not appear to justify the additional effort that would be required to implement the system.

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Soil Cleanup Criteria for Selected Petroleum Products

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ABSTRACT

A large number of sites are contaminated with petroleum products which may pose a potential health hazard. Therefore, risk assessment and acceptable soil cleanup levels for these products are urgently needed. This paper compares alternatives for developing cleanup objectives for soil contaminated with petroleum products. A soil cleanup objective based on the concentrations of total petroleum hydrocarbons versus a soil cleanup objective based on the concentration of individual chemical constituents of concern is investigated.

A review of the chemical composition of crude oil, gasolines, petroleum naphtha, fuel oil No. 1 (jet fuel, kerosene), fuel oil No. 2 (heating oil, diesel oil), fuel oil No. 6 (Bunker "C"), lubricating oil, fresh motor oil and used motor oils (over 5,000 and 10,000 km usage) was undertaken to identify individual chemical constituents that would be harmful to public health and/or the environment. The carcinogenic polycyclic aromatic hydrocarbons (CaPAHs) and benzene were identified as constituents of concern. A lifetime soil exposure model based on pica tendencies and inhalation of soil was used to estimate soil concentrations of these constituents that would result in a one in a million (1×10^{-6}) cancer risk if exposure were to occur. These levels were compared with residual concentrations of CaPAHs and benzene in soil after cleanup to 110 ppm total petroleum hydrocarbons (PHs) for each petroleum product studied. For those constituents remaining in concentrations which would exceed a 1×10^{-6} if exposure were to occur, a soil cleanup objective which reduces the health risk to an acceptable level was proposed. In addition, the proposed cleanup objectives were compared to "normal" soil background levels of CaPAHs and benzene.

With the exception of motor oils used over 10,000 km, using 100 ppm of total PHs as the soil cleanup objective results in residual soil levels of CaPAHs and benzene not yielding a 1×10^{-6} cancer risk. Changing the soil cleanup objective from 100 ppm to 60 ppm will reduce CaPAHs from used motor oils over 10,000 km to an acceptable cancer risk level of one in a million. "Normal" background soil levels of benzene are exceeded in all products for which data were available.

Determination of soil cleanup objectives based on residual soil levels of CaPAHs and benzene cannot be further refined at this time due to the limited information available on the concentration of these compounds in petroleum products and in "normal" soil background levels.

INTRODUCTION

Large-scale terrestrial pollution can result from the production, transportation, storage and voluntary land disposal of petroleum products. Exposure to these products may result in adverse effects on public health and on the environment. This paper examines alternatives for developing acceptable soil cleanup levels (ASCLs) for soil contaminated with petroleum products. The focus is on exposure to contaminated soils through ingestion (pica) and inhalation and on the migration of petroleum compounds into groundwater. The literature was reviewed to identify constituents in petroleum products that are toxic and/or harmful in the environment. ASCLs were determined for carcinogenic constituents using risk assessment techniques. Soil cleanup levels for carcinogenic constituents were compared to a total petroleum hydrocarbons (PHs) cleanup objective of 100 ppm.

DETERMINATION OF ACCEPTABLE SOIL CONTAMINANT LEVELS

Risk assessment and soil cleanup objectives are presented only for individual chemical constituents of petroleum products which have the highest toxicity, the ability to migrate and/or are present in significant amounts. Emphasis was placed on chronic toxic effects (particularly carcinogenic) due to long-term exposure to contaminated soils. In order to accomplish this task, the following was performed: (1) review of physical/chemical properties, health effects and environmental fate of selected petroleum products; (2) identification of carcinogenic constituents and estimation of concentrations present in each particular petroleum product; (3) estimates of residual soil concentrations of carcinogenic constituents when 100 ppm total petroleum hydrocarbons is used as a cleanup objective; and (4) comparison of estimates with concentrations resulting in a cancer risk of one in a million (1×10^{-6}) and with "normal" background soil levels to determine if any of the carcinogenic constituents remain in the soil in concentrations that may pose a threat to public health. Comparison to background also was made since many regulatory agencies consider cleanup to background an appropriate remedial objective.

Due to space limitations, all areas reviewed are not covered in detail. This paper discusses briefly the toxicity and environmental fate of selected petroleum products.

IDENTIFICATION AND TOXICITY OF CONSTITUENTS IN PETROLEUM PRODUCTS

The following petroleum products are reviewed in this paper for identification of toxic constituents: crude oil, petroleum naphtha, gasolines, fuel oil No. 1 (jet fuel, kerosene), fuel oil No. 2 (heating oil, diesel oil), fuel oil No. 6 (Bunker "C"), lubricating oil, fresh motor oil, and used motor oils (over 5,000 and 10,000 km usage).

A review of the literature indicates that the most toxic constituents of petroleum products are the aromatics. After the aromatic fractions, toxicity decreases from olefins through naphthanes to paraffins.[1] Within each group, the hydrocarbons of lower molecular weight tend to be more toxic.[1] Exposure to high and low boiling fractions of petroleum (crude oil) is associated with carcinogenic effects. Moreover, exposure to polycyclic aromatic hydrocarbons (PAHs) present in certain heavy

residual oils[2] and to benzene present in unleaded gasoline[3] currently is being investigated for carcinogenic effects of these products. Crude oil is mutagenic[4] and is at the present time under toxicity review.[5] Kerosene currently is being tested for carcinogenicity.[6]

This paper primarily is concerned with chronic effects due to long-term exposure to soils contaminated with petroleum products. Of all the constituents identified, the carcinogenic polycyclic aromatic hydrocarbons (CaPAHs) and benzene (a known human carcinogen) are of most concern,[2,6] and cleanup objectives for soils contaminated with petroleum products are based on these compounds.

ENVIRONMENTAL FATE

Little is known about the environmental chemistry and ultimate fate of petroleum hydrocarbons in the soil environment. Their fate in land is affected primarily by their distribution, volatilization and leaching potential.[7] Low molecular weight aromatic hydrocarbons such as benzene, toluene, xylene, etc., which have a high Henry's Law constant, tend to partly evaporate. The remainder will migrate to different depths of the soil column where little or no volatilization to the atmosphere occurs.

The proportion of the petroleum hydrocarbons that will bind to soil versus those which will continue to migrate toward groundwater depends primarily on the type of soil, the particular petroleum product, the size of the spill and the amount of rainfall.[7] In general, leaching to groundwater is favored by high rainfall and permeable soils and increases for chemicals with high solubility, low diffusion coefficients and low absorption coefficients[9] such as the aromatics benzene, toluene and xylene.

Biodegradation is an important factor for removal of PAHs in general, but high molecular weight multiring compounds such as polycyclic aromatic hydrocarbons (PAHs) tend to remain in soil for long periods of time. Biodegradation may be enhanced in soils previously contaminated with PAHs. Naphthalene, a PAH with two rings, behaves differently from other PAHs because of its lower molecular weight and relatively high water solubility.[8] The rate of microbial degradation of PAHs in subsurface soil and in groundwater is favored under aerobic conditions.

Although migration of contaminants to groundwater is of concern, this paper is concerned primarily with chronic effects due to long-term exposure to contaminated soils.

ESTIMATED CONCENTRATIONS OF CaPAHs AND BENZENE

Concentrations of CaPAHs and of benzene in petroleum products vary depending on the type of crude oil and on the fractionation process used to derive the petroleum products. Table 1 summarizes information on the concentration of CaPAHs and benzene in the various petroleum products studied. The CaPAHs (benzo[a]pyrene (BaP), benzo[b]fluoranthene, chrysene, dibenz[a,h]anthracene, fluoranthene and indeno[1,2,3,c-d]pyrene) often are present in crude oils in very small quantities relative to the other PAHs.[10] However, as indicated in Table 1, used or spent petroleum products are enriched in content of BaP and other CaPAHs by as much as 200-fold in some cases.[2]

Information on the concentration of benzene in the various petroleum products studied is very limited. Of all the products listed, gasoline has the highest concentration of benzene ranging from 0.6 ppm to 2.9 mg/l for all grades and octanes. Of the gasolines, the concentration of benzene is highest in leaded gasoline (regular) during winter time. The concentrations of total benzenes (benzene, toluene, xylene and other substituted benzenes) of 10.2% in a highly aromatic fuel oil No. 2 and of 1.0% in fuel oil No. 6[10] indicate, as expected, that higher concentrations of benzene are found in low boiling fuels than in high boiling fuels. The concentration of benzene alone in these two products was not reported.

Table 1
Estimated Concentrations (ppm) of CaPAHs and Benzene in Selected Petroleum Products

Petroleum Product	Total CaPAHs*,ppm	Benzene,% Vol.
Crude Oil	12;26.3(a)	0.2(e)
	Below 100(b)	
	22.6(c)	
Gasoline (regular)	9.3(c)	1.1-2.9(f)
Gasoline (high octane)	7.4(c)	
Gasoline (low octane)	1.7(c)	1.1-2.9(f)
Gasoline (unleaded)		0.6-2.3(g)
Petroleum naphtha		0.2(h)
Fuel Oil No. 1 (jet fuel)	0.15(d)	-
Fuel Oil No. 1 (kerosene)	0.05(b)	-
Fuel Oil No. 2 (heating oil)	4.0(a)	
Fuel Oil No. 2 (diesel oil)	0.7(b)	
	0.03(c)	
	37.3(d)	
Fuel Oil No. 6 (Bunker "C")	329(a)	
Lubricating Oil	0.3(c)	
Fresh Motor Oil	0.2(c)	
Used Motor Oil	5.8(c)	
Used Motor Oil (5,000+ km)	303.6(c)	
Used Motor Oil (10,000+ km)	466.6(c)	

*Ranging from one to four CaPAHs from a total of six depending on the study and on the particular petroleum product: Benzo[a]anthracene, chrysene, benzo[a]pyrene fluoranthene, dibenz[a]anthracene and indeno[1,2,3,c-d]pyrene.

-Insufficient information available

(a) National Academy Press[10]

(b) U.S. EPA[11]

(c) Verschueren[12]

(d) U.S. EPA[13]

(e) Sachanen[14]

(f) Shelton[16]

(g) Shelton[17]

(h) Mellan[15]

ESTIMATED RESIDUAL SOIL CONCENTRATIONS OF CaPAHs AND BENZENE

Assuming a soil cleanup level of 100 ppm of total PHs, residual levels of CaPAHs and of benzene in soil contaminated with petroleum products were estimated. Residual soil levels were estimated using the highest concentrations of CaPAHs and of benzene reported in the various studies reviewed. It was assumed that no losses of these compounds occurred due to evaporation, biodegradation or migration to groundwater. Residual soil levels of CaPAHs and benzene were then compared to concentrations of CaPAHs and benzene which would result in a one in a million cancer risk if exposure were to occur. The residual soil concentrations also were compared to "normal" soil background levels of CaPAHs and benzene.

Calculation of Acceptable Soil Contaminant Levels

The acceptable soil contaminant level (ASCL) that would protect human health is based on direct contact exposure with the contaminated soil. A worst case exposure model for carcinogens[18] modified from Ford and Gurba[19] is shown below:

$$\begin{pmatrix}\text{Acceptable Soil}\\ \text{Cleanup Level}\end{pmatrix} = \left(\frac{A}{C}\right) \times \left(\frac{1000\ \text{g/kg}}{L}\right) \quad (1)$$

where:

A = Acceptable cancer risk = 1×10^{-6} (one in a million)

C = Carcinogenic potency factor (U.S. EPA CAG)
= 11.53 $(mg/kg/day)^{-1}$ for BaP and 0.0052 $(mg/kg/day)^{-1}$ for benzene

• 1000 g/kg = conversion factor

L = Lifetime average daily soil intake = 0.0028 g/kg/day

The model takes into account exposure to contaminated soils over a lifetime. Soil exposure is based on pica tendencies (in children), hand to mouthing and inhalation of dust. It is assumed that a 1×10^{-6} cancer risk is acceptable. Potency factors were obtained from the U.S. EPA, Cancer Assessment Group (CAG). The modified model does not take into consideration the half-life of the contaminant in soil. Intake of soil during peak pica years is assumed to be 2.5 g/day and not the 10 g/day contained in the original model.

Unfortunately, carcinogenic potency factors do not exist for specific CaPAHs except for BaP. It is assumed that all CaPAHs are as carcinogenic as BaP, and the potency factor for BaP was used in the calculation. This assumption is consistent with the U.S. EPA's approach to estimating cancer risks from exposure to mixtures of PAHs. Acceptable soil contaminant levels of 0.03 ppm and 6.9 ppm were calculated for CaPAHs and benzene, respectively.

Soil Background Levels of CaPAHs and Benzene

Information on soil background levels of CaPAHs and benzene was obtained from the literature. Limited information exists on soil background levels of PAHs in general.

Natural PAHs are due to plant synthesis, forest and prairie fires, volcanoes, etc. Anthropogenic sources are primarily from the extraction, processing and burning of fossil fuels. Most of the research on soil background levels of PAHs has been performed on BaP. Therefore, selection of "normal" soil background levels of PAHs was based on BaP.

The concentration of total PAHs (the sum 5 to 20 PAHs) usually exceeds 10 times the concentration of BaP.[20] BaP levels ranging from less than 5 to 10 ppb are generally found in agricultural soils.[8] Typical concentrations of BaP in soils of the world range from about 100 to 1,000 ppb, and values exceeding 100,000 ppb have been reported near known sources.[19] It has been suggested that endogenous BaP concentrations in soil are 1-3 ppb and never exceed 10 ppb.[20] A level of 50 ppb was selected as the "normal" background of total PAHs in soil since this level is typically found as background.[8]

Limited data are available on benzene levels in soils. Levels ranging from 13 to 115 ppb of benzene were reported in soil samples taken in the vicinity of chemical plants that use or produce benzene.[21] No information exists on the level of benzene in "clean" soils. A soil background level of less than 10 ppb was selected since this level is within the range of "normal" soil background levels of most organics.[8]

The ASCL of 30 ppb for CaPAHs (assuming a 1×10^{-6} cancer risk) is within the range of typical soil background levels of PAHs. However, the ASCL of 6.9 ppm for benzene exceeds typical soil background levels of benzene.

Examination of Table 2 reveals that, after site remediation to 110 ppm of total PHs, only soil contaminated with used motor oils over 10,000 km will have concentrations of CaPAH that exceed a 1×10^{-6} cancer risk (by approximately 67%). As shown

Table 2
Estimated Residual Soil Concentrations (ppm) of CaPAHs Exceeding Concentration of CaPAHs at 10^{-6} Cancer Risk and "Normal" Soil Background Level of CaPAHs

Petroleum Product	Total CaPAHs*, ppm	Total CaPAHs Exceeding 10^{-6} Cancer Risk**	Total CaPAHs Exceeding "Normal" Soil Background***
Crude oil	3×10^{-3} (a)	N	N
Gasoline (regular)	9×10^{-4} (b)	N	N
Gasoline (high octane)	7×10^{-4} (b)	N	N
Gasoline (low octane)	2×10^{-4} (b)	N	N
Gasoline (unleaded)			
Petroleum naphtha			
Fuel Oil No. 1 (jet fuel)	2×10^{-5} (c)	N	N
Fuel Oil No. 1 (kerosene)	5×10^{-6} (d)	N	N
Fuel Oil No. 2 (heating oil)	4×10^{-3} (c)	N	N
Fuel Oil No. 2 (diesel oil)	4×10^{-2} (c)	N	N
Fuel Oil No. 6 (Bunker "C")	3×10^{-2} (b)	N	N
Lubricating Oil	3×10^{-5} (a)	N	N
Fresh Motor Oil	2×10^{-4} (b)	N	N
Used Motor Oil	6×10^{-2} (b)	N	N
Used Motor Oil (5,000+ Km)	3×10^{-2} (b)	N	N
Used Motor Oil (10,000+ Km)	5×10^{-2} (b)	Y	N

*One to four CaPAHs from a total of six depending on study and on particular petroleum product: Benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, chrysene, dibenz[a,b]anthracene, and indeno[1,2,3,c-d]pyrene.

**CaPAHs at 10^{-6} cancer risk (based on BaP): 0.03 ppm

***"Normal" soil background of PAHs: 0.05 ppm

- Insufficient information available

Y Exceeding

N Not exceeding

(a) National Academy Press,[19]

(b) Verschueren[11]

(c) U.S. EPA[11]

(d) U.S. EPA[11]

Table 3
Estimated Residual Concentrations (ppm) of Benzene Products Exceeding Concentration of Benzene at 10^{-6} Cancer Risk and "Normal" Soil Background Level of Benzene

Petroleum	Benzene, ppm	Benzene Exceeding 10^{-6} Cancer Risk**	Benzene Exceeding "Normal" Soil Background**
Crude oil	0.2(a)	N	Y
Gasoline (regular)	1.1-2.9(b)	N	Y
Gasoline (high octane)		N	Y
Gasoline (low octane)	1.1-2.9(b)	N	Y
Gasoline (unleaded)	0.6-2.3(c)	N	Y
Petroleum naphtha	0.2(d)	N	Y
Fuel Oil No. 1 (jet fuel)			-
Fuel Oil No. 1 (kerosene)	-		
Fuel Oil No. 2 (heating oil)	-		
Fuel Oil No. 2 (diesel oil)		-	
Fuel Oil No. 6 (Bunker "C")	-		-
Lubricating Oil		-	
Fresh Motor Oil		-	-
Used Motor Oil		-	-
Used Motor Oil (5,000+ Km)		-	-
Used Motor Oil (10,000+ Km)			-

*ASCL for CaPAHs at 10^{-6} cancer risk: 6.9 ppm

**"Normal" SBL of benzene: less than 0.01 ppm

- Insufficient information available

Y Exceeding

N Not exceeding

(a) Sachanen[14]

(b) Shelton[14]

(c) Shelton[11]

(d) Mellan[11]

in Table 3, soil contaminated with crude oil, naphtha and gasoline (all grades and octanes) has benzene levels below the ASCL for benzene. Comparison with "normal" soil background levels reveals that residual soil concentrations of CaPAHs are within the range of "normal" soil background levels of PAHs. However, residual soil concentrations of benzene from contamination with crude oil, petroleum naphtha and gasoline (all grades and octanes) are above the "normal" soil background level of benzene as expected. The residual soil concentrations of benzene from crude oil and naphtha exceed the soil background level of benzene in excess of 20 times and that from gasoline by 90 times.

CONCLUSIONS AND RECOMMENDATIONS

Assuming a soil cleanup level of 100 ppm for total petroleum hydrocarbons, most of the residual soil levels of CaPAHs and benzene are below their corresponding concentrations resulting in a 1×10^{-6} cancer risk. An exception is the residual soil level of CaPAHs from contamination with used motor oils over 10,000 km which has a risk of 1.6×10^{-6}. In this case, lowering the soil cleanup level of 100 ppm to 60 ppm for total PHs, will decrease soil concentrations of total CaPAHs from contamination of the above product to levels resulting in a cancer risk of 1×10^{-6}. Alternatively, testing soil samples for CaPAHs could be performed after soil is cleaned to 100 ppm of total PHs to determine if CaPAHs levels remaining in soil are acceptable.

Comparison of residual soil levels of CaPAHs and benzene with their respective soil background levels, indicates that, in general, residual levels of CaPAHs are within the range of typical soil background levels of PAHs. On the other hand, residual soil levels of benzene exceed the assumed "normal" soil background level of benzene. Further refinement of this comparison cannot be made at this time due to limited information on "normal" soil background levels of these compounds and due to the volatilization of benzene with time.

A more extensive data base on petroleum products is needed to refine the risk assessment approach proposed. Specifically, more data on the identification and concentration of chemical constituents, behavior in the soil environment, toxicity and normal soil background concentrations are needed.

More toxicity testing of petroleum products and individual constituents is needed to better understand the carcinogenic potency of individual CaPAHs and of mixtures before a more refined ASCL can be estimated.

In summary, with the exception of motor oils used over 10,000 km, 100 ppm of total PAHs as a soil cleanup objective appears to result in residual soil levels of CaPAHs and benzene not exceeding a 1×10^{-6} cancer risk. Although this cleanup objective is protective in a direct soil contact scenario, it may not adequately address groundwater protection.

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Risk Management: Personnel, Equipment and Indemnity

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ABSTRACT

Risk management always has been a key ingredient in the overall management scheme of the hazardous materials cleanup and site restoration industry. Since the industry's beginnings in the early 1970s, companies have been practicing risk management, whether or not identified by that particular name. As the industry has evolved and more has been learned about potential risks, the need for a well-defined risk management program has increased. Current health and safety regulations, increased litigatory actions and the ominous problems with insurance coverage have produced a realization of the critical nature and overall importance of risk management. Three areas where risk management can have a significant impact on company operations are personnel, equipment and general indemnity.

INTRODUCTION

Risk management can be defined as the management or control of the possibility of loss or injury. This management has both a social or moral aspect as well as practical ramifications. A waste of manpower, time, resources and efficiency are just a few of the effects of accidents that could have been managed or prevented. In order to manage risk, one must identify the following for all potential risks: degree of hazard or danger; probability of occurrence; methods of prevention; and preferred health and safety plan.

Identifying and managing risk has become so important to the hazardous waste industry and to society that many universities have recently added risk management courses to their core insurance curriculums. Businesses are beginning to employ people that have risk management as their prime job function. Personnel, equipment and general indemnity are the three areas that this paper will address.

PERSONNEL

The one area most often overlooked in an active growing company is the area of personnel management. Personnel management encompasses a wide range of functions, but for the purposes of this paper, only the area of risk management will be discussed. Risk management as it relates to personnel involves minimizing exposure to hazardous conditions, providing and requiring proper training, publicizing and maintaining employee interest in safety and instituting an efficient record-keeping system.

Hazardous materials cleanup work involves, by its very nature, a certain degree of exposure to risk. The job of risk management is to minimize the degree and quantity of that exposure. The degree of exposure relates to the individual's physical exposure, while quantity relates to the number of individuals actually exposed. Both of these concerns usually arise in operational settings where prior planning is the best solution to potential problems.

Exposure

Physical exposure is minimized by a thorough knowledge of the work site and conditions present. What chemicals are involved? What properties, concentrations, etc., did the analysis reveal? Is there potential exposure to irritants, poisons, skin absorption, etc?

Once the hazardous conditions are defined, the proper selection of protective equipment and safety measures can be made. The equipment selected may include what types of boots, gloves, respirators or supplied air system, protective suit or coveralls, are required. Once the proper type of equipment has been selected, management must make sure that the employees use and maintain the equipment correctly.

The investment in time and effort required to correctly protect employees and minimize physical exposure pays significant dividends in workplace efficiency and decreases the risk of litigatory actions.

Quantity exposure as described earlier involves numbers. Generally, in the hazardous materials business, numbers relate most directly to the number of employees specifically involved. Thorough planning before a job begins is the best method of controlling quantity exposure. A careful study of the scope of work and the proposed work plan will allow the project manager to properly select his project team. The project manager's work plan should be designed to expose the fewest number of employees. Fire departments, police departments and military units have successfully followed this principle for many years. In reality, basic common sense plus careful analysis and safety planning will minimize the number of persons exposed.

Training

How important is training? Would you fly with an untrained pilot? Would you hire an untrained lawyer? It is obvious, given the current regulatory attitude toward the work place, that proper employee training is critical. In the early days of this industry, many things were done without adequate training because the industry was so new and procedures and standards were ill-defined. As the industry has grown and aged, it has defined many of the skills required to work safely and can now train people in these skills.

Training in the hazardous materials industry is a cross between EMT, fire department and military training programs. A training program should include a discussion of standard work practices, personal hygiene, first aid, CPR, etc. Detailed training in the selection and proper wearing of protective equipment is essential. Training with the proper content and attitude is like preventive maintenance for your work force.

Record Keeping

The last area that will be discussed under personnel is record keeping. So far, the discussion of risk management has had a pure health and safety theme. Record keeping, however, is necessary to facilitate the treatment of an employee and to serve as proof that adequate training was offered and required. The question of risk management versus liability will be discussed in the last section of this paper.

Keeping accurate records is proof that a particular health condition was or was not job related, or that someone was or was not injured by exposure to a hazardous situation. Given the occupational health and safety and workmen's compensation laws currently in existence, detailed personnel records are an absolute must.

EQUIPMENT

Risk management with regard to equipment, particularly over-the-road equipment, in view of the current insurance crisis and large injury awards for equipment-related injuries must be an integral part of business strategy. The following example illustrates this.

An employee driving a company truck is involved in an "at fault" accident. It is determined that the employee was DUI in a truck with faulty brakes, and the other driver sustained injuries. Is this scenario not an example of the importance of driving safely and adhering to company policy adequately communicated to the driver? No business can afford to fail to communicate the importance of proper equipment maintenance to its operations department. The difficulty of obtaining insurance continues to reinforce the necessity of the proper maintenance and use of equipment.

The hazardous waste industry requires a variety of equipment including trucks, cars, heavy equipment, protective suits, respirators, masks, hand tools, eye wash bottles, decontamination equipment, etc. Often, the major emphasis or interest is focused on equipment which can be driven on public highways. However, no piece of equipment should be placed in operation until it has been inspected by a qualified person and found to be in safe operating condition. Routine inspection after each project should be made, and inspection reports and service records should be kept on file.

Obviously, the most logical way to minimize equipment related injuries and losses is through the proper maintenance and use of that equipment. A U.S. Army Corps of Engineer study revealed that a "great majority of accidents were caused by inadequate maintenance of equipment, insufficient instruction in safe practices or lack of insistence that safe practices be observed." Unsafe practices contributed to 80% of all injuries. Remember the example given earlier in this section: equipment related losses can become extremely complicated and costly if they are not positively affected by good risk management practices.

INDEMNITY

According to Webster, indemnification is "the action of securing against hurt, loss or damage." Nothing causes more concern, argument, loss of coverage or law suits than the subject of indemnity. The most difficult area to negotiate for any contract is the indemnity section. Ideally, you would want to be indemnified for everything and yet give indemnification for nothing. Practically, you must negotiate the best position you can with the other party. One of the important things to remember is that most insurance coverages are tied very closely to indemnification and how it affects the risk that you are being insured against. The first rule of good business practice is to be absolutely sure that you can live with the indemnification you agree to because you just may have to live with it. Never agree to accept a risk expressly prohibited by your insurance coverage unless you intend to self-insure that risk.

This paper will not discuss all the legal ramifications of indemnities. However, one major point should be recognized. The law does not make an engineer completely responsible for a project's success. Engineering is not a perfect science, and "acts of God" can occur even when an engineer exercises professional judgment and utilizes adequate skills. Indemnification clauses, written to the advantage of your client, can make the engineer (and your company) a guarantor, an insuree, of a project's success. Do not agree to this.

Indemnification is a major vehicle to either increase or decrease risks, so be aware of what you agree to indemnify. It is the recommendation of the authors that you only be liable for your own negligence.

CONCLUSIONS

Risk Management is a function of management that requires thought, planning, implementation and considerable expertise. It becomes more important as the hazardous waste industry continues to be plagued by loss of insurance coverage, workmen's compensation claims, litigation and huge jury awards. The importance of managing risk is being recognized by industry and academia and is fast becoming an integral part of successful companies' management plans. Good risk management in the areas of personnel, equipment and indemnification is good business, and good business is what makes a good profit.

Innovative Approach to Site Remediation Involving an RCRA Part B Permit

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ABSTRACT

A preliminary investigation of an abandoned industrial waste disposal site indicated the presence of materials containing hazardous substances and groundwater contamination. The parties involved are the owner, the Iowa Department of Water, Air and Waste Management (IDWAWM) and the U.S. EPA Region 7. As a result of the preliminary investigation, a stipulation between the owner and IDWAWM was enacted. A detailed site investigation confirmed the following:

- A complex geophysical structure
- The presence of material containing hazardous substances
- The presence of a layer of floating volatile organic compounds (VOCs)
- The presence of contaminated groundwater in the vicinity of the site

To date, the owner has undertaken the remedial investigation activities and proposes to voluntarily undertake the feasibility study and cleanup. To meet the needs of the owner and satisfy the requirements of the regulatory agencies, it was determined that a Part B permit for Waste Piles would be required as part of an innovative approach to site remediation.

INTRODUCTION

Industrial wastes resulting from the manufacture of paint and varnish products were placed into a land disposal facility. The aquifer directly under the site is utilized as a source of water for domestic and agricultural uses throughout the area. This proximity of waste and groundwater was sufficient cause to place the site on the proposed National Priority List. In this paper, the authors describe the following: site history; remedial investigation activities; summary of releases/contamination; proposed remedial action plan; owner/regulatory agencies relationship; Part B permit; and the innovative approach to site remediation.

SITE DESCRIPTION AND HISTORY

Prior to the early 1970s, the owner disposed of his wastes by open burning. Enactment of the Clean Air Act, however, prohibited this practice, and an alternate method of disposal was necessary. The owner sought the aid of the State of Iowa, and an agreement was reached whereby the owner's wastes were to be disposed at an abandoned gravel pit in rural Iowa.

Between 1971 and 1979, solid and liquid wastes generated from the owner's paint and varnish manufacturing operations were disposed in a series of 12 trenches at the site (Fig. 1). The trenches were slot-dozed to a depth of between 8 and 12 ft. After the trenches were opened, they were filled with waste fluids poured from 55-gal drums. Each trench remained open for an extended period of time to allow for evaporation of volatile hydrocarbons. Before a trench was closed, it was topped off by placing in it a relatively large quantity of drums and small buckets containing waste paint sludges, resins, solvents and general trash. After the level of waste material in each trench approached the natural ground surface, the trench was covered with 1 to 2 ft of the clayey silt loess soils initially excavated from the trenches.

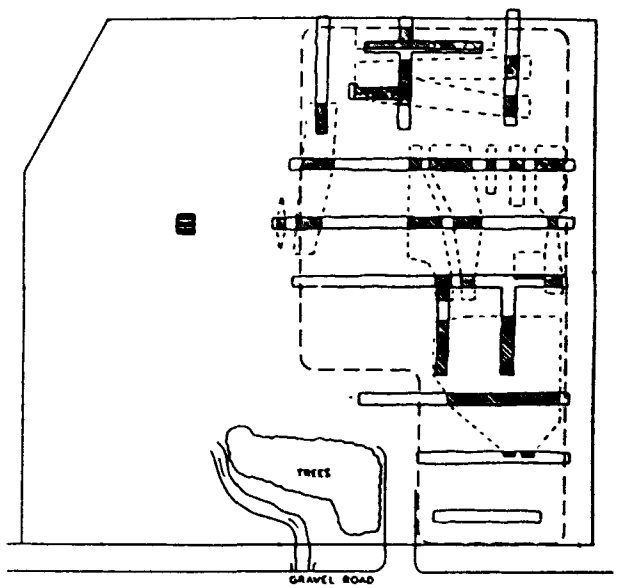

Figure 1
Plan View of Waste Disposal Trenches

Although accurate records were not kept by the owner, an estimated 150 to 300 drums (55-gal) were buried at the site and as many as 43,000 gal of liquids were dumped in the trenches. The wastes contained approximately 6,000 lb of heavy metals (e.g., lead, cadmium, chromium, zinc and mercury) and an unknown quantity of volatile organic compounds (e.g., xylene, toluene, ethylbenzene, methylethyl ketone and mineral spirits).

The waste disposal site was closed in 1979. Wastes generated after 1979 were disposed in properly permitted facilities.

REMEDIAL INVESTIGATION

Remedial investigation activities began in 1979 at the request of the State of Iowa. The ultimate goal of these activities was to obtain sufficient information regarding the soil and groundwater contamination at the site so that a closure plan could be developed and implemented. Because of the complex geophysical na-

ture of the site, remedial investigation activities were conducted in several phases between 1979 and the end of 1984. A brief summary of the activities performed during this time is presented below.

1979—Activities were limited to a subsurface investigation to determine potential off-site migration of wastes. Thirty of thirty-five borings were drilled on and immediately adjacent to the site. Only water level measurements were taken, and the borings were subsequently backfilled.

1982—Five monitoring wells were installed. Floating hydrocarbons were detected in one of the wells and samples were taken during subsequent months for chemical analyses.

1983-1984—The presence of a substantial thickness of floating hydrocarbons in two of the monitoring wells prompted IDWAWM to issue an administrative order requiring containment and recovery of the contaminant plume, proper disposal of recovered waste and proper closure of the site.

May 1984—Observation pits were dug at the site to determine the approximate quantities of waste materials buried in the trenches. Samples also were taken from the trenches and from other soil borings to determine the concentrations of hazardous constituents in the trenches and soil. The geological stratigraphy of the site was evaluated. Seventeen monitoring wells were installed and developed. Groundwater samples were subsequently obtained and analyzed for contamination.

August 1984—IDWAWM ordered the owner to remove floating hydrocarbons periodically and to take quarterly samples from the monitoring wells.

September 1984—Nine additional monitoring wells were installed and developed. Testing was conducted to determine the aquifer characteristics.

Present—The owner continues to remove floating hydrocarbons, make biweekly water level measurements in the monitoring wells and take quarterly groundwater samples.

SUMMARY OF RELEASES/CONTAMINATION

As a result of the disposal of hazardous waste liquids in the trenches beginning in 1971, the most immediate impact has been the release of hazardous materials to the underlying shallow aquifer system. A secondary impact due to the continuing deterioration of buried drums probably is resulting in more recent and continual releases of hazardous materials to the aquifer.

Due to the unique characteristics of the hydrogeology in the area of the site, the extent of groundwater contamination appears to be limited to the site and to a distance only several hundred feet away from the site. The degree of groundwater contamination depends on the compound. The maximum concentration of the volatile organic compounds ranges from 28 mg/l for toluene to 260 mg/l for xylene. The maximum concentration of heavy metals ranges from 50 µg/l for lead to 80 µg/l for chromium.

The extent of soil contamination is limited primarily to the waste disposal trenches and the vadose zone directly below the site. The maximum degree of soil contamination ranges from 15 ppm for chromium to 1,700 ppm for xylene.

As mentioned in the remedial investigation section, there is a floating layer of relatively pure hydrocarbons that is unique to a small portion of the groundwater adjacent to the site. These hydrocarbons are removed by pumping biweekly as part of an IDWAWM stipulation.

PROPOSED REMEDIAL ACTION PLAN

A feasibility study currently is being written to compare various remedial action alternatives for cleanup of the disposal site. The objective of the feasibility study is to recommend a remedial action plan for cleanup of soil and groundwater that effectively provides protection of human health and the environment at the least cost.

The proposed remedial action plan will likely include the cleanup activities discussed below.

Source Removal and Ultimate Treatment

Hazardous wastes will be exhumed from the trenches and will be disposed in properly permitted facilities or will be treated in a manner to render the wastes non-hazardous.

Free-standing liquid wastes in the trenches and liquids taken from drums will be stored temporarily in a tanker truck. Then the liquids either will be recovered in the owner's distillation equipment or will be sent off-site and ultimately destroyed by incineration.

Solid wastes (e.g., contaminated soil, drums, buckets, trash, etc.) will be stored temporarily on-site in above-ground concrete bunker silos. Treatment technologies for the solid wastes will be investigated and/or tested while the wastes are safely stored in the silos. Treatment methods may include incineration, air stripping, encapsulation, biodegradation and physical/chemical treatment.

Recovery and Treatment of Groundwater

Groundwater will be pumped, treated and reinjected into the aquifer. The treatment/flushing action will continue until the groundwater is rendered non-hazardous. Treatment methods likely will include air stripping and carbon adsorption.

Owner's Involvement

The owner has expressed a high degree of interest in the proposed remedial action plan presented above. His basic philosophy is to have as much control of his present and future liability as possible. He believes that the proposed remedial action plan will provide effective remediation of the site at the least cost and with the least liability. In addition, the least cost treatment technology which will render the wastes non-hazardous may be found while the waste is safely stored on the owner's property. Not surprisingly, this general type of remedial action (i.e., on-site storage/treatment) is favored by the U.S. EPA.

OWNER/REGULATORY AGENCIES RELATIONSHIP

Three parties (the owner, IDWAWM and the U.S. EPA Region 7) are involved with the cleanup of the disposal site. Due to the nature of the relationships among the three parties, there could have been some potential problems. The owner is a responsible private party willing to finance the remedial investigation/feasibility study and site cleanup. IDWAWM is responsible for the cleanup and monitoring of uncontrolled hazardous waste disposal sites in the State of Iowa. The U.S. EPA Region 7 is responsible for all RCRA programs.

The State of Iowa returned RCRA responsibility to the U.S. EPA in mid-1985. Included in the U.S. EPA's RCRA responsibility is the issuing of Part B permits for treatment, storage and disposal facilities and the monitoring of these same facilities. Cooperation among the three parties in the past and at the present time has allowed effective progress toward site cleanup.

When the owner expressed interest in storing the exhumed wastes on-site, a meeting was convened with the regulatory agencies to discuss the ramifications of this proposed action. Although the owner's disposal site is on the proposed National Priorities List (NPL), the owner learned that an RCRA permit would be required prior to the construction of the storage facility. Because the site was not under an emergency cleanup order, the requirements of other environmental laws (e.g., RCRA) would have to be followed. The regulatory review of a Part B permit applica-

tion can take a great deal of time. The owner wished to lean up the site as quickly as possible and was naturally disappointed when he learned a permit was required. It would have been easy for the owner to criticize the U.S. EPA for "dragging its feet" regarding the cleanup of the site; however, the requirements of the RCRA permit program were seen by the owner as necessary to protect human health and the environment from potential damage as a result of the cleanup.

It is especially important to develop good relationships between the owner and the regulatory agencies involved in a site cleanup. Issues can be addressed and problems can be solved only if each party keeps an open mind and communicates and cooperates with the others.

PART B PERMIT

To fulfill the owner's desire to store the exhumed hazardous wastes in an above-ground facility, a Part B permit was required. As mentioned previously, the cleanup of this site required the adherence to other environmental laws, most notably RCRA. The filing of a Part B permit application for this innovative approach to site remediation is unique. Historically, cleanup of an uncontrolled waste site involves the transportation of the wastes to an off-site RCRA-permitted disposal facility. This action does not require the owner of the uncontrolled waste site to wait while a permit is reviewed and approved; however, it also does not give the owner much control over his liability. In the case study reported in this paper, the owner is willing to wait for a Part B permit in order to implement an innovative approach that allows him to better control his liability.

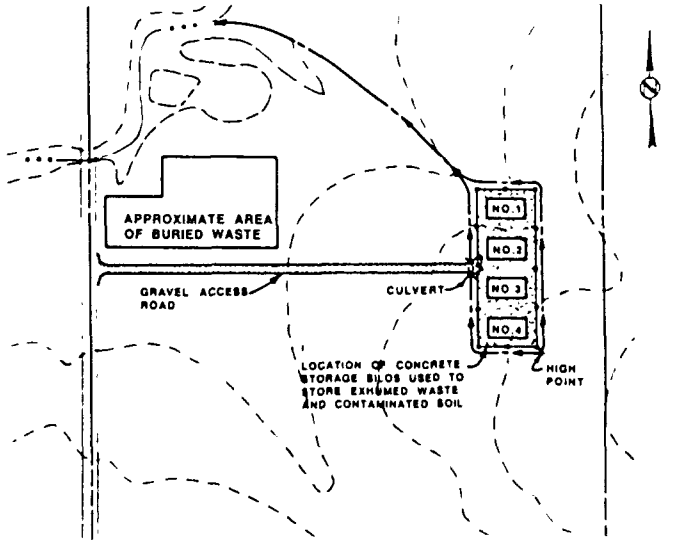

Figure 2
Location of Bunker Silos Relative to Disposal Site

Facility Description and Use

The Part B permit application was made for a new on-site storage facility comprised of four above-ground bunker silos located adjacent to the waste disposal site (Figs. 2 and 3). Each silo will be rectangular with its dimensions being 56 ft wide, 104 ft long and a wall height of 12 ft. Each silo is expected to store, in piles, approximately 1,750 yd³ of waste.

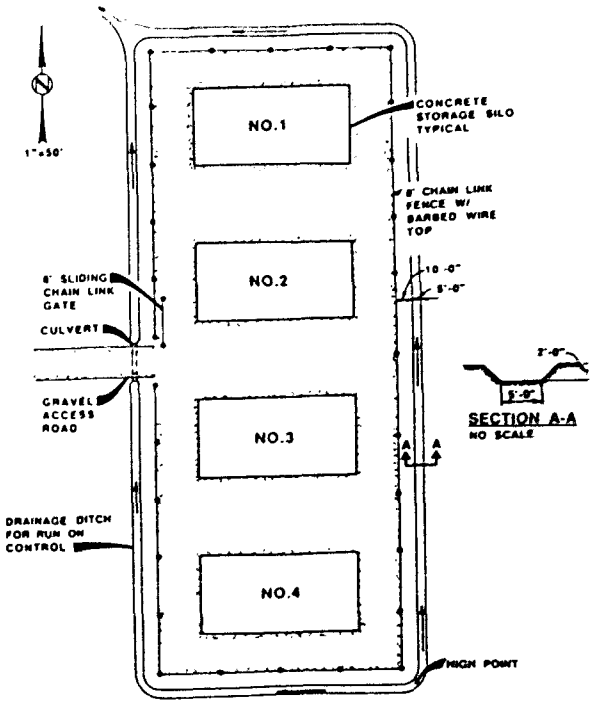

Figure 3
Site Plan of Bunker Silos

The sole purpose of the facility is to temporarily store contaminated soils and other hazardous solid wastes that will be removed from the waste disposal site. Liquid wastes or soils containing free liquids will not be stored. These materials are to be either solidified on-site prior to storage or manifested and transported to a licensed facility for incineration.

The waste materials are to remain in storage while various technologies are investigated and/or tested to treat them. The ultimate goal is to treat the materials in the storage facility to permanently render them nonhazardous. Then the waste materials can be delisted. The treated soils can be returned to the disposal site, and the other solid materials can be disposed as non-hazardous wastes.

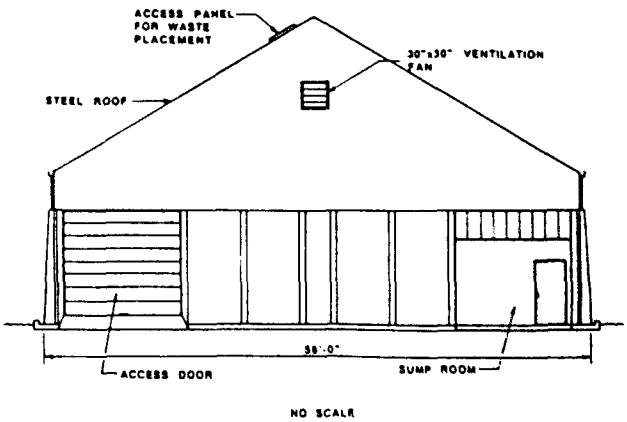

Figure 4
Elevation View of Typical Bunker Silo

Bunker Silo Design Elements

The bunker silos are designed to provide protection of the waste piles from precipitation so that neither runoff nor leachate is generated. Each silo will have a reinforced concrete base, concrete walls and a steel roof (Figs. 4 and 5). A 6-in. concrete curb will surround the silo, thus providing protection from surface water run-on. Because the waste pile will be enclosed by walls and a roof, the wastes will not be dispersed by the wind. Because liquids will not be placed in the piles, leachate is not expected to be generated by biological or chemical degradation during the time the piles are in existence. Each silo also will be equipped with a ventilation fan to minimize the buildup of organic vapors to explosive levels.

The above elements of the structure are considered sufficient to allow the owner to request an exemption from liner and leachate standards and from groundwater monitoring requirements under the 1984 RCRA Amendments. Although a request was made for the above exemptions, it is the owner's stated intent to provide a state-of-the-art facility. Therefore, for added protection of human health and the environment resulting from the potential release of hazardous wastes, a double synthetic liner system will be installed accompanied by leak detection and leachate collection systems (Figs. 5 and 6).

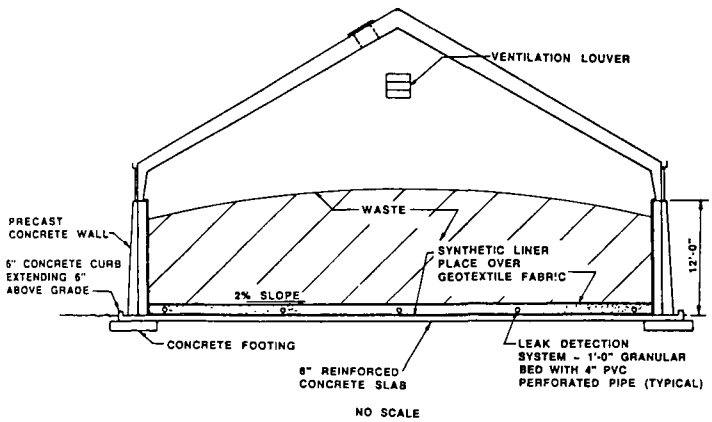

Figure 5
Typical Cross Section of Silo Showing Design Elements

The owner chose to include synthetic liners and leak detection/leachate collection systems in the design of the storage silos to serve as an additional safety factor. The owner had enough foresight to realize that, for a relatively small increase in cost, he could decrease his liability considerably by minimizing the potential for a non-sudden release of hazardous waste.

Placement of Wastes

An auger will be used to transfer the waste materials into each silo via open panels in the roof. Inside the silo, a small end loader will move the materials into a pile. Plastic sheeting will be placed on the ground around the auger to collect spillage. Portable wind screens near the auger will prevent wind dispersal of dry waste materials.

Closure of Facility

As mentioned previously, the goal of the remediation program is to ultimately treat the soils and wastes so that they can be disposed as non-hazardous materials. The duration of storage in the bunker silos is unknown and will be dependent upon the development of appropriate technologies and subsequent testing of these

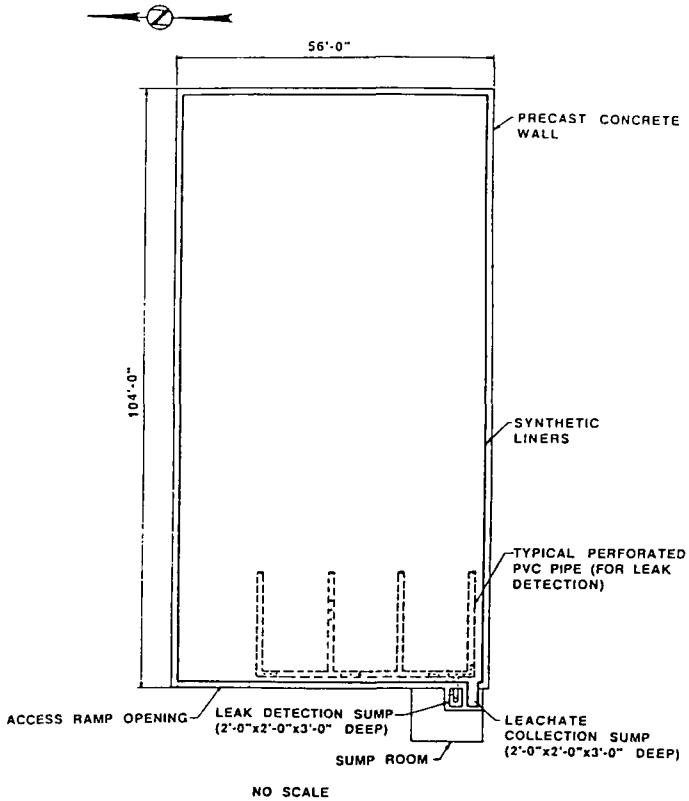

Figure 6
Plan View Cross Section of Typical Bunker Silo

technologies on the stored wastes to determine what constitutes effective treatment. It is possible that future technologies will not prove completely effective and that one or more of the silos may need to be repermitted as disposal facilities.

If treatment technologies are proven effective and the wastes in the piles are removed and rendered non-hazardous, the storage silos will be closed. The bunker silos and equipment stored within them will be tested to determine if they are contaminated. Appropriate procedures will be used to decontaminate any contaminated structure or equipment.

INNOVATIVE APPROACH TO SITE REMEDIATION

Because the owner wanted to clean up his site as soon as possible, a two-stage approach to remediation originally was conceived. The scenario was as follows. The first stage of this approach would involve removal of the source of contamination. A feasibility study addressing source removal would be written, followed by review and approval by ISWAWM. Following approval, the cleanup of the source would begin and take approximately 6 to 7 months using the services of local contractors.

While the source is being removed, the second stage of the approach, remediation of groundwater, would be addressed. A feasibility study for this stage would be prepared. Following IDWAWM review and approval, the groundwater cleanup would begin in the subsequent calendar year.

When it was learned that a Part B permit would be required for on-site storage, it was determined that a two-stage approach would not work. Instead, the owner was faced with making a choice between two options concerning the logistics of remediation. The first, and more traditional, option involved writing a feasibility study for total site remediation, followed by

IDWAWM review and approval of the recommended alternative. If a Part B permit was required before site cleanup could begin, the permit application would then be prepared, followed by U.S. EPA review and approval. The problem with this option is that it would take a minimum of 1 year to receive a Part B permit after the U.S. EPA received the application. All parties involved (owner, ISWAWM and U.S. EPA) thought that this option would unnecessarily delay site cleanup and a second option was considered.

The second option involved a more innovative approach to remediation. This option involved first preparing a Part B permit application under the assumption that the on-site storage alternative ultimately would be the approved alternative for source cleanup. In conjunction with the U.S. EPA review of the permit application, a feasibility study for total site remediation would be prepared, followed by IDAWAWM review and approval. Copies of the Part B permit application and feasibility study would be shared by both regulatory agencies so that a coordinated approach to site cleanup would result. The major risk involved with this option would be that if on-site storage was not the approved alternative, the expense of preparing a Part B permit application would be wasted.

The owner chose to pursue the second, more innovative, option to site remediation. At the present time, a Part B permit application for the on-site bunker silos is being reviewed by the U.S. EPA. A feasibility study is being written concurrently and will be reviewed by IDWAWM. Because the owner and regulatory agencies discussed the options at an early stage, the risk involved in pursuing the innovative approach is considered minimal. The result of this action likely will be a faster cleanup of an NPL site (savings of time of at least 1 year) than if the traditional approach was pursued.

CONCLUSIONS

The proposed remediation of an uncontrolled waste disposal site in rural Iowa is being implemented using an innovative alternative for storage of wastes and an innovative approach to the regulatory review process. Conclusions made from the work performed to date are:

- Off-site storage of exhumed solid wastes in above-ground bunker silos is an attractive and innovative alternative compared to simply transporting and disposing the wastes in a distant landfill. The owner of the wastes is better able to control his liability with an on-site facility, and the wastes can be stored safely while subsequent testing is conducted to determine the most effective and least costly ultimate treatment alternative.
- Although the above-ground silos are designed to effectively contain the waste, the owner likely will implement a double synthetic liner system to give added protection.
- An innovative approach to the regulatory process is being implemented whereby a Part B permit application for the storage facility is being submitted prior to the submission of a feasibility study addressing site remediation. This approach likely will result in a more expedient cleanup of the site relative to a traditional approach.
- Innovative approaches to the regulatory process are more likely to be successful if all parties involved in the process (e.g., owner, regulatory agency) can effectively communicate, cooperate and keep an open mind. This is especially important when more than one regulatory agency is involved.

Overview of the Proposed Natural Resource Damage Assessment Regulations

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ABSTRACT

This paper describes and explains the natural resource damage assessment regulations issued in proposed form in December 1985. These regulations were developed by the U.S. Department of the Interior under the authority of section 301(c) of CERCLA. The regulations are to be used for assessing damages to natural resources which result from a release of a hazardous substance or oil. Claims for such damages can be presented to a responsible party under the liability provisions of CERCLA, section 311(f)(4) and (5) of the Clean Water Act or the Superfund. Some examples of the resources involved include groundwater, surface water, park and recreation areas, wetlands, wildlife habitat, fish and wildlife, air and soil. They are applicable to all Federal and State agencies that manage natural resources including, among others, the U.S. Department of Defense, State fish and game agencies, the U.S. Department of Energy and State park authorities.

INTRODUCTION

CERCLA and the Clean Water Act are the major federal authorities for responding to releases of hazardous substances and oil. Although the response authorities and the funding mechanism for these responses constitute the focus for most discussions of these laws, this paper focuses on the issues embodied in the second half of CERCLA's title: compensation and liability. Specifically, the paper deals with the liability of the parties responsible for the release for resulting damages to natural resources and the appropriate measurement of the compensation. These issues form the nucleus of the proposed natural resource damage assessment regulations required by section 301(c) of CERCLA and promulgated by the U.S. Department of the Interior in December 1985.

Although promulgated by the Department of Interior, the section 301(c) natural resource damage assessment regulations are written for the use of all Federal and State agencies which claim trusteeship for natural resources under CERCLA. CERCLA broadly defines natural resources to include all elements of the environment, including such living resources as fish, wildlife and other biota and such physical resources as land, air, drinking water and groundwater. Examples of agencies that may make use of the regulations include park authorities, fish and wildlife agencies, and land and water management agencies. A rebuttable presumption is a legal mechanism which effectively gives the claimant an advantage in any administrative or litigative actions. The use of these rules in some instances will provide a rebuttable presumption for the assessment.

*This paper represents the views of the authors and not those of the U.S. Department of the Interior.

Section 301(c) requires that two types of regulations be developed; the so-called type A and type B regulations. The type A regulations are to be standard procedures for simplified assessments involving minimal field work. The type B procedures are to include alternative protocols for the assessment of damages on a case-by-case basis. This paper provides an overview of the entire damage assessment process and focuses on the type B assessment procedures. It does not address the type A procedures.

DAMAGES ARE THE RESIDUAL OF RESPONSE ACTIONS

Section 107(a) of CERCLA outlines the liability of responsible parties for CERCLA-covered releases to include:

- The costs of removal and remedial action incurred by the United States Government or a State that are not inconsistent with the National Contingency Plan
- Any other necessary costs of response incurred by any other person consistent with the National Contingency Plan
- Damages for injury to, destruction of, or loss of natural resources, including the reasonable costs of assessing such injury, destruction or loss resulting from such a release

Liability under CERCLA can be summarized to removal, remedial actions (jointly referred to as response actions) and damages (hereafter referred to as "damages"). Liability for the first two components has long been an established part of the CERCLA program. However, liability for damages only recently has been raised as a concern. A major reason for this situation is the lack of a consistent understanding throughout all levels of government, industry and the general public as to what constitutes damages. CERCLA's definition of damages provides little guidance. Section 101(16) of CERCLA simply states that damages "means damages for injury or loss of natural resources..."

The first boundary on the term "damages" is provided by the method in which CERCLA establishes the liability. Section 107(a) discusses the three elements of liability (costs by the Federal or State government, costs by any other party and damages) as separate and distinguishable components. Therefore, damages are those injuries or losses of natural resources that are not covered by the first two components. In other words, damages are those residual impacts that remain after factoring in the effects of the removal and remedial actions.

The remainder of this paper looks more closely at the issue of what constitutes damages. In so doing, the paper discusses what constitutes "injury to, destruction of, or loss of natural resources," how these injuries should be measured and finally, the process of natural resource damage assessment proposed in the Department of the Interior's regulations.

WHAT ARE DAMAGES?

CERCLA requires that damages be determined for the injury, destruction or loss of a natural resource due to the release of a hazardous substance or oil. For simplicity, the terms "injury," "destruction," or "loss" all can be referred to generically as injury since they refer to degrees of injury. In common law, at least two major categories of damages are recognized: punitive damages and compensatory damages. To determine which type of damage applies to CERCLA cases, both the statute and its legislative history need to be examined.

That CERCLA requires compensatory, rather than punitive, damages is clear from its language. Section 301(c) of CERCLA requires that an assessment of damages be performed using the "best available procedures." Use of best available procedures would not be required if damages were to be punitive. If Congress had meant damages under CERCLA to be punitive, all that would be needed is a penalty table. This penalty table could have been but was not included in the legislation.

The legislative history of CERCLA also demonstrates that punitive damages were not intended. For example, the Senate Committee on Environment and Public Works stated that the type B regulations should contain "methodologies for determining value [for injury to natural resources due to a release of a hazardous substance or oil]..." This determination of value, as discussed below, is a critical part of determining compensatory, not punitive, damages.

Damages are thus the compensation for an injury to a natural resource. Liability for this compensation is to the agency acting as trustee of the injured natural resource. As compensation for the injury resulting from the release, the agency is entitled to be made "whole," at least in monetary terms. That is, the agency should be made approximately as well off as it was prior to the release.

HOW ARE DAMAGES MEASURED?

Economics, common law and CERCLA agree that when measuring damages, making the agency "whole" should be achieved in a cost-effective manner. This requirement gives the agency the lessor of: (1) the costs of restoration, rehabilitation, replacement or acquisition of an equivalent to the injured natural resource (restoration for short); or (2) the amount of lost use values resulting from the release.

That is, if use values are higher than the costs of restoration, it would be rational to restore the injured natural resource to its former condition. In this case, society regains its lost uses for a cost that is less than the value of those lost uses. Conversely, if restoration costs are higher than the value of lost uses, it is rational to compensate society by giving it the value of those lost uses. In the latter case, society receives the value of the lost uses, which is less than the costs of restoration of the resource which would regain those lost uses.

Federal and State agencies should be required to decide whether restoration or use values will form the basis of further work to determine damages. This decision should be made early in the assessment process. "Off-the-shelf" information should be used to make this decision. Past studies on restoration techniques and valuation estimates should be used to obtain an "order of magnitude" estimate of restoration costs and use values. These rough estimates are a surrogate for the site-specific determination of either restoration costs or the loss of use values that will be made later in the damage assessment process. The sole purpose of this early estimate is to determine whether restoration costs or use values will form the basis for further analyses.

One major reason for requiring the decision between restoration and use values relatively early in the assessment process is that it helps focus the assessment process on the determination of damages rather than on general research. This agreement can be achieved by an early meeting of the entire group of specialists that will perform the assessment. In most instances, these personnel will have different areas of specialization. These individuals must work together if reasonable costs, as discussed later in this paper, are to be achieved. If these individuals do not get together early in the assessment process, there is a possibility that either the information collected in the measurement of injury will not be useful in determining damages, or that the demands for information to determine damages will be unrealistic. These problems have been acute in several previous damage assessments.

Congress and State legislatures have determined that certain natural resources are worthy of protection, even if their use values are relatively low. In effect, these legislative bodies have removed these special resources from the ordinary workings of economics and common law. If agencies were held to a strict rule of the lessor of a loss of use values or restoration costs, some of these special resources might be left unrestored which would be contrary to Congress' or the State legislature's intent. Therefore, it would be rational to assume that when a special resource is injured due to a release, restoration costs would be the measure of damages. However, even in these cases, the costs of restoration should not be grossly disproportionate to the benefits of restoration.

To determine restoration costs, the Federal or State agency must determine the services lost due to the release. Natural resources provide services to other resources and also to people. When people are the ultimate recipient of the service, the service is called a use. Restoration costs are the costs of restoring the lost services previously provided by the injured natural resource. For example, a lake can serve as a habitat for a fish population. If a hazardous substance is released into the lake, the water may be contaminated to a point where the lake is no longer habitable for the fish. In this instance, the services provided by the lake have been lost to the fish population. Restoration would entail the restoration of the lake as a suitable habitat for a fish population. In this example, replacement of the fish population should not be attempted if the habitat would not be restored to support the fish population. However, damages based on restoration are limited to the amounts required to return the resource to its baseline condition. The costs of enhancement of the resource beyond its baseline condition should not be included in determining compensation for an injury. In the above example, this would imply that the lake be restored to a suitable habitat for the species of fish that existed in the body of water prior to the release, not to a species that an agency would like to introduce.

The restoration of services, not simply the replacement of organisms, is paramount in determining the costs of restoration. This concept was affirmed in the decision reached in the *Commonwealth of Puerto Rico v. The SS Zoe Colocotroni*, 628 F. 2d 652, 673 (1st Cir. 1980) where the cost of replacement was held not to be a measure of damage if the replacement is not contemplated.

In determining damages based on restoration costs, the loss of use values, over the time required for restoration to be completed, would also be compensable to the agency. This compensation is owed because society suffers a real loss by not being able to utilize the resource at its fullest potential during the period of time required for its restoration.

In addition to defining restoration in terms of services, agencies must consider the ability of the resource to recover naturally. Section 301(c)(2) of CERCLA requires that the "ability of the ecosystem or resource to recover" be factored into the determination of damages. The time required for the resource to recover

naturally will provide the period during which a loss of use will be experienced if no restoration actions are performed. Thus, the natural ability of the aforementioned lake to recover must be included in determining restoration costs.

Uses, as stated above, refer to the human use of services provided by natural resources. In the example, fishing may have been a use of the lake. If so, the loss of fishing could be an alternative to restoration costs in determining damages. Common law and economics dictate that an ordering of methodologies be used to value injuries to natural resources under CERCLA. This ordering would start with the change in market prices when applicable. Second, if market prices are not applicable, appraisals should be used. Third, if neither prices nor appraisals are applicable, certain types of non-market methodologies should be used. The logic for this ordering is that if a market or a comparable market exists for the injured natural resource, the information from these markets always should be used to value the resource.

If neither the market price nor appraisal methodology is appropriate, a non-market methodology that measures either willingness to pay or willingness to accept compensation would be appropriate. Willingness to pay and willingness to accept compensation are the fundamental concepts which underlie the compensation principle in economics. As such, any methodology to determine compensation must be consistent with one of these concepts.

A paramount concern in determining damages is the type of values for which the agency may be compensated. CERCLA provides that a Federal or State agency is acting as a trustee when seeking to recover for an injury to a natural resource resulting from a release. As such, the agency can collect only losses to the public at large because of the release. These include: (1) losses in recreation or other public uses; (2) losses in fees and other payments made to the public for the private use of the public's resource; and (3) economic rent lost due to the release.

The third type of loss may need additional explanation. Economic rent is the excess of the total earnings of a producer of a good or service over the payment required to induce that producer to supply the same quantity currently being supplied. This economic rent usually exists because the agency does not charge a price or fee for the private use of the public's resource. These amounts are compensable to the agency as the use value of the resource in place, i.e., the value of the natural resource in the production of marketed goods when the government does not charge a fee or price for the use of its resource.

Two categories of revenues associated with the private use of the public's resource should be excluded in the calculation of damages. First, losses in tax revenue should not be included in damages. Taxes are transfers of income from individuals to the government. As such, taxes are not considered "real" damages. Second, wages and other income lost by private individuals, with the exception of economic rent, should not be compensable to the agency. This income does not accrue to the agency or the public at large and may be subject to privately brought non-CERCLA law suits.

To determine damages, the existing and planned uses (and services) of the injured natural resource must be determined. The determination of damages is dependent upon the uses (or services) forgone because of the release. The basis for determining damages should be the committed use of the resource prior to the release. Committed use would mean that a current or planned use has been documented through a financial, legal, budgetary or other similar type of commitment made by the agency or some other individual or body with the authority to commit the use of the resource. That agencies must be able to document current and prospective uses follows from the need to determine compensatory damages. To determine compensatory damages, purely speculative uses of the injured natural resource cannot be allowed.

WHAT CONSTITUTES AN INJURY TO A NATURAL RESOURCE?

To this point, the discussion has focused on methods for calculating compensation for damages to natural resources. However, damages are for injury to a natural resource. Therefore, to calculate a damage, an injury first must be established.

The first step in identifying what constitutes an injury is to provide a general definition of the term. This definition should develop from the purposes to which the definition will be put. The purpose to which this concept of injury will be put is to provide justification for a compensation. Since the level of compensation will be tied to the level of injury, the first element that must be included in the concept of injury is measurability. Compensation obviously implies a loss or some reduction. Therefore, the second element of this definition, this reduction, can be viewed as a decrease in those basic characteristics that constitute the quality of that resource. Finally, in the discussion of the liability, CERCLA states that the injury must have resulted from the release. Therefore, injury can be viewed as a measurable adverse change in the physical, chemical or biological characteristics of the resource which resulted from the release.

To this definition should be added CERCLA's guidance that requires the inclusion of long-term and short-term as well as direct and indirect injuries. In addition, the term "resulting from the release" would have to include products of the substances released and reactions caused by such products or substances.

This general definition needs to be translated into specific resource definitions for applicability. As stated earlier, CERCLA covers a wide range of natural resources. These resources need to be grouped into some manageable number that still provides meaningful guidance.

The emphasis on physical, chemical and biological characteristics in the general definition suggests distinguishing between physical and biological resources. Although biological resources can be considered as one group of resources, physical resources are more easily discussed as either air, groundwater, surface water or geologic resources. All of these resource groups include a wide range of resources. However, the type of guidance that can be provided in such a general set of regulations suggests that these five groups of resources are adequate.

The physical, chemical or biological characteristics of concern in an injury definition would be those characteristics that relate to the quality of the resource relative to the services that it is expected to provide. The concept of services as explained earlier includes such services to people and the environment as drinking water supplies, habitat and growth medium for vegetation. The most obvious services that can be considered include those linkages that exist between resources that may cause exposure and injury to other resources. In the earlier example, a body of water may have been contaminated such that the fish within that body of water die. Obviously, the fish are injured, but the water can be considered injured as well since it no longer serves as a healthy environment for the resources that depended upon it. Similar linkages exist among all of the resource groups. These linkages are easier to identify in some resources than in others. However, in no cases should the linkages between the resource groups constitute the only method of identifying an injury.

Several of the resource groups include Federal and State standards which can be viewed as defining a characteristic of quality for the resource. The clearest sample of such standards are the water quality criteria developed under the Clean Water Act.

These standards were developed with a view toward the services that the water provided. Frequently, these standards were focused on the potential affects on aquatic life. Similar quality standards or threshold levels exist for drinking water and air. For geologic and biological resources, equivalent standards have had to be developed.

Geologic resources include such elements of the Earth's crust as soils, rocks and minerals. The major services provided by geologic resources include providing a medium for growth of vegetation, a habitat for biota (soils), a source of minerals for development purposes and the unsaturated zone for aquifers. After a release, geologic resources also may qualify as hazardous substances under the provisions of RCRA. The physical, chemical and biological characteristics of geologic resources that affect the quality of the resource to provide such services (i.e., respiration, pH or microbial populations) can be defined and used as an easily identified standard to judge if the resource has been injured.

The primary service of concern in biological resources is continuation of the species or population viability. However, for a small but important subset of biological resources (those that are consumed) a resource should be considered injured if concentrations of the substance released within the edible portions of the resource exceed applicable Food and Drug Administration (FDA) action or tolerance levels or equivalent State standards.

Examples of injuries that affect population viability are death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions and physical deformations. Unfortunately, determining whether or not one of these injuries has occurred as a result of the released substance is difficult. Studies on the toxicity of chemicals on various non-human biological resources are not widespread and frequently are not universally accepted. Examples abound of results appearing in laboratory situations that cannot be replicated in field studies and vice versa. However, if the use of the procedure is to provide a rebuttable presumption to the assessment, it is critical to include only those responses that are caused by the substance released. If a procedure cannot prove that a particular chemical caused an effect, the procedure should not be used in any litigative or administrative action. Therefore, the specific definition of injury to a biological resource is necessarily tied heavily to the testing procedure for the biological response.

This last point highlights a dilemma inherent in CERCLA's damage assessment requirement. CERCLA requires that the regulations include the best available procedures for assessment of damages. Clearly, it is not advisable to hinder research into natural resource injuries caused by chemical releases by requiring the use of the few techniques currently available, given the state-of-the-art of assessment techniques. In addition, it is not feasible to include every testing procedure that has ever been attempted in a set of regulations that is general in nature. The solution to this problem is to provide criteria by which the techniques can be judged rather than specific techniques. Such criteria would necessarily center on the general acceptability of the procedure and the replicability of the results.

Identifying that a resource has suffered an injury is insufficient for the purposes of establishing a damage claim. CERCLA requires that some linkage between the source of the release and the injured resource be established. This process requires the identification of a potential pathway through which the substance could have traveled. Each of the resource groups has the capability of acting as a component in this pathway.

Substances may be transported through direct exposure, the food chain or via one of the air or water mechanisms. Modeling or sampling would be appropriate means of determining the pathway.

In summary, injury for the purposes of liability under CERCLA can be viewed generally as a measureable, adverse change in the physical, chemical or biological characteristics of a resource that resulted from a release. This general definition can be applied to specific groupings of resources so that clearly recognizable affects can be attributed to the substance released. Once identified as injured, these resources can be measured, and the extent of the impacts can be calculated.

HOW IS INJURY MEASURED?

The measurement of injury is the link between the physical and biological demonstration of injury and the monetary determination of damages. Injury determination demonstrates that either: (1) a physical or chemical based standard has been violated; or (2) an adverse biological response is the result of a release. This injury determination must then be measured to calculate how much of the resource has been injured, how badly the resource has been injured and over what time period the injury has taken place. This process is the quantification of the injury.

One major task in the quantification of the injury is to determine the changes in services previously provided by the injured resource. To quantify the effects of the release, the agency must determine baseline services; the amount, type and quality of services that would have been supplied by the injured natural resource in the absence of the release. This amount is then compared to the amount, type and quality of services supplied by the injured natural resource. The difference between these two quantities is the reduction in services that an agency can use as the basis for either restoration costs or use values when determining damages. Since damages are the residual after any response actions, the quantification of the injury must incorporate the effects of any actual or anticipated response actions on the current and future services of the resource.

Quantification extends to baseline, rather than standards or conditions causing the biological responses, and is a direct consequence of providing compensation to make the agency "whole." Because baseline is the point from which compensation is determined, the agency is being compensated for what would have occurred had the release not occurred.

As mentioned earlier, any quantification of injury must incorporate the ability of the resource to recover naturally. In addition, recovery rates of the resource with alternative management actions need to be specified. This calculation allows specification of alternative costs of restoration which, in turn, allows selection of the most cost-effective alternative to restore the resource.

THE NATURAL RESOURCE DAMAGE ASSESSMENT PROCESS

The concepts of damage and injury are important for the understanding of the proposed natural resource damage assessment process. However, there are three additional important concepts that surface throughout the proposed natural resource damage assessment process. These concepts, discussed briefly below, include:

- Cost-effectiveness and reasonable costs as they apply to the assessment process
- The involvement of the public and the potentially responsible party in the damage assessment process
- The application of any awards for restoration purposes

Cost-Effectiveness/Reasonable Costs

CERCLA requires that natural resource damage assessments achieve reasonable costs. CERCLA's legislative history also indicates that these assessments be cost-effective. Cost-effectiveness is the achievement of an objective with the least expenditure of

financial or other resources. Agencies should use cost-effectiveness in determining how they will perform all aspects of the assessment process. To achieve this requirement, agencies must have well-defined goals. For example, testing and sampling for injury to surface water should be limited to those tests which can determine the injury as opposed to any general research studies. Given local conditions, the agency should select, from the set of tests that could show injury, the one which is the least costly.

Section 107(a)(4)(C) of CERCLA stated that a responsible party is liable for the "reasonable costs of assessing..." injury as well as the amount of damages determined in the damage assessment. The concept of reasonable costs incorporates the concept of cost-effectiveness, but is broader in scope. Reasonable cost criteria require that the benefits of alternative testing or estimation procedures outweigh their costs.

In addition, reasonable cost criteria require that the parts of an assessment plan be coordinated and supply only the information necessary to move from one section to another. This requirement exists because the sole purpose of a damage assessment is to determine the damages caused by a release.

Involvement of the Public and Potentially Responsible Party

As indicated by the previous discussion, a damage assessment requires a significant number of choices. The performance of a damage assessment requires the selection of methodologies to: (1) test and sample for injury; (2) determine the pathway which exposed the resource to the release; (3) measure of the extent of injury; and (4) determine a dollar amount due the agency as compensation for the injury. Given the universe of methodologies that exists, the selection of appropriate methodologies to perform all of these tasks is difficult.

The amount of discretion available argues for the use of an administrative process in the damage assessment. Administrative processes are characterized by their openness and ability to gain the views of all interested individuals. The outcome of such a process generally is perceived to be fair because all parties have an opportunity to review and comment on the process. This perception of fairness is an important issue in the performance of a damage assessment. If the courts do not perceive the assessment process as being an impartial assessment of damages, the likelihood that the results of the assessment will be successfully challenged in court increases. This increases costs for all involved.

Any administrative process to determine damages must give final authority to the agency performing the assessment for the selection of methodologies. Input from the public and potentially responsible parties should be useful in selecting methodologies for and actual performance of damage assessments. In addition, there may be instances when the potentially responsible party may wish to perform the damage assessment. However, the agency generally will have the management authority for the resources in question and must have the final authority to determine all aspects of the assessment process as an extension of its management responsibilities.

The Application of Any Awards for Restoration Purposes

One final concept that needs to be highlighted in the process is the requirement in CERCLA that all funds received as compensation for the natural resource injuries be made available for restoration. This concern for the disposition of the awards was taken very seriously in the development of the proposed rule and is considered critical for the general credibility of the damage claim. In the Zoe Colocotroni case, one reason that the courts disallowed the initial claim was the determination that the government had no intention to restore the resources, and the replacement of resources formed the basis of the claim. Therefore, the commitment to restoration should strengthen the acceptability of the damage claim.

Obviously, restoration is not always feasible. In those instances when restoration is not feasible, the acquisition of resources providing services similar to those lost is a viable alternative.

PROPOSED NATURAL RESOURCE DAMAGE ASSESSMENT PROCESS

The natural resource damage assessment process proposed by the Department of the Interior is designed to be performed in phases. The more costly phases occur after several screens have been passed to ensure that assessments are not performed needlessly. The major steps in the process are provided on Table 1. The remainder of this paper will briefly describe each of these steps.

Initiation of Process

Natural resource damage assessments should be a follow-on to any removal or remedial actions taken by the U.S. EPA, the U.S. Coast Guard or any other agency designated as the lead agency under the National Contingency Plan. That plan requires that the lead agency notify trustees of any potential natural resource injuries. In instances where the agency identifies a possible injury to resources under its jurisdiction and suspects a CERCLA or CWA covered source, the agency is directed to the procedures in the National Contingency Plan for reporting the release. Regardless of how the agency was notified, once alerted to the potential injury, the agency should determine whether any emergency restoration actions are necessary.

Emergency Restorations

Section 111(i) of CERCLA provides authority for emergency restorations. Emergency restoration actions are those limited actions necessary to abate a continuing threat to or the immediate destruction of the resource. The agency should notify the National Response Center of the need for emergency action. If the U.S. EPA or the U.S. Coast Guard cannot take the necessary actions, the agency may use whatever authorities it has to prevent the transport of the substance to the resource. Upon completion of the limited actions, the agency would start the natural resource damage assessment process.

Pre-Assessment Screen

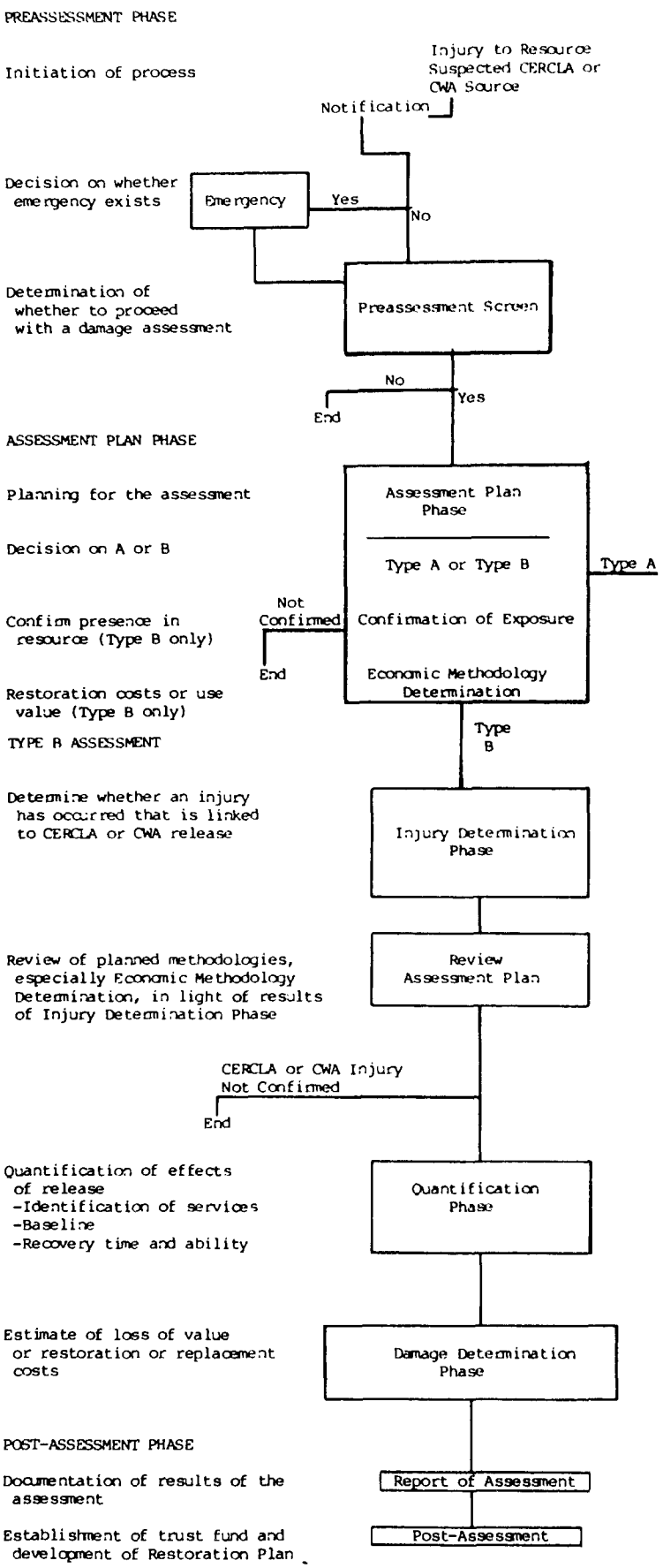
The first step in the assessment process is the pre-assessment screen. The purpose of this screen is to determine whether the release justifies a natural resource damage assessment. This screen is viewed as a "desk top" review of existing data, capable of being completed in a matter of days. It should not duplicate or repeat information gathered by the agency or by other parties as part of the response action.

A documented determination is required upon completion of this screen. The determination to proceed will be based upon ensuring that:

- The release was covered by CERCLA or the CWA
- It might have resulted in some injury to a resource under the jurisdiction of the agency
- The resource and the extent of potential injury was of sufficient concern to the agency to continue

If, as a result of the pre-assessment screen, the agency determines that a natural resource damage assessment is in order, the agency will initiate the Assessment Plan phase.

Table 1
Natural Resource Damage Assessment Process



Assessment Plan Phase

The agency should document its decisions on the selection of the methodologies that will be performed. This documentation must be given in an Assessment Plan. This Assessment Plan should ensure that the mandate to keep assessment costs reasonable will be fulfilled.

There are several efforts that need to be undertaken by the agency prior to developing the Assessment Plan. These efforts center on initiating the involvement of multiple trustees, potentially responsible parties and the public in the assessment.

The potentially responsible party or parties should be identified. A Notice of Intent to Perform an Assessment must be sent to any identified potentially responsible party (PRP). This notice is intended to involve the PRP early in the assessment in an attempt to minimize disagreements in the performance of the assessment. However, all decisions concerning the assessment are ultimately the responsibility of the lead official.

The public is encouraged to become involved in the Assessment Plan. The public participation element of the Assessment Plan includes a 30-day review period prior to implementation of the plan or major modifications. Any comments and responses must be maintained as part of the administrative record.

There are several requirements specific to a type B assessment that must be included in the Assessment Plan. These requirements include:

- Confirmation of exposure
- Quality Assurance Plan
- Objectives of testing and sampling for injury or pathways
- Economic Methodology Determination

The confirmation of exposure is the second screen in the damage assessment process. It is intended to ensure prior to initiating an expensive type B assessment that the released substance has actually come into contact with the resource of concern. The Quality Assurance Plan should be prepared following the same requirements that apply to other actions taken under CERCLA. The testing and sampling objectives should clearly state the purposes of all proposed testing and sampling.

The Economic Methodology Determination is where the agency must make a choice between using the costs of either restoring or replacing the injured resource of the value of lost uses as the measure of damages. The decision will affect the choice of methodologies to be selected in the second phase of the assessment, referred to as the Quantification phase, and to a lesser extent in the first phase, referred to as the Injury Determination phase. Therefore, the decision must be made early, but may be deferred or changed after the Injury Determination phase is completed.

The selection of use value or restoration costs only affects the method of damage determination. It does not imply any decisions concerning whether the resources will be restored. Except in the case of defined special resources, the method of determining the damage will be the lesser of the lost use value or restoration costs.

Type B Assessment

Performing a damage assessment by using a type B procedure involves three general steps:

- Establishing that an injury has occurred and that the injury resulted from the release
- Quantifying the effects of the release on the injured resource
- Determining the damage

Injury Determination Phase

This phase of the type B assessment acts as the third screen of the natural resource damage assessment. To assert a natural resource damage claim, the agency would have to establish that an injury occurred or to link that injury to the release. The Injury Determination phase is where the agency must determine whether one of the specific definitions of injury for the five resource groups has been met. Acceptance criteria for determining when a procedure meets the requirements for the rebuttable presumption are provided to assist the agency in making this determination. Finally, it is in this phase that the agency must determine the pathway that the substance could have traveled to reach the injured resource.

Review of the Assessment Plan

Upon completion of the Injury Determination phase, the agency will review the methodologies selected in the Assessment Plan. The purpose of this review is to ensure that the selection of methodologies for the last two phases of the type B assessment is compatible with the findings of that first phase. If an injury cannot be determined or cannot be linked to the release, the results of the Injury Determination phase should be documented and any further assessment efforts included in the plan should be deleted.

If it is determined that the injury resulted from the release, the agency will ensure that the methodologies selected for the next two phases are consistent with the findings of the Injury Determination. At this stage, if the agency has not previously done so, a decision must be made on whether use value or restoration or replacement costs will form the basis of the damage determination.

Quantification

Having established that a resource was injured by the release, the second step in the type B assessment is to quantify the effects on the injured resource. As the purpose of the natural resource damage assessment is compensation rather than a decision on the cleanup level, this phase requires ascertaining the baseline level for the resource. The baseline level is compared to the level projected upon the completion of any response actions to determine the residual change resulting from the release. The baseline level will include consideration of the resource's natural cyclical changes.

Damage Determination Phase

The outputs of the second step should act as inputs to the third general step in the type B process, estimating the damage. The method of estimating the damage, either using the cost of restoration or replacement or the loss of use, was determined earlier during the development of the Assessment Plan.

If restoration or replacement is to be the measure, a plan for the restoration or replacement, referred to as the Restoration Methodology Plan, must be developed in this Damage Determination phase. This plan must have sufficient detail to ensure that all major elements of costs are included and that these costs represent the cost-efficient means of restoring or replacing the services lost as a result of the release. This plan also will serve as the foundation for the final restoration plan that must be developed after the award.

Report of Assessment

In some instances, damage assessments using this natural resource damage assessment process will receive a rebuttable presumption. To assert this rebuttable presumption, at the conclusion of a type B assessment, the agency must document the results of the major steps of the process in a report referred to as the Report of Assessment. These major steps include the Pre-Assessment Screen Determination, the Assessment Plan with all comments and responses, the Injury Determination, the Quantification Determination and the Damage Determination, including the Restoration Methodology Plan if prepared.

Post-Assessment

Based upon CERCLA's mandates, funds recovered as a result of the assessment process provided in the proposed rules must be available for restoration, rehabilitation, replacement or the acquisition of the equivalent of the injured resource. To accomplish this mandate, a trust fund must be established to hold all awards except those amounts which represent reimbursement of costs including assessment, administrative and litigative costs. These reimbursements may be returned to the general treasury of the governmental unit that incurred the costs. The agency shall prepare a Restoration Plan. This plan shall be based upon the decisions made in the Restoration Methodology Plan, if one has been prepared; the plan shall be modified to the extent necessary to accommodate new information before calculating the amount of the award. The trust fund will be used to pay for the implementation of this Restoration Plan.

In recognition of the fact that restoration of some injured resources is technically infeasible, replacement and acquisition of the equivalent are defined to include acquisition of resources that provide similar services to the injured resource. However, there is a limitation on the use of the fund. Where acquisition of similar resources would involve purchase of land for federal management, the award must be paid to the general treasury. The appropriations process must be used where land is being acquired to expand the total federal landholdings.

CONCLUSIONS

CERCLA and the Clean Water Act authorize liability for response actions and damages to natural resources caused by releases of hazardous substances and oil. This paper has examined the extent of the liability of parties responsible for the release and resulting damage to natural resources and the proposed process through which these damages can be calculated.

The proposed process is driven by two basic premises: damages under CERCLA are compensatory; and a rebuttable presumption attaches to assessments performed in accordance with these regulations. The fact that damages are compensatory stems from a reading of the law and its legislative history. The rebuttable presumption is specified in section 111(h)(2) of CERCLA.

The concepts discussed in this paper are the basis of Interior's proposed natural resource damage assessment regulations. These regulations provide a proposed procedure for agencies to determine damages under CERCLA. It is hoped that by exploring the issues of damages, injury and the appropriate measure of these terms, the proposed rule has initiated a discussion of the appropriate role of natural resource damages in the overall hazardous material control strategy.

Regulatory Impact Analysis for the Toxicity Characteristic

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ABSTRACT

The U.S. EPA is expanding the use of the toxicity characteristic as a means of identifying hazardous waste. Because of the projected impact of this new regulation, a detailed Regulatory Impact Analysis (RIA) was prepared to support the development of the new regulations. This RIA addresses the benefits and costs of the regulation including a benefit/cost assessment, risk assessment and uncertainty analysis. This paper provides an overview of the methodology employed and the results obtained; it does not represent the views of the U.S. EPA.

INTRODUCTION

The U.S. EPA is proposing to expand its regulation of hazardous wastes to comply with RCRA by regulating additional wastes. Executive Order 12291 requires regulatory agencies to maximize the net social benefit of regulations and to conduct a Regulatory Impact Analysis (RIA) for any major rule. A major rule is one likely to result in one or more of the following:

- An annual effect on the economy of $100 million or more.
- A major increase in costs or prices for consumers; individual industries; Federal, State or local government agencies; or geographic regions.
- Significant adverse effects on competition, employment, investment, productivity, innovation or the ability of United States-based enterprises to compete in domestic or export markets.

This RIA provides an analysis of the U.S. EPA's proposed regulation based on the guidelines contained in the Office of Management and Budget's "Interim Regulatory Impact Analysis Guidance" (June 12, 1981) and the U.S. EPA's *Guidelines for Performing Regulatory Impact Analysis* (1983).

PROPOSED ACTION

The U.S. EPA is proposing to expand the existing Extraction Procedure Toxicity Characteristic (EPTC) (40 CFR 261.24). This characteristic currently involves a leaching test (known as the Extraction Procedure or EP), which is used to determine how much a toxic chemical would leach if a waste containing it were disposed of along with municipal wastes in a sanitary landfill. A problem with the EP toxicity test is that it originally was not designed to measure leaching of organic chemicals from solid wastes. It was designed primarily to model the leaching of metals.

Currently, wastes containing toxic constituents are designated as hazardous primarily through the listing mechanism. Listing is a slow, resource-intensive process that is specific to hazardous wastes generated in a particular industry. At present, only a small percentage of potentially hazardous wastes containing toxic constituents are listed because the U.S. EPA has had limited resources to devote to the industry studies program that prepares the listings.

The U.S. EPA perceived a need for a more comprehensive and self-regulating means of identifying wastes as hazardous and believed the best way to meet this need is to expand the existing EPTC. The expanded EPTC (known as the Toxicity Characteristic Leaching Procedure—TCLP) applies to all wastes, not just metals and pesticides, and requires the waste generator to determine if its waste exceeds an acceptable concentration level.

The U.S. EPA is proposing to initially regulate the 52 chemicals listed in Table 1. These chemicals have been selected for regulation on the basis of:

- Existence of an acceptable exposure level
- Existence of adequate fate and transport data needed to run the groundwater transport model

For a given toxic constituent, the U.S. EPA proposes to determine a toxicity threshold of that constituent in groundwater. For noncarcinogens, the toxicity threshold can be approximated using a percentage of the acceptable daily intake (ADI). The percentage used depends on the extent to which simultaneous exposure through air and ingestion occurs. The ADI is the amount of a chemical (in mg/day) that can be ingested every day for a 70-year lifetime without adverse health effects. (Criteria for establishing ADIs are discussed in 45 FR 79318.) The resulting fraction of the ADI is referred to as the Health Based Starting Limit (HBSL). For carcinogens, the U.S. EPA's Carcinogen Assessment Group (CAG) has calculated the probability of cancer arising per unit dose. This unit cancer risk (UCR) is the risk of cancer for a dose of 1 mg/kg per body weight/day over a 70-year lifetime. The dose corresponding to a cancer risk of 1 in 10^6 for each carcinogen is derived from the UCR. That level is the virtually safe dose (VSD). For carcinogens, the HBSL can be approximated using the VSD.

Once the HBSL is established for a toxic waste constituent and the degree of attenuation between the disposal site leachate and the well water is estimated, the level of the constituent in a leachate that yields constituent concentrations at or above the HBSL at a well near a land disposal facility is calculated. That level is called the regulatory level (RL). The RL determines the leachate concentration of a constituent (as measured by the TCLP) that would cause the waste containing that constituent to be considered hazardous under RCRA. Any waste that has a TCLP concentration greater than its RL is hazardous by definition and subject to regulation under RCRA as a hazardous waste.

Table 1
Selected Chemicals Considered for Regulation Using TCLP

Acrylonitrile	Isobutanol
Arsenic	Lead
Barium	Lindane
Benzene	Mercury
Bis(2-chloroethyl)ether	Methoxychlor
Cadmium	Methylene chloride
Carbon disulfide	Methyl ethyl ketone
Carbon tetrachloride	Nitrobenzene
Chlordane, technical	Pentachlorophenol
Chlorobenzene	Phenol
Chloroform	Pyridine
Chromium(VI)	Selenium
o-Cresol	Silver
m-Cresol	1,1,1,2-Tetrachloroethane
p-Cresol	1,1,2,2-Tetrachloroethane
2,4-D, salts and esters	Tetrachloroethylene
1,2-Dichlorobenzene	2,3,4,6-Tetrachlorophenol
1,4-Dichlorobenzene	Toluene
1,2-Dichloroethane	Toxaphene
1,1-Dichloroethylene	1,1,1-Trichloroethane
2,4-Dinitrotoluene	1,1,2-Trichloroethane
Endrin	Trichloroethylene
Heptachlor	2,4,5-Trichlorophenol
Hexachlorobenzene	2,4,6-Trichlorophenol
Hexachlorobutadiene	2,4,5-TP
Hexachloroethane	Vinyl chloride

REGULATORY ALTERNATIVES ANALYZED

Benefits and costs are determined for the following three selected regulatory alternatives and the Status Quo (i.e., no regulation):

- *Alternative 1:* Includes all currently unregulated wastes that would produce a TCLP extract containing any of the 52 contaminants at a level greater than or equal to 100 times the chronic health based threshold.
- *Alternative 2:* Includes all currently unregulated wastes that would produce a TCLP extract containing any of the 52 contaminants at a level greater than or equal to 10 times the chronic health based threshold.
- *Alternative 3:* Includes all currently regulated wastes that would produce a TCLP extract containing any of the 52 contaminants at a level greater than or equal to 1,000 times the chronic health based threshold.
- *Status Quo:* No regulation.

Benefits and costs for each regulatory alternative are compared to those of the baseline Status Quo. Under the Status Quo, industry does not incur additional waste management costs for more stringent requirements. However, society will incur the costs of not regulating these wastes. These social costs of the Status Quo are assumed to be the benefits that would occur if the wastes were regulated; they vary with the number of affected facilities.

AFFECTED INDUSTRIES

Because the proposed action is chemical-specific rather than industry-specific, it affects a wide range of industries. Table 2 shows the affected industries by Standard Industrial Classification (SIC) code. Most of the plants that produce and use the proposed chemicals appear in the chemical industry. Any facility that has one of the selected chemicals in a waste stream at concentrations greater than the RL will be affected. (Those wastes currently regulated under RCRA are not included in the analysis.) The number of affected facilities may include plants that produce or use more than one of the chemicals.

ECONOMIC IMPACT METHODOLOGY

A partial equilibrium multimarket (PEM) model is employed to project the economic impacts of the regulatory alternatives. All 11 industries that would be directly affected by the regulatory alternatives are modeled.

The primary objective of the PEM model is to project changes in equilibrium prices and output rates in both directly and indirectly affected industries. Related impacts on industry employment also are projected by the model.

The projected economic impacts are of interest for two reasons. First, they indicate the types and magnitudes of industry changes that might be expected as a consequence of the regulatory alternatives.

Table 2
Directly Affected Sectors

Industry	SIC Code No.
Plastics materials and resins	2821
Synthetic rubber	2822
Medicinals and botanicals	2833
Soap and other detergents	2841
Surface active agents	2843
Paints and allied products	2851
Cyclic crudes and intermediates	2865
Industrial organic chemicals	2869
Agricultural chemicals	2879
Petroleum refining	2911
Nonferrous wire drawing and insulating	3357

Second, the price and output rate impacts represent resource reallocations that impose costs on affected parties. The projected equilibrium impacts are thus the key ingredient in the regulatory cost projections.

As modeled, industry supply curves are perfectly elastic. Regulatory price impacts thus reflect production cost changes. The model accounts for both direct cost changes attributable to control and indirect cost changes attributable to inter-industry transactions.

Demand curves for outputs of modeled industries are downward sloping. When product prices increase, quantities demanded decline. Production rates decline to restore equilibrium, and changes in employment and capital expenditures result. The model does not account for demand shifts that might occur, but these are believed to be insignificant.

BENEFIT ESTIMATION METHODOLOGY

Regulation of wastes containing any one of the selected chemicals should result in a reduced risk of groundwater contamination and subsequently contamination of the drinking water of many communities. If the contaminating chemical is a carcinogen, drinking the water may result in an excess incidence of cancer cases in the population. Ingestion of noncarcinogenic chem-

icals in drinking water at a level above the ADI may be correlated with toxic, reproductive or genetic effects, depending on the particular chemical. Switching to an alternative water source to avoid drinking contaminated groundwater imposes substantial costs for the affected communities. Often, if a chemical has been detected in the groundwater, the contaminated aquifer is cleaned up and the landfill treated, resulting in additional costs to the community.

For each chemical, estimates are made of the health effects, switching and cleanup costs (corrective costs) attributable to the presence of that chemical for wastes currently disposed of in unregulated landfills. Regulation of the waste is assumed to prevent these estimated health effects and corrective costs completely. The estimated benefits attributable to the regulation are the adverse health effects and corrective costs avoided by its implementation.

Four steps are used to determine benefits:

- Estimate quantity and concentration of chemical in landfill
- Estimate concentration of chemical in leachate
- Estimate chemical concentration at well
- Estimate health effects and corrective costs attributable to contamination of the wellwater.

The unregulated wastes are assumed to be disposed of in a landfill each year for 20 years (the average lifetime of a landfill). The amount of the chemical contaminant that leaches through the landfill and the leaching duration are determined using data on the persistence and mobility of each chemical and the form of the waste stream. From the bottom of the landfill, the contaminant is transported through the aquifer to the community well. The concentration of the contaminant at the well varies over time and is tracked over a maximum of 100 years. The attenuation factor assumed depends both on dilution of leachate in the aquifer and on the specific properties of the chemical. The adverse health effects and corrective costs attributable to the contaminated well are then estimated. Excess cancers are estimated using a life table model. For noncarcinogenic health effects, the person-years of exposure above the HBSL are estimated.

The Base Case Method is employed to estimate the concentration of the chemical in the leachate and at the well. Key assumptions of this method include:

- The landfill receives predominantly domestic refuse, with only 5% of the landfill holding industrial waste.
- The character of the leaching fluid to which wastes are exposed is primarily a function of the nonindustrial material in the landfill.
- The landfill is located over an aquifer that is a source of drinking water for 2,000 persons in the region of the landfill.
- Soil below the landfill has limited attenuative capacity.
- The nearest drinking water wells are 150 m (500 ft) downgradient from the landfill.
- As constituents migrate from the landfill through the unsaturated and saturated zones to the source of drinking water, they are attenuated by a factor of 100.

COST ESTIMATION METHODOLOGY

The current disposal costs or baseline must be established to estimate the increased disposal costs incurred by waste generators resulting from the proposed regulation. Current disposal costs are a function of the disposal alternatives in use. Where the waste is not a listed hazardous waste, current disposal practices are identified by examining the technical literature, by analogy to similar wastes for which disposal practice is known, or by assumption.

Some baseline disposal alternatives may understate the actual treatment and disposal applied to that waste because no effort has been made to determine which wastes may be affected by State and local regulations that are more stringent than Federal regulations. This also may occur because firms may be voluntarily applying more thorough treatment and disposal than required by regulation. The result of this potential understatement of baseline treatment and disposal alternatives is that the estimated increase in disposal costs to comply with the characteristic approach will be greater than the actual increase.

For currently landfilled wastes not listed as hazardous but subject to the regulation, disposal practice after regulation will become more stringent and costs will increase. Disposal costs are assumed to remain the same for wastes currently incinerated or deepwell-injected. Solvent wastes and a few other wastes that have been assumed to be landfilled will be containerized prior to disposal.

Using model plant information, estimates of the incremental disposal and operating and maintenance costs associated with the implementation of the alternatives are projected. These estimated costs then are compared to the cost of contracting with commercial disposal services to estimate properly the minimum costs incurred by the affected facilities. These costs are annualized to reflect an accurate measure of the increased production costs associated with the new regulation. Estimates of percentage cost changes are generated for use in the production/consumption model. Under the assumption of full-cost pricing, these percentage estimates are determined by dividing the annualized incremental costs by the value of shipments in affected SIC industries.

The economic impacts model is used to derive all costs or welfare losses borne by consumers of directly affected products. Consumers suffer a welfare loss when regulatory compliance increases prices because they lose consumer surplus, or the value placed on consumption in excess of the amount required to purchase a product. Economic theory allows the estimation of total consumer costs through impacts in the directly affected markets. Thus, input and output market data are not required.

Consumer surplus losses represent the only recurrent or annual costs. Changes in waste disposal methods in response to a regulation are represented by an upward shift in the supply function. The higher production costs that result create a new equilibrium and a consumer surplus loss. The new equilibrium will have lower production at a higher cost than the initial equilibrium. A real resource cost is the value of the additional costs incurred at the new lower level of output. A deadweight loss is the loss in surplus value consumers placed on those units that no longer will be produced.

Extension of the above analysis to a multimarket situation is straightforward. Because impacts in input and output markets need not be considered to project approximate welfare costs, total welfare costs are developed by summing welfare costs in the 11 directly affected markets.

Consumer surplus and deadweight costs represent annual costs. Within this analysis, all baseline data are presented for the year 1982. However, consumer surplus losses will be incurred for an unknown number of years. To develop cost estimates for future years, costs first are estimated for 1982 and then assumed to be constant for all subsequent years. This simplifying assumption is used because time constraints precluded the projection of market trends.

Implementation costs, consisting of transaction costs and employment losses, represent one-time losses in welfare. Transaction costs represent the value of resources that would be expended to determine if a waste stream is to be regulated. These costs are based on an estimated cost of sampling and analyzing each waste stream by affected facilities. Employment losses occur because

consumption of goods and services are foregone when individuals are unemployed. Losses are based on the projected changes in production and employment-to-output ratios for each directly affected market. These losses are not valued in dollar terms because it is difficult to project the length of time an employee will be unemployed. Also, the value placed on this time period depends on a variety of such unknown parameters as an individual's job skills, age, education and personal dislike of being unemployed.

RESULTS—

Aggregate Benefits

Continued use of current practices for managing wastes containing the selected chemicals is expected to result in the deterioration of environmental quality. This deterioration may elevate risks to human health and reduce the quality of environmental resources, such as uncontaminated drinking water. The major route expected to affect environmental quality is through the leaching of contaminated wastes into groundwater. Over 50% of the U.S. population uses groundwater for drinking water. Further, contaminated groundwater can enter surface water, reducing its quality. The capacity of both groundwater and surface water to assimilate toxic chemicals is limited.

If people drink contaminated groundwater, a wide range of health effects may occur, from simple gastrointestinal problems to cancer and birth defects. We focus on the possible excess cancer cases if the selected chemicals are not regulated. We assume that contaminated water would continue to be used as a drinking water source unless the concentration reached taste or odor thresholds of the average person. If that threshold is attained, we assume they would switch to alternative water sources and no adverse health effects would occur. When a landfill is recognized as a source of groundwater contamination, we also assume the municipality would take action to prevent further leaching of the chemicals. Switching and cleanup incur significant financial costs. Estimates were developed for a representative community of 2,000 persons and were aggregated to obtain national totals. The aggregation process assumed that each plant's waste affected a single community. Because this aggregation process is not very precise, the reader is cautioned to interpret the results carefully. The results for each regulatory alternative are summarized in Table 3.

Table 3
Benefit-Cost Assessment

Benefits/costs	Regulatory Alternative 1	2	3
Monetized benefits:[a]			
Avoided cost of alternative water source			
Present value ($10^6)[b]	3,218	3,317	3,174
Annualized ($10^6/yr)	378	390	373
Avoided cost of aquifer cleanup			
Present value ($10^6)[b]	11,897	12,316	11,719
Annualized ($10^6/yr)	1,398	1,447	1,377
Monetized costs:			
Real resource cost			
Present value ($10^6)[b]	1,285	1,287	1,186
Annualized ($10^6/yr)	151	151	139
Deadweight consumer surplus cost			
Present value ($10^6)[b]	1.15	1.16	1.03
Annualized ($10^6/yr)	0.14	0.14	0.12
Transaction cost ($10^6)[c]	1.22	1.26	1.17
Net monetized benefits:[d]			
Present value ($10^6)[b]	13,830	14,345	13,706
Annualized ($10^6/yr)	1,625	1,685	1,610
Nonmonetized benefits:[a]			
Avoided cancer cases	54	54	53
Avoided person-years of exposure above the HBSL ($10^6)[e]	4.8	4.8	0
Nonmonetized costs:			
Employment dislocations	407	407	372

aBenefits are based on the Base Case Method.
b20-Year cost discounted at 10%.
cOne-time cost incurred first year.
dMonetized benefits minus monetized costs excluding transaction costs.
eHBSL = Health based starting limit.

Aggregate Costs

Benefits of the regulatory alternatives would be accompanied by costs. Total costs of the regulatory alternatives include real resource costs, deadweight consumer surplus losses, deadweight producer surplus losses (capital value losses), employee dislocation costs and government transaction costs.

Two of these welfare costs have not been projected in this analysis. Employee dislocations have been quantified, but their social costs have not been evaluated. Capital value losses incurred by owners of affected capital also have not been evaluated.

Projected real resource and deadweight consumer surplus costs of the three regulatory alternatives are reported in Table 3. Projected employee dislocations also are presented.

BENEFIT-COST ANALYSIS

Table 3 summarizes the benefits and costs of the three regulatory alternatives. The differences between the monetized benefits (i.e., avoided corrective costs) and monetized costs (i.e., real resource and deadweight consumer surplus costs) are compared using the annualized method. The differences are positive for all regulatory alternatives. Thus, each alternative would provide an improvement in economic welfare. The maximum improvement, ignoring health benefits, is under Regulatory Alternative 2.

An evaluation of Regulatory Alternatives 1 and 2 will allow a comparison of the results of the 100 x HBSL and the more stringent 10 x HBSL regulatory levels. These two alternatives have virtually no differences in health benefits. However, Regulatory Alternative 2 yields an increase in net monetized benefits of $60.59 million annually.

Moving from Regulatory Alternative 1 to Regulatory Alternative 3 results in a decrease in the stringency of the regulatory level from 100 x HBSL to 1,000 x HBSL. As a result of this change, avoided cancer cases will decrease slightly by a total of 0.39 cases. However, the 4.8 million person-years of avoided exposures above the HBSL in Regulatory Alternative 1 decreases to 0 under Regulatory Alternative 3. Additionally, net monetized benefits are $14.44 million annually higher in Regulatory Alternative 1 than in Regulatory Alternative 3.

CONCLUSIONS

The proposed expansion of the toxicity characteristic will provide an additional, cost-effective method for the U.S. EPA to use in regulating hazardous wastes. For those regulatory alternatives analyzed, the benefits are significantly greater than the costs of regulating additional wastes containing any of the 52 chemicals.

Preliminary Assessments and Site Investigations Under the Corrective Action Authorities of RCRA: Analysis of Early Experiences

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ABSTRACT

Implementation of Section 3004(u) of RCRA requires the evaluation of solid waste management units not regulated under other RCRA authorities to determine if these units have continuous releases of hazardous wastes or constituents. The first step of this evaluation, a preliminary assessment and site investigation (PA/SI), often is conducted in conjunction with the RCRA Part B permit application review process. The authors have assisted the U.S. EPA in conducting several of the earliest RCRA PA/SIs. In this paper, the authors present a composite description of the PA/SI methodologies employed in those reviews, discuss critical obstacles encountered and describe the process used to determine the need for RCRA permit conditions to address releases of hazardous wastes or constituents to the environment.

INTRODUCTION

One of the most important new authorities provided to the U.S. EPA under the Hazardous and Solid Waste Amendments of 1984 (HSWA) is Section 3004(u) which requires that all RCRA permits issued to treatment, storage and disposal facilities after November 1984 shall require corrective action for all releases of hazardous wastes or constituents from solid waste management units at these facilities. In addition, under Section 3008(h), the U.S. EPA is given authority to issue corrective action enforcement orders to facilities managing hazardous waste under RCRA interim status. Another extremely important related provision, Section 3004(v), extends RCRA corrective action authority beyond the boundaries of the facility.

The authorities provided under these provisions extend the scope of RCRA well beyond that to which treaters, storers and disposers of hazardous waste previously had been covered. Prior to the amendments, facilities and operators had to be concerned with obtaining permits for regulated units used for treating, storing and disposing of hazardous wastes as defined by the U.S. EPA under 40 CFR Part 261. Now, a new process has been put into place which extends the permitting process to include a review of essentially every unit within a facility's boundaries which is used or has been used to manage solid wastes.

The U.S. EPA is approaching implementation of these new authorities under a process involving three general steps which roughly parallel the process used under CERCLA:[1]

Stage 1: Assessment of Need for Corrective Measures. This stage usually involves a preliminary assessment and site investigation (PA/SI), which includes an evaluation of readily available information to determine if releases posing a threat to human health and the environment have occurred or if there is a likelihood that such releases may have occurred. The U.S. EPA issued a draft guidance document on August 5, 1985, providing procedures for conducting RCRA PA/SIs.[2]

Stage 2: Remedial Investigation and Development of a Proposed Program of Corrective Measures. If the results of the PA/SI indicate that releases have occurred or may be occurring at one or more units, owners and operators will be required to conduct a remedial investigation to make a more definitive determination regarding the potential for releases and to identify the nature and extent of releases that are found.

The second step in this phase of the corrective action process is the development of a program of corrective measures to clean up the releases found in the remedial investigation. If this program is developed as part of a RCRA permit condition, the permit will need to be modified to incorporate the corrective measures program after public comment is solicited and received on the proposed measures.

Stage 3: Selecting and Performing Corrective Measures. This stage is the actual establishment and implementation of the corrective measures program, which may be carried out according to schedules of compliance in the facility's modified RCRA permit or under an enforcement order.

The authors have assisted the U.S. EPA in conducting some of the earliest PA/SIs under this process, using the procedures in the Agency's August 1985 guidance. The guidance currently is being reviewed by the U.S. EPA based on the results of field testing of the document. From their early experiences with the RCRA PA/SI process, the authors present some observations which they believe will be helpful to facility owners and operators in determining how they can participate most effectively in the PA/SI reviews of their facilities and to regulatory officials who are faced with the challenging task of conducting RCRA PA/SIs.

CONCEPTUAL APPROACH TO PA/SIs

The approach used by the authors in conducting RCRA PA/SIs roughly involves a sequential exclusionary process for each unit at a facility in which solid waste management units (SWMUs) are systematically eliminated from further consideration if certain criteria are met. Figure 1 illustrates the line of inquiry used by the investigator in this process. In practice, data limitations restrict the ability of the investigator to make simple "yes/no" determinations. Rather than being a sequential process, the actual process almost always requires a degree of professional judgment in weighing a number of factors. Nevertheless, in an ideal situation, the investigator would have all the information needed and the line of inquiry would take place as follows: Is the unit an SWMU?

Units at a facility which are considered SWMUs for purposes of RCRA corrective action reviews are very broadly de-

fined. In general, the types of units include: landfills, surface impoundments, waste piles, land treatment units, incinerators, injection wells, tanks (including 90-day accumulation tanks), container storage areas, transfer stations and waste recycling operations. Units specifically exempted from RCRA regulation under 40 CFR Part 264 are included in this universe, i.e., wastewater treatment and elementary neutralization tanks. Units may be active, inactive or completely abandoned. Units which are not managing or have never managed RCRA-regulated hazardous wastes still are considered as SWMUs subject to review, since the potential for the release of hazardous constituents also must be evaluated.

Does the Unit Manage Hazardous Waste?

Waste characterization is one of the most critical steps in the PA/SI process. The scope of materials of concern is considerably larger than wastes which are regulated under RCRA on the basis of listing or hazardous characteristics. In a PA/SI, units which manage or have managed wastes containing hazardous constituents included in 40 CFR Part 261, Appendix VIII, must be reviewed for the potential of releases of these constituents to the environment. Further, units used to manage bulk putrescible wastes (such as sanitary sludges) must be assessed for the potential of methane gas generation and subsequent migration of subsurface gases to adjoining structures.

In an ideal case, the PA/SI investigator would have detailed information available about the types, volumes and locations of waste within the units. If the data clearly show that no hazardous wastes, hazardous constituents or wastes capable of methane generation have ever been managed in the unit, the unit may be eliminated from further consideration. If hazardous wastes or constituents are present, the chemical/physical properties, toxicity, persistence and mobility of the wastes can be evaluated to determine the potential of the wastes for releases to air, groundwater, surface water and/or soils; also the threat posed to human health and the environment by such releases can be assessed.

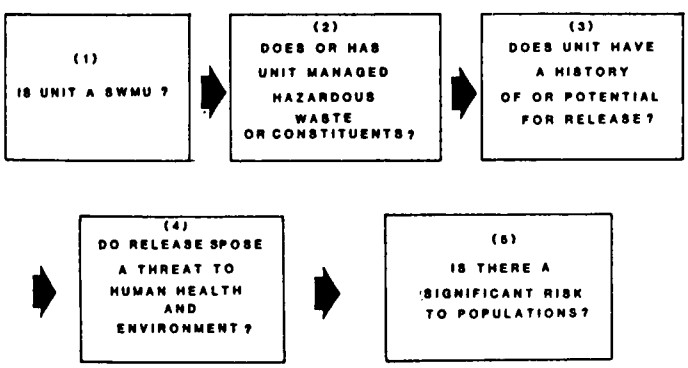

Figure 1
Conceptual RCRA PA/SI Process

Is There a Potential for Releases?

If the investigator has key design and operating data, he can make a reasonable evaluation of the potential for releases from the unit. A common unit investigated is a tank which has an adequate secondary containment system, closed roof and sufficient flood protection; commonly available are records demonstrating that the tank has been inspected frequently and maintained. In this case, the investigator may eliminate the unit from further consideration on the basis of the unlikely potential for releases, regardless of the types of wastes or constituents managed.

Is There a Threat to Human Health and the Environment?

At this point in the "idealized" evaluation, the investigator has determined that a solid waste management unit has managed hazardous wastes or wastes which have hazardous constituents and that there is a high likelihood of releases. It still may be possible to eliminate this unit on the basis of consideration of the pathways available to the releases into each environmental medium. For example, subsurface releases may not present a threat to groundwater if the underlying aquifer is deep, if soils are relatively impermeable and/or if the aquifer underlays sufficiently impermeable bedrock. Even if the hydrogeological setting indicates that there is a potential for infiltration to the underlying aquifer, the owner/operator may have monitoring data available demonstrating that no contamination attributable to releases from the unit are occurring.

Is There a Risk to the Neighbors?

Even if the unit has failed all of the above tests, it may be possible to determine that the risks posed by the releases do not pose a threat to human health and the environment. For example, air releases may not be of concern if there are no downwind populations. However, since U.S. EPA policies regarding risk assessment in RCRA PA/SIs still are evolving, the role of risk in the process is unclear at this time.

Key Information Used in RCRA PA/SIs

The process just described assumes that the investigator has in-hand all necessary information required to make the determinations just described.

The most important pieces of information and their common uses in RCRA PA/SIs are displayed in Figure 2. The following discussion summarizes the common roles of these data in RCRA PA/SIs.

In many circumstances, the PA/SI for a facility will begin after submission of a Part B permit application and after the owner/operator has responded to the regulatory agency's request for information about its solid waste management units. Although these information requests have been fairly general in practice, there are certain specific data items which should be included in each letter responding to such information requests. These include identification of each solid waste management unit:[3]

- Description of the type of unit
- Location of each unit within the facility on a topographic map
- Dimensions and available information on release controls
- Status and history of operation
- Description of wastes managed

All available information which could indicate the potential for releases from any of the units, including:

- Available environmental monitoring data (groundwater, surface water, air, soil samples)
- History of releases to any environmental medium

Information in the applicant's response to this information request, combined with the RCRA Part B application, generally provides the core of data for initiation of a PA/SI. Some of the most relevant data for PA/SIs which are generally found in Part B applications include:

Waste Characterization: Although the waste analyses in Part Bs are only applicable to those wastes which are managed at regulated units in the application, the information may be useful for providing a general picture of waste generation trends at the facility.

Likely Information Use in PA/SI / Information Source	Description of Unit	Waste Characterization	Surficial Setting	Sub Surface Setting	Operating History/ Release History	Environmental Monitoring Data	Exposure Information
RCRA Part B Application		•	•	•		•	•
SWMU Information Letter	•	•	•		•	•	
CERCLA Sources	•	•	•	•	•	•	•
EPA / State RCRA Inspection Files			•	•		•	
Permit Files From Non-RCRA Programs	•	•	•	•	•	•	
Aerial Photography	•		•		•		•

Figure 2
Information Sources Frequently Used in RCRA PA/SIs

General Facility Description: Descriptions of the facility can be used by the PA/SI investigator to gain some understanding of the overall facility layout, surrounding land use and general topography.

Floodplain Delineation: The determination of whether or not individual solid waste management units are situated in floodplains is a critical part of the PA/SI. Corrective measures for a unit which may not otherwise have a potential for releases to the environment may be required if flooding could threaten the structural integrity of the unit and/or result in direct runoff or discharge to adjoining surface waters.

Hydrogeological Data: For Part Bs for land disposal units, an extensive amount of data regarding the hydrogeologic setting of these units is required. While these data are specific to the regulated units at the facility, they sometimes can be used in PA/SIs of other units at the facility in lieu of available information for these units.

Exposure Information: Under Section 3019 of RCRA, permit applications for landfills and surface impoundments must include exposure information reports. This information is valuable in determining the potential migration pathways of contaminants released from SWMUs and for identifying populations potentially at risk from such releases.

Contingency Plans: Contingency plans, required of all RCRA permittees, may be useful in determining if the permit applicant has identified all SWMUs at the facility. For example, the plan may provide for temporary storage or impoundment of hazardous wastes in specific areas at the facility; these areas would be solid waste management units which should be included in the PA/SI review.

As indicated in Figure 2, there are numerous other important sources of information which should be available to the investigator to supplement the facility's Part B and SWMU information letters. These sources are noted below.

CERCLA Sources: If a preliminary assessment and/or site investigation has been performed for the facility under the CERCLA program, the results and supporting documentation are clearly a critical imput to the RCRA PA/SI. Hazard Ranking System documentation and CERCLA Section 103(c) notifications also can be valuable information sources. The most important differences between CERCLA and RCRA PA/SIs, which will be described in the following paragraphs, must be borne in mind when using this information.

U.S. EPA/State Inspection Files: Generally, the PA/SI investigator will find it extremely beneficial to perform a file search of the regulatory agency's (State or U.S. EPA) records of inspections performed previously at the facility. RCRA inspections, as well as inspections performed under the NPDES program, sometimes can help the investigator identify environmental problems and releases which have occurred. Inspection records for State-regulated units, such as non-hazardous solid waste landfills, also can be extremely valuable. An unquantifiable, but nevertheless important, aspect of this review is the general insight provided about general environmental management practices at the facility.

Monitoring Data: Any relevant type of environmental monitoring data, even if the monitoring was not performed for RCRA-hazardous constituents, may be important to the PA/SI investigation. Indications of conventional contaminants in groundwater, for example, may be indicative of releases of other constituents of concern from a solid waste management unit.

Other Data Sources: Other sources of information, such as aerial photography, may be very important to the PA/SI investigator. Basically, any type of information which can help the investigator understand the nature and operation of the unit, its history, wastes managed and operational practices should be considered in the review.

Relationship Between RCRA and CERCLA PA/SIs

There are obvious analogies between the PA/SI procedures used in the CERCLA and RCRA programs. Generally, the same types of factors are considered by the investigator, including the types of wastes managed at the unit, environmental setting, structural integrity of the unit and release controls, history of unit operation, history of releases and surrounding land uses. For this reason, prior CERCLA investigations are generally extremely useful sources of information for the RCRA PA/SI.

While many of the procedures for conducting PA/SIs for facility SWMUs under RCRA are similar to those used by CERCLA field teams, there are fundamental differences between these two processes that may render different outcomes in terms of resulting requirements placed upon facility owner/operators. The most basic difference is in the ultimate objectives of each of the reviews.

The objective of a CERCLA PA/SI is to develop information sufficient to develop a score under the Hazard Ranking System (HRS), which in turn is used to establish priorities for further action at the site. Ultimately a site may be placed on the National Priority List with subsequent remedial investigations, feasibility studies and selection and implementation of remedial actions. An HRS score is established for an entire facility and may be the result of cumulative environmental impacts of a number of units within the facility.

In contrast to the CERCLA process, the objective of an RCRA PA/SI is to determine whether or not releases may be occurring at individual units within a facility. The outcome of the investigation is not a numeric score, but a finding for each unit regarding its potential for releases to the environment. This distinction can mean that facilities which have relatively low HRS scores may nevertheless be required to conduct corrective measures under RCRA.

OBSTACLES TO THE PA/SI REVIEW PROCESS

The conceptual RCRA PA/SI process has been described in detail to highlight two of its most significant features: first, an extensive amount of information is needed to fully complete every step of the process and, secondly, facility owners and operators need to be actively involved in the process to assure that the most accurate and timely information is used. The lack of data necessary to derive conclusions regarding the likelihood of releases of hazardous wastes and constituents to the environment likely will result in RCRA permit conditions requiring the facility owner and operator to develop the needed information under mandated deadlines.

It is clearly in the facility owner/operator's best interests to come forward with all available relevant information at the PA/SI stage of the permitting process rather than to defer substantive input until the RCRA permit reaches the formal proposal stage. Of course, in many cases, critical information may not be available to the owner/operator. Facilities simply did not have a need to keep records on many of their units operated prior to RCRA enactment. The lack of adequate records poses one of the most critical obstacles to the RCRA PA/SI process.

The most frequently occurring data problem is inadequate characterization of the wastes placed in the unit. Without reliable waste management data, it is not possible to determine if there are or are not hazardous constituents within the waste material. Since the entire corrective action program is keyed by releases of hazardous constituents, the PA/SI process is truncated by lack of waste characterization data. A case frequently encountered is a landfill unit known to have been used to dispose of plant trash which may (or may not) have included off-specification production products with hazardous constituents or containers with hazardous residues.

In some cases, it has been possible to ascertain the presence of hazardous constituents in a particular disposal facility through process knowledge of the industry in question. In many cases, however, this is not possible—particularly where several disposal areas have been utilized and no records have been kept to define the wastes placed in each area.

In these cases, the PA/SI review process essentially becomes stalled until adequate data are obtained. In some cases, this review has been accomplished by mandating data collection through permit conditions in the RCRA permit. In other cases, facility owners and operators have been able to provide historical data on general facility waste management practices which demonstrated that the facility's hazardous wastes were transported off-site during the period of operation of the unit in question.

Another frequent obstacle to the PA/SI review process is inadequate description of the surrounding environment, primarily those elements which serve as vehicles for contaminant transport (soils, groundwater and surface waters). Typically, existing waste management units are not located in proximity to abandoned units. As a result, environmental information provided in the Part B application or Exposure Information Report may not be germane to remotely located, abandoned units. If the Part B application is for non-land disposal units, facilities are not required to provide hydrogeologic information which might be helpful to the PA/SI review.

Lacking critical information, such as soils permeability or depth to groundwater, it is not possible to make reasonable judgments regarding the potential for releases of hazardous constituents, even when the presence of hazardous constituents in the unit has been firmly established. Again, in this case it is likely that the responsibility for providing the needed data will fall to the owner/operator. Often, this step requires extensive field studies, including soils testing, groundwater investigations or sampling of surface waters.

A third obstacle that frequently impedes the PA/SI decision-making process is the lack of evidence regarding releases from SWMUs. This is especially true in the case of long-abandoned units that predate the current era of environmental awareness. In these and other cases, the facility has no reason to monitor groundwater, surface waters, air or soils. Lacking direct evidence of releases, it sometimes is possible to make judgments regarding the potential for or probability of a release. This decision can be made when the properties of the waste and the local transport media (groundwater, etc.) are well defined.

More often than not, however, only sketchy information is available. In those cases, there are two approaches that can remove the decision-making obstacles. The first step is to directly monitor the appropriate media to detect evidence of contamination resulting from a release from the unit in question. This process frequently involves monitoring of surface of groundwaters.

Alternatively, it may be more feasible to conduct the studies necessary to assess the potential for release. This approach involves investigation of the waste properties and characterization of the surrounding environmental media.

In some complex situations, a hybrid of both approaches must be used. This can occur when there are several units in proximity and knowledge of environmental conditions is insufficient to properly design a monitoring program to detect releases. This situation presents a more difficult case where both background environmental studies (e.g., geohydrological investigations) and monitoring must be undertaken to detect contamination.

Another obstacle arises when environmental data indicate that there is a problem at the facility, but the PA/SI investigation cannot identify the unit or units most likely to be causing the problem. This situation can arise, for example, when groundwater monitoring data from samples collected at various locations within the facility indicate concentrations of hazardous constituents above natural background levels, but inadequate hydrogeologic data preclude determining the source. In this case, the facility might be required to conduct a remedial investigation for

the area of the facility where the problem has been found. The remedial investigation may, in certain cases, be mandated for the entire facility.

Finally, difficulties in identifying and locating all solid waste management units within a facility often are encountered. In some cases, facility owners and operators have not understood that units which have not previously been considered in the RCRA program, such as 90-day waste accumulation areas, non-hazardous waste disposal units and elementary neutralization tanks, are now included in the PA/SI process. In other cases, the owner/operators were not aware of the existence of abandoned units until the PA/SI investigators questioned how wastes were measured at the facility prior to initiation of current management practices. In answering these questions, which may require the owner/operator to interview current or past facility employees, the owner/operator may be surprised by the number of old waste disposal units within the facility's boundaries. In the authors' experience, it is not uncommon for older, large chemical manufacturing facilities, particularly those which are more than 20 years old, to have 20 or more SWMUs which must be evaluated.

This discussion has focused on the critical obstacles experienced while conducting some of the first PA/SIs under RCRA. More experience by PA/SI investigators and an increased understanding of the process by facility owners and operators likely will serve to sharpen the analytical and implementation procedures to address these issues.

CONCLUSIONS

This paper has provided an explanation of the RCRA PA/SI process, likely sources of data and their uses in the process and some of the critical obstacles which have impeded the process.

Several conclusions can be derived:

- The RCRA PA/SI process requires the use of as much relevant available data as can be reasonably assembled. Key information sources include the facility's Part B application, response to the regulatory authorities' request for SWMU information, RCRA and other environmental program inspection files and previous CERCLA investigation data. Facility owners and operators should be prepared to provide significantly more information in response to RCRA PA/SIs than to the pre-HSWA permitting process.
- The fundamental differences between RCRA and CERCLA PA/SIs may result in different outcomes. Facilities with relatively low HRS scores may nevertheless be required to perform corrective measures under RCRA.
- Since the lack of data during an RCRA PA/SI review can result in mandatory requirements to obtain the needed data, it is in the best interests of facility owners and operators to collect and provide as much relevant information as possible and to be involved early in the process.

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Assessment of the Application of RCRA Part 264 Standards to CERCLA Site Remediation

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ABSTRACT

The purpose of this investigation was to evaluate recent revisions to the National Contingency Plan requiring application of RCRA Part 264 standards to CERCLA site remediation. This assessment was conducted in three phases. The first phase involved review of the regulatory background to determine consistency with existing laws and regulations. The second phase assessed technical validity and identified technical problem areas of the proposed policy with particular attention to requirements of Part 264 Subparts F and G.

The third phase investigated the cost-effectiveness of applying RCRA Part 264 standards to CERCLA sites. Two National Priority List sites were studied. Costs were based on actual closure costs under the original NCP policy and projected expenditures for closure under the revised policy requiring application of RCRA Part 264 standards. Effectiveness was quantified in terms of risk reduction using the U.S. EPA Hazard Ranking System and a computerized deterministic groundwater risk model for calculation of lifetime mortality risks.

INTRODUCTION

In the Feb. 12, 1985, *Federal Register,* the U.S. EPA proposed revisions to the National Contingency Plan (NCP) which would require that CERCLA (Superfund) remedial actions "attain or exceed all applicable or relevant Federal public health or environmental standards." The U.S. EPA specifically explained in the *Federal Register* that this includes compliance with RCRA Part 264 standards.[1]

On Oct. 10, 1985, Lee Thomas, U.S. EPA Administrator, signed the final version of the revised National Contingency Plan. The final version is virtually the same as the version proposed in February with a change in the phrase "applicable or relevant" to "applicable or relevant and appropriate." The addition of the words "and appropriate" suggests that the U.S. EPA received sufficient public comment to recognize the problems associated with strict application of Federal public health standards, including RCRA Part 264.

Among the comments received by the U.S. EPA was an extensive study conducted by this author as an employee of the State of Tennessee. The study specifically assessed the applicability of RCRA Part 264 standards to closure of CERCLA sites. The purpose of the following report is to relate the results of that study. The study was broken into three phases; regulatory review, technical assessment and cost-effectiveness investigation.

PHASE I: REGULATORY REVIEW

The pertinent laws and regulations reviewed in association with this issue were: (1) RCRA and its amendments; (2) RCRA Part 264 Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities; (3) CERCLA (authorizing the Federal Superfund program); and (4) the NCP used to direct Superfund activities. The review of these laws and regulations revealed information on the intentions of Congress and the U.S. EPA.

RCRA Section 3004 directed the development of regulations for "treatment, storage or disposal of hazardous waste...as may be necessary to protect human health and environment."[3] The same section also required that the Administrator shall, where appropriate, distinguish in such standards between new and existing facilities. Through these sections Congress limited the regulatory requirements to that which is actually necessary for protection and provided recognition of the problems associated with applying new standards to existing facilities.

Part 264 standards were originally promulgated in the July 26, 1982, *Federal Register.* Section VI.A.1. of the Preamble listed five important considerations involved in the U.S. EPA's strategy for protection of groundwater: (1) avoid complicated uncertain predictions; (2) recognize the ability to limit the impact of polluted groundwater by limiting use; (3) prevent stifling of innovation; (4) provide timely and expeditious regulation; and (5) use limited financial resources in the most cost-effective manner possible.[4]

Section 105 of CERCLA specified that the NCP provide a means of assuring that remedial action measures are cost-effective (Section 105(7)). The law also required the NCP to provide criteria for determining priorities among releases or threatened releases and methods for determining the appropriate extent of remedial action to be conducted, "including analyses of relative costs" (Section 105(2,3,8))[5].

The NCP was revised pursuant to CERCLA Section 105 to provide for Superfund activities. It was published in the *Federal Register* on July 16, 1982, and became effective on Dec. 10, 1982.[6,7] Section 300.68 defined the method of selection for remedial action at a Superfund site. The final selection criteria in the NCP were dependent on cost-effectiveness, i.e., the lowest cost alternative that is technologically feasible and reliable and which effectively minimizes damage to and provides adequate protection of public health, welfare or the environment."[6] Thus, the three factors involved in the cost-effectiveness selection were cost, technical feasibility and adequate risk reduction. An obvious question is "What is adequate?"

The proposed revisions to the NCP published in the Feb. 12, 1985, *Federal Register* were signed into effect on Oct. 10, 1985. The final version was not available at the time of this writing. U.S. EPA officials state that the final version was virtually the same as the proposed version. The final selection process as revised deleted the reference to the "lowest cost alternative" and added a requirement to attain or exceed "all applicable or rele-

vant and appropriate" Federal public health standards.[2] Although the term "cost-effective" remains in the selection criteria, it is overridden by the requirement to attain or exceed public health standards.

The only situation in which cost would override the requirement to attain standards is in "Fund-balancing" of Federal Superfund dollars. In a situation where limited Federal Superfund dollars cannot take care of all sites requiring remediation and the site represents less hazard than other sites, a lesser alternative can be accepted. Unfortunately, this waiver does not extend to State Superfund programs with multiple sites and limited funds or to Responsible Parties with multiple environmental problems (possibly including more serious air, water, solid waste or radiological waste problems).

The elimination of cost-effectiveness as one of the major criteria in selecting remedial actions creates a conflict with the apparent intentions of Congress stated in RCRA, Part 264 (Preamble), CERCLA and the original NCP.

PHASE II: TECHNICAL ASSESSMENT

In the preamble to the proposed version of the National Contingency Plan, the U.S. EPA specified that RCRA Part 264 standards would be considered relevant to response at CERCLA sites.[1] The purpose of this section is to assess the technical validity of applying Part 264 standards to CERCLA sites. The two major subparts of Part 264 which would be of importance to CERCLA sites are Subpart F—Groundwater Protection and Subpart F—Closure and Post-Closure Standards.

Subpart F—Groundwater Protection regulations outline a three phase program: (1) detection monitoring; (2) compliance monitoring; and (3) corrective action. The standards defined by Subpart F generally could be applied to CERCLA sites to help establish the point(s) of compliance, location of monitoring wells, frequency and duration of sampling, analytical parameters and cleanup levels. However, two areas of controversy exist which create severe problems in the utilization of the Subpart F standards in the CERCLA program. These two areas are the analytical requirements for the 375 constituents in 40 CFR Part 261 Appendix VIII and the determination of Alternate Concentration Limits (ACLs).

The major problems associated with analysis of 40 CFR Appendix VIII constituents involve the high cost of analysis, technical questions on the validity of analytical techniques required, instability of some contaminants in water (which are therefore not expected to appear in sample analysis) and frequency of analysis. The U.S. EPA recognizes that these problems exist and is making efforts to address these concerns. The U.S. EPA has proposed a revision to Appendix VIII to exempt requirements for 23 constituents which are unstable in water for for which no laboratory standard for analytical calibration has been developed. Until other concerns are resolved, the public still is required to follow the standards as written.[8]

Subpart F—Groundwater Protection standards provide three bases for groundwater cleanup. The three cleanup levels which are considered acceptable for groundwater under Subpart F are: (1) Background Levels, (2) Maximum Concentration Limits (MCLs for Drinking Water Standards), and (3) Alternate Concentration Limits (ACLs, standards for compliance at the site based on acceptable levels of exposure some distance from the site). It is anticipated that for most CERCLA sites it will not be technically or economically practicable to achieve background or MCL levels. Therefore, groundwater protection standards typically will be based on Alternate Concentration Limits.

Section 264.94(b) outlines the standards used in the development of ACLs. These standards provide a reasonable framework for information which should be collected. However, the level of detail required by the U.S. EPA in the guidance document for ACLs[9] requires time-consuming and burdensome data development and collection programs. For example, detailed information is required on exact waste quantities and types, definitive hydrogeologic data and specific toxicological effects (including synergistic effects of combinations).

Although all of these pieces of information are important, it is questionable whether precise quantification is possible and whether it will appreciably improve assessment over that attainable with more generalized information. It is technically inconsistent to require extensive detailed investigations to obtain high levels of confidence in some of the data used in an ACL determination while recognizing the large number of speculative input factors involved, such as meteorological conditions, population growth in the area and future uses of surface water and groundwater over the life of the site. It is suggested that a greater degree of consistency among the required levels of accuracy be established. The excessive quantities of time and money currently required for field and laboratory research could better be invested in remedial action activities.

The RCRA Part 264 Subpart G—Closure and Post Closure standards provide general closure performance standards. These standards emphasize prevention and base closure on a "to the extent necessary" performance criteria (Section 264.11). This approach allows the most cost-effective methods of closure to be used and provides for site specific interpretation of the "to the extent necessary" terminology. In contradiction to this approach, Subpart G references closure standards in Subpart N—Landfills where closure criteria more specifically require use of a final cover which provides long-term minimization of liquid migration through the closed landfill (Sections 264.310(a)).

The RCRA Guidance Document entitled Landfill Design—Liner Systems and Final Cover, July, 1982,[10] defines the minimum cover design considered acceptable. The required cover design consists of 2 ft of clay (with a permeability of 10^{-7} cm/sec or less) overlain with 1 ft of gravel (with a permeability of 10^{-3} cm/sec or greater) for drainage. These two layers are covered by a layer of soil (1.5 ft) and topsoil (0.5 ft) graded and seeded to support vegetation. For sites having an impermeable underliner, a synthetic membrane liner is required between the clay and gravel layers.[10]

Strict application of these RCRA Part 264 closure requirements is not technically valid for remediation of all CERCLA sites. For many inactive hazardous substance sites, prevention or minimization of infiltration is not a critical factor. Some situations where sites would not greatly benefit by direct application of these technology based standards are: (1) sites where waste materials are virtually insoluble; (2) sites subject to surface-water flooding and subsequent rising groundwater; and (3) sites located in quarries or hollows where underground springs feed into the waste. For these sites, an impermeable cap would not provide a cost-effective solution to the problem and, for the second and third cases, would be completely ineffective in preventing liquid migration through the site.

It is recommended that each CERCLA site be assessed to determine the potential sources of liquids which may reach the site and the potential impact of liquid migration through the site on public health and the environment. Following this assessment, the original language of Section 264.11 concerning "to the extent necessary" should be considered instead of the strict infiltration technology based standards. Flexibility in closure design must be allowed in order to provide appropriate and cost-effective remediation on a site specific basis.

PHASE III: COST-EFFECTIVENESS INVESTIGATION

The purpose of this phase was to investigate the cost-effectiveness of applying RCRA Section 264 standards and guidelines to closure of CERCLA sites. The investigation was conducted using two case studies: the North Hollywood Dump Site in Memphis, Tennessee and the Hardeman County Dump Site (also called the Velsicol Chemical Corporation Dump) near Toone, Tennessee. Both sites are on the CERCLA National Priority List and have been closed under the original NCP policy. Three site conditions were considered: (1) the original condition of the site when disposal activities ceased prior to any remedial action activities, (2) the condition of the site following closure under the original NCP policy (as published on July 28, 1982) and (3) the condition of the site if closed under the revised policy by following RCRA Part 264 standards and ensuing guidance.

Costs for the cost-effectiveness determination were developed from actual closure costs under the original NCP policy including emergency remedial action activities, Remedial Investigation/Feasibility Study (RI/FS) development and covering/capping of the sites. Both sites under study have been closed under the original NCP policy, so actual costs for closure were available.[11,12,13] Estimated costs for closure under RCRA Part 264 included costs for emergency remedial actions, extensive RI/FS development, ACL determination and a RCRA cap as required under Subpart G guidance. Costs for extensive RI/FS development and ACL determination for the sites were drawn from U.S. EPA Region 4 estimates and work plans.[14,15,16] Costs for RCRA capping activities were based on contractor estimates for cap construction.[17] The cost of the closure activities conducted when disposal ceased (nominal covering) was not taken into account for this study, allowing the original condition to be the baseline for cost. Table 1 provides a summary and comparison of costs for closure under each policy for Hollywood and Hardeman County Dump Sites.

The cost for closure of the Hollywood Dump using RCRA Part 264 standards was estimated to be $9,212,300, over four times the cost for the current closure under the original NCP policy ($1,693,600). The largest cost increase was due to the addition of $5.07 million for RCRA capping activities.

The difference between closure costs for Hardeman County under the two policies was less dramatic, although there was still a significant 67% increase in costs. The increase in cost was less than that for Hollywood Dump because the existing RI/FS was already fairly extensive and the existing cap is smaller in area and much closer to RCRA standards than that used at Hollywood. The total cost for closure of Hardeman County Dump was estimated to be $3,678,300 under the original NCP policy and $6,152,000 under the revised NCP policy requiring application of RCRA Part 264 standards.

Effectiveness of closure was based in the study on a quantified level of risk reduction, comparing risk following closure of the sites under each policy to the risk associated with the original condition of the site. Risk was quantified using two methods. The first method was the Hazard Ranking System used by the U.S. EPA in prioritizing National Priority List (CERCLA) sites.[6] The original condition of the sites was scored disregarding observed release data.[14,18-22] Pathway data were developed and used in order to allow for adjustments resulting from closure under each of the policies. Scores were developed for each closure policy by changing net precipitation and 1-year, 24-hr rainfall values (assuming a relative decrease in infiltration) and facility slope and intervening terrain values (following regrading of the site during closure). The results showed that both policies appreciably reduced site risk below the risk level established for original conditions of the site.

However, the model did not differentiate between effectiveness of the original NCP policy versus the revised (RCRA) policy (i.e., the model indicated that the two policies were equally effective). According to these results, the more expensive option, closure under the revised NCP policy using RCRA standards, is not cost-effective since no additional risk reduction is provided with the additional cost. Table 2 provides a summary of the Hazard Ranking System scores for original conditions and closure under either policy for Hollywood and Hardeman County Dump Sites.

Table 1
Summary and Comparison of Costs for Closure Under Each Policy for Hollywood and Hardeman County Dump Sites

Site/Activity	Cost in Dollars: Original Policy	Cost in Dollars: RCRA Policy	Increase in Cost[a]: Dollars	Increase in Cost[a]: Percent
HOLLYWOOD DUMP SITE				
RI/FS	$ 605,000	$1,963,500	$1,358,500	225%
Alternate Concentration Limit Determination	[b]	1,091,800	1,091,800	[c]
Remedial Action	1,080,600	6,157,000	5,068,400	466%
TOTAL CLOSURE COST	$1,693,600	$9,212,300	$7,518,700	444%
HARDEMAN COUNTY DUMP SITE				
RI/FS	$1,378,500	$1,878,500	$ 500,000	36%
Alternate Concentration Limit Determination	[b]	1,091,800	1,091,800	[c]
Remedial Action	2,299,800	3,181,700	881,900	38%
TOTAL CLOSURE COST	$3,678,300	$6,152,000	$2,473,700	67%

[a] Increase in cost of proposal policy activities vs. current policy activities.
[b] There is no equivalent under current policy for the ACL determination required under RCRA.
[c] Undefined.

Table 2
Summary of HRS Scores Substituting Pathway Data for Observed Release Data, North Hollywood and Hardeman County Dump Sites

Site/Hazard Category	Scores: Original Conditions	Scores: Either Closure	Percent Decrease
NORTH HOLLYWOOD DUMP SITE			
Groundwater (S_{gw})	31.84	26.53	16.7%
Surface Water (S_{sw})	10.18	8.00	21.4%
Air (S_a)	0	0	0
Migration (S_{m})[a]	19.32	16.02	17.1%
Fire and Explosion	0	0	0
Direct Contact	41.67	0	100%
HARDEMAN COUNTY DUMP SITE			
Groundwater (S_{gw})	68.98	63.67	7.6%
Surface Water (S_{sw})	20.36	16.00	21.4%
Air (S_a)	0	0	0
Migration (S_{m})[a]	41.57	38.12	8.3%
Fire and Explosion	0	0	0
Direct Contact	25.00	0	100%

[a] $S_m = \sqrt{S_{gw}^2 + S_{sw}^2 + S_a^2} \div 1.73$

The Hazard Ranking System was not developed to assess closure options and may not be sensitive enough to properly assess effectiveness of the two policies. However, it cannot be disregarded. The model was developed by the U.S. EPA for the purpose of assessing site hazards and is one of the nationally standardized systems for prioritizing hazardous waste sites. Due to the many uncontrolled influences on a site, the physical differences between closure under the original NCP policy and closure under the revised NCP policy may not be significant when incorporated into the variable framework of the entire site surroundings.

The second method used to assess effectiveness involved the use of a computerized deterministic groundwater model to quantify risk associated with each site in terms of annual and lifetime mortality risk. The model used hydrogeological, demographic, chemical, physical and toxicological data with a one-dimensional advection-dispersion equation to project contaminant concentrations and levels of annual and lifetime mortality risk at selected points.[23] This groundwater risk model is schematically depicted in Figure 1. The acceptable level of lifetime mortality risk for this study was based on the U.S. EPA's designated level of 10^{-4} to 10^{-8}.[24-26]

The hazards under consideration for each site were drinking water risk associated with contaminated groundwater, direct contact/erosion hazards and risk associated with consumption of contaminated fish in nearby surface waters. Indicator parameters used for modeling were chosen based on toxicity, prevalence in the site and relative mobility. Chlordane was chosen as the indicator parameter for Hollywood Dump Site.[19,27] Carbon tetrachloride, chloroform and heptachlor were chosen for Hardeman County Dump Site to respectively represent two highly soluble, prevalent compounds and one highly insoluble low level concentration compound.[20,22]

Table 3 summarizes the results of this risk modeling effort for each site under the three site conditions being studied. A variety of site specific and technical information references was used to develop these results.[19,20,22,27-33]

Drinking water risk for the Hollywood Dump Site was extremely low under the original site conditions due to the deep layer of relatively impermeable clay beneath the site. Since the original risk was so low, mitigation would be unnecessary. Therefore, closure under either policy would not be cost-effective for mitigation of this hazard. Alternatively, the drinking water hazard for the Hazardous County Dump Site was so high that neither closure method could adequately remediate the site to provide acceptable risk levels. Therefore, the groundwater would still be unusable and neither policy provided a cost-effective solution.

Since model calculations were based on ingestion, direct contact hazards were not quantified. Direct contact hazards were considered to be completely mitigated under either method by

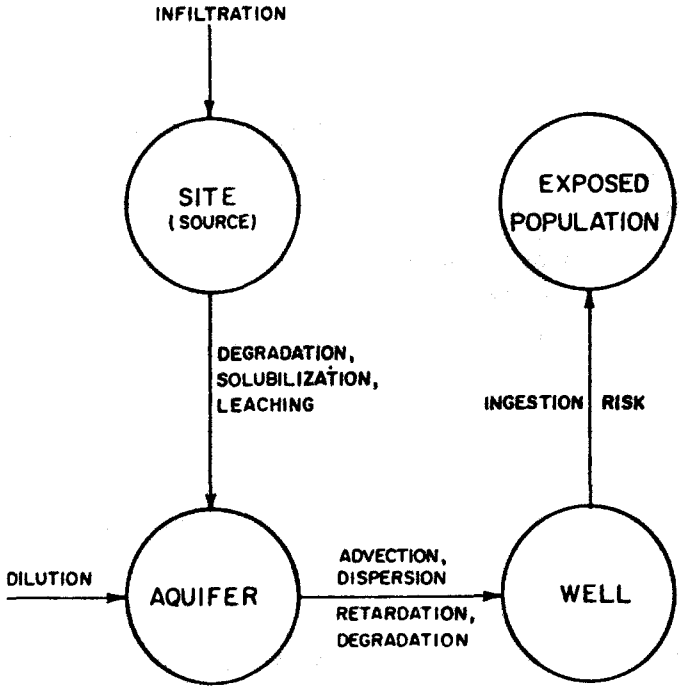

Figure 1
Schematic Diagram for Groundwater Risk Model

Table 3
Summary of Risk Reduction Provided by Closure Options, North Hollywood and Hardeman County Dump Sites

Site/Hazard Category	Maximum Lifetime Mortality Risk: Original Condition	Original Policy	Revised (RCRA) Policy	Risk Reduction: Original Policy	Revised (RCRA) Policy
North Hollywood Dump					
Drinking Water	9.0×10^{-13}	[a]	[a]	[b]	[b]
Direct Contact/Erosion	[c]	[c]	[c]	100%	100%
Fish Ingestion (Maximum Consumption)	5.94×10^{-4}	2.23×10^{-4}	5.95×10^{-6}	62.5%	99%
Hardeman County Dump					
Drinking Water					
Carbon Tetrachloride, CCl_4	1.0	0.17	0.30	83%	57%
Chloroform, $CHCl_3$	1.0	0.07	0.01	93%	99%
Heptachlor, $C_{10}H_7Cl_7$	4.2×10^{-16}	6.9×10^{-17}	1.3×10^{-17}	84%	97%
Direct Contact/Erosion	[d]	[d]	[d]	100%	100%
Fish Ingestion (Worst Case Scenario Maximum Consumption)	2.36×10^{-3}	1.39×10^{-4}	2.27×10^{-5}	94%	99%

[a] Values were not calculated for either closure method since the original risk was so minute.
[b] No credit is given for risk reduction since the original risk was below the lowest U.S. EPA target range value of 10^{-8}.
[c] Direct Contact was not quantified but was considered to be mitigated completely by either method. This assumes proper maintenance of whichever closure method is utilized.
[d] These risk levels assume theoretical use of the groundwater for drinking water purposes, disregarding the alternate water supply currently used.

creating an earthen barrier which eliminates access to waste materials. For this hazard category, the additional cost for closure under the more stringent and expensive revised policy is not considered cost-effective.

The risk associated with fish ingestion at both sites under original conditions was above the acceptable EPA range of 10^{-6} to 10^{-8}. Risk is decreased by closure under the original NCP policy at each site but remains just above acceptable levels. The application of RCRA Part 264 standards draws the risk value within the U.S. EPA's acceptable range but results in a dramatic increase in costs (see Table 1).

At this point, the cost-effectiveness issue reverts to a more subjective debate. The type of risk is a voluntary risk where the exposed individual has been warned of the risk through posting of signs and, at Hollywood, has been limited by fencing. The risk calculations were based on worst case conditions using high solubility values and the unlikely consumption rate for an individual of 21 kg/yr of fish strictly from these waters every year for 70 years.[29] Recognizing that the citizens have been appropriately warned, that the risk values were purposely inflated and the risk under the original NCP policy is close to the suggested U.S. EPA risk range, it is concluded that the greatly increased cost associated with closure under the revised policy is not justifiable for purposes of decreasing fish ingestion risk.

Figure 2 provides a graphical representation of the costs of closure under the two policies versus the lifetime mortality risk associated with fish ingestion at both sites and with drinking water (carbon tetrachloride and chloroform) at Hardeman County. The U.S. EPA target risk range is shown for comparison. Additional comparison is provided by the insertion of some "generally accepted" risks along the top of the figure.[34]

CONCLUSIONS

RCRA Part 264 standards provide a reasonable framework for assessment and cleanup of hazardous waste sites but strict adherence to standards and guidance eliminates the flexibility necessary for remediation of CERCLA sites. RCRA Part 264 Subpart F—"Groundwater Protection" standards outline a rational methodology for assessment and remediation of groundwater contamination. However, compliance with Appendix VIII and ACL determination requirements would be time consuming, costly and technically questionable. If problems in dealing with Appendix VIII analytical requirements and ACL determinations can be resolved, the approach outlined in Subpart F would be desirable for application to CERCLA sites. RCRA Part 264 Subpart G—"Closure and Post-Closure" standards in Section 264.11 are reasonable but the standards specific to landfills in Subpart N, Section 264.310 and the ensuing guidance are too restrictive to be technically valid for application to all CERCLA sites.

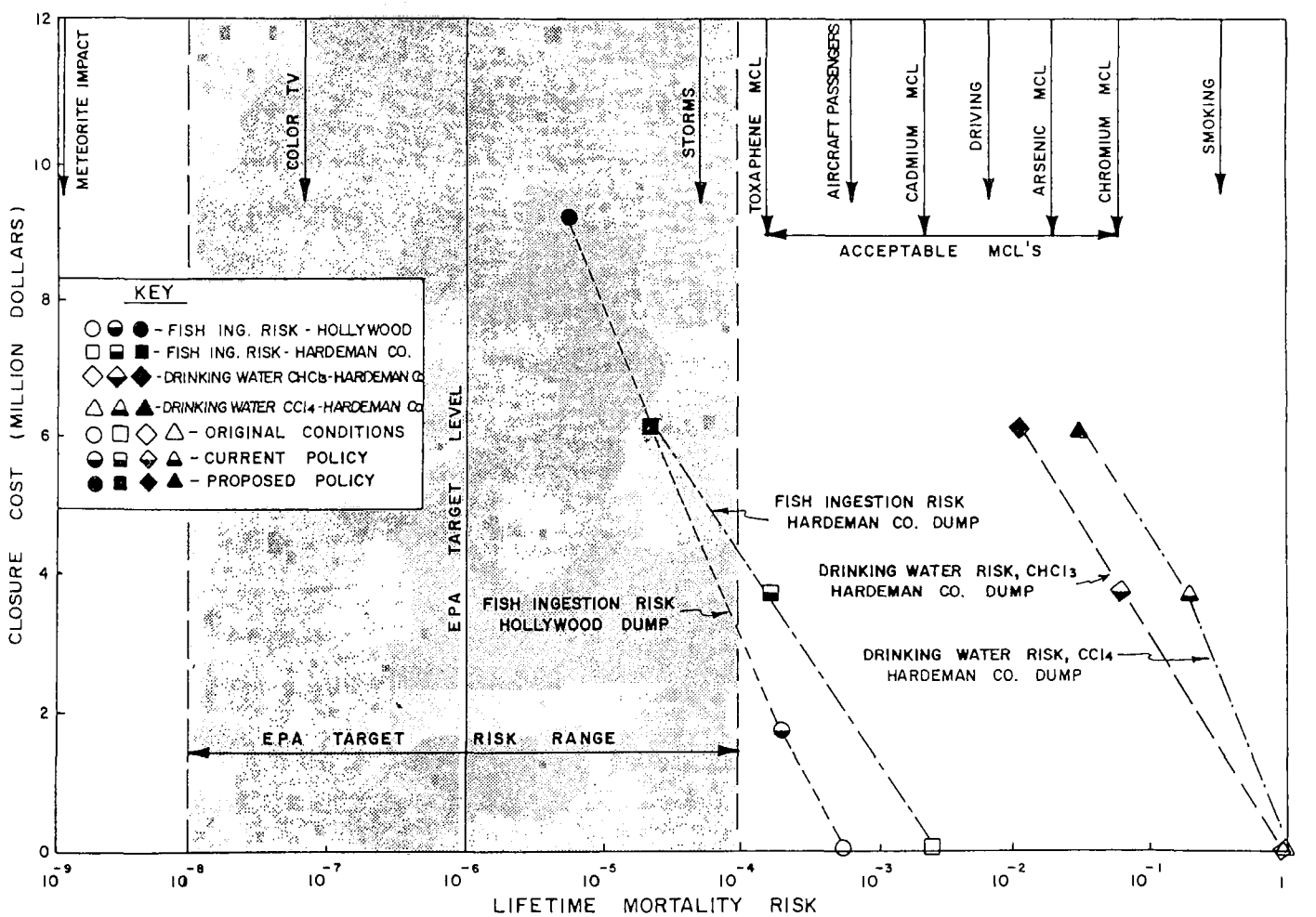

Figure 2
Closure Cost Versus Lifetime Mortality Risk

The cost effectiveness of the original and the revised policies was investigated through estimates of cost and quantification of risk reduction. It was determined that the revised policy, requiring application of RCRA Part 264 standards and ensuing guidance to CERCLA sites, was not cost-effective for mitigation of any of the hazard categories investigated at either site studied in this report. This determination was based on the high incremental cost required to achieve little or no incremental risk reduction under the revised policy.

The proposed revisions to the NCP required compliance with "all applicable or relevant" Federal public health standards. The final revised version of the NCP changed these words to read "all applicable or relevant and appropriate."[2] It is recommended that RCRA Part 264 standards be considered as a reference rather than a requirement for CERCLA sites and that site specific conditions dictate when RCRA Part 264 standards are "appropriate."

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Small Quantity Generators: The Maryland Approach to Regulation and Assistance

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ABSTRACT

With the enactment of the Hazardous and Solid Waste Amendments of 1984 (HSWA), the universe of regulated hazardous waste generators nationwide increased by 1,000%. The provisions for small quantity generators are the prime reason for the increase. While the U.S. EPA and various states rush to understand the amendments and meet Congressionally mandated due dates and requirements, the State of Maryland is actively implementing its program.

The Maryland Department of Health and Mental Hygiene received the statutory authority for regulating small quantity generators, that is, those generators producing 100 kg to 1,000 kg/month of hazardous waste, in July 1984. This authority came from the State legislature. The law is more stringent than the HSWA provision, and the regulations supporting the law are more stringent than those proposed by the U.S. EPA. These facts, in addition to earlier effective dates for manifesting and disposing at hazardous waste facilities, confuse the business community. However, the State developed an approach that helps ease the burden of notification and manifesting requirements and helps the small businesses to identify their hazardous wastes and means for disposal.

INTRODUCTION

During the one-year grace period, from July 1, 1984 to July 1, 1985, provided in the legislation, the State participated in a multimedia effort to inform the newly regulated community and to offer technical assistance and information. The approach involved the Maryland Chamber of Commerce, the University of Maryland, the Controlled Hazardous Substances Advisory Council, the Maryland Environmental Service and the Department of Health and Mental Hygiene (DHMH).

Through the production and distribution of a question and answer brochure, mass mailings of regulatory requirements and seminars with trade associations and county governments, the State reached the vast majority of affected businesses and municipal and local governments. While the response may not be considered favorable, it has been cooperative. The interaction with the affected community has helped to identify problem areas in existing regulations and has led to regulatory amendments. Particularly troublesome areas involved recycling and on-site treatment at non-permitted facilities. The approach is proving instructive to the regulatory agency and responsive to the needs of those being regulated.

REACHING THE REGULATED

The first response to the new legislation lowering the exemption limit to 100 kg/month of generated hazardous waste was in effect no response. Very few inquiries were received after the first mass mailings. Notices of new regulations and legislation were probably treated as unwanted junk mail. Many were probably never read by small business people. When the Administration directly contacted the trade associations of some of these small businesses, a frequent response was "we do not have a problem; this legislation does not affect us."

It was obvious to the Administration that the lack of response was not an indication of complete compliance, but one of not understanding the breadth of the law. As a public agency, the Administration could not wait for the law to become effective and then enforce it against an unknowing regulated community. That approach can be very effective in getting attention and compliance, but it creates resistance and ill will.

During the initial phase of notifying the public, contact was made with the Maryland Chamber of Commerce. It was felt that the Chamber could further disseminate information to the business community. At the same time, the U.S. EPA was accepting proposals for grants to assist in the dissemination of information about the small quantity generator requirements. The Chamber, along with the Maryland Environmental Service, proposed a multi-faceted program involving the business, government and university sectors with the Chamber taking the lead. Rather than draw on its resources only, the Administration joined this effort. After several months of work, this group produced a question and answer brochure that attempted to lead affected persons through the maze of requirements of the new law. It was distributed to nearly 7,000 businesses and organizations.

In addition to the brochure and regulation mailouts, the Administration made itself available to speak to various groups and organizations to further explain the law and requirements. Also, a second part of the grant provided for technical assistance by the University of Maryland.

The total program is basically structured as follows: the Maryland Chamber of Commerce is the lead agency since it has the primary contacts with the business community. The Maryland Environmental Service (MES), which is an agency of the Department of Natural Resources, works closely with the Chamber since it, too, has many contacts with industry; MES also administers the grant. Also working with these two groups is the Controlled Hazardous Substances Advisory Council, which is the State advisory board for hazardous waste. It was reasoned that, with the non-governmental groups in the lead, the business community would be more receptive to the assistance.

The role of the Waste Management (WMA) is to explain the requirements and assist the business sector to come into compliance. The University's role is to provide technical assistance to business on an industry-wide rather than individual basis: for

example, the University is prepared to work on problems of the drycleaning industry, but not for individual drycleaning establishments. Hopefully they can study two or three representative facilities and develop solutions that can be applied industry-wide.

The business community is not the only regulated sector. Federal, State and local government agencies also are affected. County school systems generate hazardous waste in their science laboratories and maintenance shops. State, county and municipal maintenance shops generate hazardous waste from automotive maintenance. People in these agencies usually do not apply the requirements to themselves and certainly do not budget for the increased costs of hazardous waste management.

PROBLEM AREAS

The most significant problem for the small quantity generator consists of two parts: understanding the requirements and dealing with the paperwork. RCRA was the most massive regulatory program ever, prior to the HWSA of 1984. The amendments have expanded RCRA even more. Although only a small portion of the Act affects the small quantity generator, it is enough to be overwhelming. Small business people in particular are not familiar with environmental requirements. They are not prepared to deal with the information needs and the paperwork. They seldom have technical backgrounds or knowledgeable staff to coordinate the paperwork.

One must add that the increase in paperwork affects the regulatory agency too. All of the manifests go to an agency for review. The WMA receives 30,000 manifests per year as of FY 85. Estimates of the increase for FY86 range from 10,000 to 80,000 manifests. These higher numbers will have a significant impact on personnel resources.

A second problem is the amount of helpful information available. One would think that more information on a topic would be better. With the small quantity generator requirements, this is not the case. Primarily, the problem lies in the fact that Maryland implemented its own regulatory program before RCRA was enacted. Businesses, through their trade organizations, receive information on the Federal program. At the same time, they receive information on the State program. Since the two programs are somewhat different, the business person becomes confused or frustrated.

Recycling of hazardous waste is also complicated. State law requires that hazardous wastes being recycled must be treated as hazardous waste. In the case of listed wastes and sludges, they must be manifested and transported by certified haulers. The statute also can be read to include characteristic wastes under the transportation requirements. There is also a very thin-line distinction between what is a recycling activity and what is a treatment activity. Recycling is exempt from permitting activities while treatment must go through the entire RCRA review and permit process. The WMA encourages recycling and makes every attempt to be open to new ideas.

A good example of the difficulty with recycling involved a new car dealer association. The question was whether or not the body shop was a TSP facility. One dealer had installed a solvent recovery still in the autobody shop. The distillation process was very simple, consisting of a hot oil jacketed still and a condenser; 4 to 6 gal of paint solvent can be distilled in four hours. The clean solvent is reused in paint or reused as a degreaser in the shop. The still bottoms are removed and shipped as hazardous waste. No off-site solvent is distilled.

A fourth problem area that has serious potential is the existence of numerous exempt sources. When hazardous waste is shipped from a generator, it must go to a RCRA-permitted facility. Exempt quantities (that are non-liquid) may go to a permitted sanitary landfill. Exempt generators, such as schools and county garages, may not generate more than 100 kg/month or accumulate that quantity on an individual basis. In the aggregate, they likely do exceed the exempt limit.

Existing regulations prohibit the establishment of a central collection center unless it is a RCRA-permitted facility. In theory, this center could serve as the generator. For example, all the hazardous waste from the school system would go to the central location where it is properly packaged and transported to a proper treatment, storage or disposal (TSD) facility. This approach cannot be used in Maryland because the central site is, in effect, an unpermitted TSD facility. Schools, being individually exempt, may then dispose of their hazardous wastes in municipal landfills. Thus the move to more properly manage hazardous waste from numerous small sources is abridged.

Another problem that is closely related to the previous one involves the transporters. Maryland regulations allow for stoppage of a vehicle hauling hazardous waste for no more than 72 hr at a permitted TSD facility. The waste load must be transported to a facility or out-of-state within 5 days from initial pickup. Hauling companies are having difficulty meeting these requirements because of the dispersed location of small generators and the small quantities of generated waste. It takes longer than the permitted periods of time in the rural areas of the State to collect a full truck load of waste.

One last area that may become a problem is transportation and treatment/disposal capacity. Several trade organizations and counties have raised the question: Is there sufficient capacity to handle the additional hazardous waste? That is a difficult question to answer. Although the State has no hazardous waste landfills and only three TSD facilities that accept off-site generated waste, there does not seem to be difficulty in shipping waste. The real question may be a related question: Is there an economical means for transporting/disposing of hazardous waste? This question is more pertinent to the small generator, and particularly so to a small generator in a rural area. The owner can ship the waste if willing to pay the price. The capacity is there but perhaps not within the financial means of the generator.

ANSWER TO PROBLEMS

It is very difficult to ensure that all the regulated community understands the regulatory requirements. As described previously, Maryland's approach to multiple mailings and seminars or talks to specific groups is the most practical approach. Keeping the message simple and to the point is imperative. A regulated business owner need only hear what the State requires him to do. The owner does not need a discussion of what the U.S. EPA and the other states are doing. Information sent to a business should provide the following: (1) regulatory requirements; (2) types of waste that the business may generate that are hazardous; (3) application packets for U.S. EPA ID numbers; (4) how to order and use manifests; and (5) telephone numbers for help. Also, the State agency should have listings of certified haulers and TSD facilities.

The anticipated increased volume of manifests did generate concern in the WMA about how to cope with the increase. One particular area where the number of manifests can be reduced is the batch toll operation. This operation involves a company that in effect leases cleaning/degreasing solvents to commercial concerns such as auto maintenance shops. When the material needs to be replaced, the company delivers new solvent and removes the old. The company claims that the material is not generated by the commercial shop but that it is owned by the company. Thus, the company is the generator.

If the commercial shop or user is considered the generator, it needs a fully completed manifest with each shipment of used solvent. The WMA is not anxious to receive possibly 50,000 to 60,000 additional manifests for this type of operation from one company. The State, after review of its statutes and regulations, reached a compromise: the company distributing the solvent is the generator; the generator may use one manifest per collection truck per day; each pickup must be recorded on the manifest, but the name and location of the pickup is not needed; each solvent (if more than one at a pickup site) must be listed individually; daily totals must be shown on the manifest; and the agreement only applies to generators of less than 1,000 kg/month of hazardous waste. It is estimated that this method of handling the manifest will reduce the number of manifests by 80% for one company.

Recycling activities have required extensive review of the Maryland statute and regulations along with the redefinition of solid waste. The WMA sought the advice of the Office of the Attorney General in determining whether or not an auto body shop redistilling its own solvents was a treatment facility. The factors leading to the determination of whether or not it was a TSD facility and required a permit were: the distillation product is reused directly in the original process; it is generated on-site; the still bottoms are treated as hazardous waste; and used solvent is not stored before recycling.

This decision fits very well into the redefinition of solid waste as promulgated by the U.S. EPA on January 4, 1985 (40 CFR, Parts 260-266). However, there are parts of the new definition that are difficult to understand and apply. It is going to be particularly difficult to apply the regulations to the small quantity generator.

A question being asked is: "Can the waste from multiple small sources in one system be collected at a central location and shipped from that point?" The argument raised in favor of this concept is that it is efficient to ship from one central location and that it will provide for environmentally safe disposal. It is argued further that, left to individual means, each school probably will dispose of hazardous waste in municipal waste sites. This disposal practice certainly is legal under the small quantity generator regulations, but it defeats their intent.

An answer is to allow diverse generators of a single school system or government agency to centralize waste collection without requiring the central location to become a permitted TSD facility. County and municipal governments are reluctant to pursue a hazardous waste facility permit. This issue is under review.

Another of the problems that does not have a definite solution is that of stoppage. An attempt has been made to allow longer stoppage periods in Maryland (7 to 10 days). Consideration has been given to providing for stoppage or holding terminals that would be exempt from the need for a permit. These terminals would be required to have a bond and to meet certain hazardous waste management requirements. However, no transfer could take place at the terminals.

There are problems with this approach because enforcement of storage times would be difficult. Also, haulers may choose to use large trailers to collect waste since no transfer at the terminal would be permitted. This system could cause a safety hazard by having large trailers full of hazardous waste making collection runs. The WMA decided to leave its regulation unchanged and review problems on a case-by-case basis.

If there is a problem with TSD capacity, the business community must solve it. The question is raised: "Why doesn't the State open facilities?" The State, through MES, unsuccessfully made an attempt to operate a hazardous waste landfill. For various reasons, it could not compete with industry and was closed. The difficulty with bringing industry into the off-site TSD facility business is that the cheap and easy method of landfilling is no longer a viable alternative. A new hazardous waste landfill will be extremely difficult if not impossible to build. The other methods, incineration and chemical treatment or recycling, are expensive and technology-intensive. Supply and demand will create the incentive and wherewithal to deal with any capacity problems. A market is emerging.

CONCLUSIONS

The small quantity generator requirements appear massive on first impression. With work, they can be made less imposing and can be presented to the generator in understandable language. Every effort needs to be made to accommodate recycling and disposal needs within the regulations. Waste from small quantity generators can be minimized as evidenced in the recycling efforts of the automobile dealers. If an agency takes too strict a posture, the small quantity generator may seek out environmentally damaging or illegal alternatives for disposal.

Siting Efforts in Southern California

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INTRODUCTION

The management of hazardous waste in Southern California is closely linked to the history of the development of this area. Southern California, particularly Los Angeles County, developed extensively following the turn of the century with an even speedier pace after the second World War. There were several factors that predisposed the area to rapid development at this time. The first was the fact that large quantities of water were available throughout Los Angeles County, primarily from imported sources. In the 1910s, the City of Los Angeles constructed an aqueduct to bring water approximately 270 miles from the Owens Valley (in the Eastern Sierra Nevada Mountains) to Los Angeles. In the 1930s work began on an aqueduct from the Colorado River (at the California-Arizona border) to move water approximately 300 miles across the Colorado desert.

A second factor that was very important in the region's growth was the presence of large petroleum deposits. Development of oil began around the turn of the century in Los Angeles and financed a great deal of the public improvements that were constructed in the form of aqueducts. Oil also provided a great deal of the economic vitality of the region.

A third factor that played a very large part in the development of the region was its climate. The Mediterranean-type climate of Southern California was an excellent place for testing aircraft. This led to a cluster of aircraft manufacturers, including the Douglas Aircraft Company, Northrop, Lockheed and Hughes. This industry, which was very important during the second World War, eventually led to a high concentration of technical talent in the aircraft and, later, the aerospace industries and fostered the development of the aerospace, defense and transportation industries as major components of the Southern California economy.

The last factor that contributed to the development of Southern California was a general attitude on the part of government that government intervention was not only acceptable, but necessary, in order to develop and foster the economy of the area. This philosophy led to government involvement in the development of aqueducts, in the dredging and filling of harbors around the Ports of Los Angeles and Long Beach and in the construction of an extensive system of flood control that allowed the development of many otherwise unavailable areas.

HAZARDOUS WASTE DISPOSAL HISTORY

The history of hazardous waste disposal in Southern California is not as well recorded as that of other major developments. However, evidence from the unearthing of old industrial sites and from the legacy of past improper disposal gives us a reasonably good idea of what occurred. Prior to 1965 most of the hazardous wastes generated by the region's industries were disposed of at the point of generation, offshore or into the closest municipal landfill. Around 1965 three Class I disposal sites were opened in the Palos Verdes Peninsula, the San Jose Hills in the City of West Covina and in the Santa Monica Mountains west of the San Fernando Valley. These sites, which were allowed to take virtually all wastes except radioactives and explosives, became the backbone of the disposal system for hazardous waste within the County for approximately 20 years.

During this same time period, the nation was becoming more conscious of the environmental consequences of its actions and began, through a series of Federal Laws, to clean the nation's air and water. Major federal legislation in these areas was enacted in 1970 and 1972, respectively. These laws, which were designed to protect the air and water, did so by concentrating pollutants that formerly were dispersed and placing them upon the land. In the late 1970s, it was becoming increasingly obvious that all three environmental media (air, water and land), needed protection, and that careful attention had to be paid to pollutants going into all three.

RCRA IMPACT

In 1976 Congress passed the first version of RCRA which made much progress in regulating hazardous wastes but, unfortunately, did little to force hazardous wastes to go to treatment facilities. In 1984, with the major amendments to RCRA, Congress changed the law radically and will require virtually all hazardous waste to receive treatment prior to land disposal.

In 1980 two of the previously mentioned sites, Palos Verdes and Calabasas, were closed. The first because it was full and the second because the geologic requirements for hazardous waste disposal sites had changed (whereas the geology of the site had not). This left Los Angeles County heavily dependent upon one hazardous waste disposal site, the BKK Landfill in West Covina. Pressure immediately began to build; the citizens of West Covina wanted closure of this landfill, which they felt represented an excessively large threat to the community.

In early 1981 the Environmental Protection Agency, the State Health Department, the State Water Resources Control Board and the Counties of Ventura, Los Angeles, Orange, San Diego, Imperial, Riverside and San Bernardino banded together to form the Southern California Hazardous Waste Management Project. The initial charge of this study was to find replacement disposal sites for BKK.

Search for Alternatives

There was soon an increasing awareness at the State level that treatment without disposal would be unacceptable both environmentally and politically. The efforts of the Southern California

project were redirected to include substantial work toward getting waste treated close to its generation. This included performing a detailed waste characterization and facility needs assessment, developing goals and policies for hazardous waste management and developing detailed siting criteria for hazardous waste treatment and disposal facilities. However, the redirected project was unable to come to terms with the hard practical question of where to site hazardous waste treatment and disposal facilities.

BKK Closes to Hazardous Waste

At that time it was assumed that there were many locations where hazardous waste treatment could be performed and that the private sector would be willing to establish treatment facilities in Southern California. As it turned out, the extremely volatile nature of the business of hazardous waste management, coupled with the lack of any firm guarantees of business for treatment facilities, has thus far prevented the establishment of any major hazardous waste treatment facilities in Southern California. Therefore, when the BKK Landfill announced that it would cease accepting hazardous waste at the end of November 1984, the Board of Supervisors of Los Angeles County asked the Los Angeles County Sanitation Districts and the Department of Public Works to prepare a report listing specific locations that would be suitable for hazardous waste treatment and disposal sites. The Board initially asked for this report in 90 days and appropriated a total of $500,000 for this effort.

TASK FORCE ESTABLISHED

The task force for this project began screening to eliminate grossly unsuitable areas from any further consideration. This process was carried out for both treatment and disposal facilities. For treatment facilities, it was decided that compatible land use was the most important criterion and, therefore, the search centered on the industrial areas in the County. Other significant factors entering into the siting of a treatment facility were access (primarily by road), isolation from homes and availability of adequate sewer connections to remove treated wastewater.

After the industrial areas were screened using these criteria, an industrial real estate firm was hired to find available properties between 5 and 15 acres in size that potentially could be used as waste treatment facilities. The realtor reported that there were 56 such properties available. The project then studied these further and came out with a list of the best 20.

Potential Sites Identified

Concurrent with the search for waste treatment facilities, a search for disposal sites in the County was done. Los Angeles has a population of approximately 7.5 million people, and a variety of land uses preclude waste disposal sites in all but a few areas of the County. State law requires that waste disposal facilities be at least 2,000 ft from any homes. The central part of Los Angeles County is occupied primarily by National Forests which are excluded from consideration by Federal law. In addition, most of the valleys are geologically unsuited for hazardous waste disposal.

Using these criteria, eliminating earthquake zones, flood-prone lands and significant ecological areas, the project quickly focused on eight areas as potential sites for hazardous waste disposal. The disposal operations that are envisioned in these areas would be for treated residuals only and would not take raw, untreated hazardous waste. The sites would accept no liquids and would be specially engineered and operated to keep rainwater infiltration to a minimum.

Preliminary geologic investigations of available literature were performed on all eight perspective locations. One piece of land, on County-owned property, was drilled to determine if the subsurface met the promise that the surface provided. At the time of this writing, attempts are being made to obtain permission to drill three other pieces of property.

CONCLUSIONS

In 1985 several of the counties around Southern California formed a Joint Powers Agency dedicated to better management of hazardous wastes throughout the region. At the time of its inception, Los Angeles County (which dominates the region in terms of waste generation) declined to join this Joint Powers Agency. The regional political dynamics of Southern California make it imperative for Los Angeles to have a system in place for managing its wastes. Unless this happens, other political jurisdictions will be reluctant to site hazardous waste management facilities, fearing that these will become magnets for waste from Los Angeles. Therefore, it is critical that Los Angeles County lead the area in terms of hazardous waste management in Southern California.

The California Site Mitigation Decision Tree

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ABSTRACT

The California Department of Health Services has developed a process that provides state decision-makers with a consistent approach to mitigating abandoned and uncontrolled hazardous waste sites. This process, called the California Site Mitigation Decision Tree Process, contains unique elements that: specify how exposure criteria, known as Applied Action Levels (AALs), will be developed; identify site characterization data that must be collected or developed; present preferred data collection strategies and techniques; and set appropriate site mitigation criteria for various alternative remedial actions. Selection of the best alternative remedial action is based upon technical and scientific evaluations concerning protection of public health and the environment while considering other nontechnical factors such as demography, land use and input from the public.

INTRODUCTION

The mitigation of abandoned and uncontrolled hazardous waste sites is a challenge faced by federal, state and local agencies across the United States. The citizens of California demonstrated their concern and commitment to facing this challenge by overwhelmingly passing Proposition 27, the $100 Million Hazardous Substance Cleanup Bond Act of 1984. With the passage of Proposition 27, the Toxic Substances Control Division (TSCD) of the California Department of Health Services (DHS) was designated the lead state agency responsible for investigating, characterizing and mitigating abandoned and uncontrolled hazardous waste sites ranked on the California Site Priority Ranking List (SPRL).

To facilitate expeditious and consistent mitigation of sites on the SPRL as well as other unlisted hazardous waste sites, the Alternative Technology and Policy Development Section (ATPDS) of TSCD developed the California Site Mitigation Decision Tree Manual. The Decision Tree Manual provides state decision-makers with a technical guidance document that presents a systematic and standardized method for evaluating the existing and potential public health and environmental risks associated with hazardous waste sites under various alternative remedial actions.

THE DECISION TREE PROCESS

The Decision Tree Process, as presented in the Decision Tree Manual, consists of five basic components:

- Preliminary Site Appraisal
- Site Assessment
- Risk Appraisal
- Environmental Fate and Risk Determination
- Development of Site Mitigation Strategies and Selection of Remedial Action

Each of these five basic components is made up of several steps, procedures and decision points developed to provide a technical and scientific basis for selecting remedial actions to mitigate hazardous waste sites. Each of the five basic components of the Decision Tree Process is discussed below. Also presented is a discussion of the relationship between risk management and risk appraisal under the Decision Tree Process.

Preliminary Site Appraisal

The Decision Tree Process is activated through discovery and ranking of an abandoned or uncontrolled hazardous waste site on the SPRL. The procedures used by the State of California to assign a numerical score for migration potential and public health and environmental impacts to a site are identical with those developed by the U.S. EPA. However, once the site has been scored according to its potential public health and environmental impacts, the California procedure assigns a final rank to the site after also developing a preliminary cost/benefit analysis. Thus, DHS can more efficiently manage its resources by focusing initially on those sites that can be most effectively mitigated.

Those hazardous waste sites with sufficiently high numerical scores for migration potential and public and environmental impacts are submitted to the U.S. EPA to be placed on the National Priority List (NPL). Funds made available through passage of Proposition 27 can be utilized to provide the State's share of costs associated with NPL sites within California. By utilizing both state and federal Superfund processes, DHS can direct state resources to mitigate those sites with the greatest potential public health benefits per unit cost and can still direct federal resources to those sites that require the greatest costs.

Site Assessment

Under the Decision Tree Process, hazardous waste sites are regarded as consisting of source materials (including wastes and contaminated soils) and exposure pathways that facilitate transport of hazardous chemicals from the location of the source to a point of exposure. Thus, there are two major objectives of the Site Assessment component. The first objective is to characterize the nature and extent of chemical contamination in all pertinent media of exposure. The second objective is to characterize the migration or accumulation of chemical contaminants along pertinent exposure pathways.

The first objective of the Site Assessment component is satisfied through the collection and chemical analysis of samples of the various exposure media to determine the extents of contamination and concentrations of chemicals of concern. Guidance is offered throughout the Decision Tree Manual on preferred sampling, handling and analytical techniques. A section on the necessary quality assurance/quality control (QA/QC) procedures to verify the accuracy and representativeness of chemical analyses is also included.

With regard to the second objective, pathway characterization, the Decision Tree Manual includes discussions of those data, parameters and interpretations necessary to characterize a pathway. The manual also presents preferred and recommended techniques for sample collection and analysis. For example, recommended components of a drilling program may include, as appropriate, continuous coring, collection and analysis of undisturbed samples, as well as paired borings where the stratigraphy and observations made in the first boring can focus and direct the collection of samples for chemical analysis in the second. With regard to groundwater investigations, discussions of preferred data collection techniques include drilling methods, well and piezometer design, construction, development and sampling.

The representations of transport pathways are referred to as modules and are developed from data collected in the Site Assessment Phase. Each module may consist of observations, deductions, calculations, numerical models and professional judgments that allow the analyst to make scientifically and technically defensible statements and conclusions regarding the behavior and transport of chemical contaminants at the site.

Risk Appraisal

In the third component of the Decision Tree Process, Risk Appraisal, a basis is developed for evaluating risks of adverse toxicological effects associated with exposures to chemical contaminants identified at a given site. The basis for evaluating the risk of an adverse toxicological effect is a numerical criterion known as the Applied Action Level (AAL).

The key to understanding the risk appraisal concept is that an AAL is an exposure criterion. An AAL is developed in a consistent and documented manner as specified in the Decision Tree Manual and is intended for use only to evaluate potential risks of adverse effects associated with chronic, low level exposure to toxic chemicals on hazardous waste sites. The appropriate location for evaluating potential risk through the Decision Tree Process is at the terminus of an exposure pathway where a sensitive organism, referred to as a sensitive biological receptor, may come into contact with toxic chemicals associated with the particular hazardous waste site. An AAL is a media-specific, biological receptor-specific criterion that is applicable statewide to evaluate the risk of an adverse toxicological effect from exposure to toxic chemicals.

The formal evaluation of risk associated with exposure to contaminants on a hazardous waste site can be accomplished by applying a series of three risk appraisal tests. These risk appraisal tests evaluate single medium/single chemical exposure, multiple media/single chemical exposure and multiple media/multiple chemical exposure, respectively. Risk appraisal tests are performed first to determine if existing exposures of biological receptors present a risk of an adverse toxicologic effect. If so, a risk management process should be initiated to mitigate that risk by an interim remedial measure.

The first test in the risk appraisal process compares the level of exposure in a medium, abbreviated as Cmedium, with the AAL criterion for that medium, AALmedium. The first risk appraisal test is:

$$\text{If} \quad \frac{C_{medium}}{AAL_{medium}} > 1, \tag{1}$$

then the test fails, a sensitive biological receptor is considered to be at risk of an adverse impact and a risk management process should be initiated.

The second test in the risk appraisal process considers risks posed to a sensitive biological receptor through exposure to a single contaminant via all pertinent media of exposure. The second risk appraisal test is:

$$\text{If} \quad \sum_{medium=1}^{n} \frac{C_{medium}}{AAL_{medium}} > 1, \tag{2}$$

then the test fails, a sensitive biological receptor is considered to be at risk of an adverse impact and a risk management process should be initiated.

The third test in the risk appraisal mechanism determines whether a sensitive biological receptor may be considered at risk due to exposure to an aggregate of substances that produce the same toxic manifestation. Lacking data that are contradictive of the assumption of additivity, the third test in the risk appraisal mechanism is:

$$\text{If} \quad \sum_{Sub=1}^{z} \sum_{Medium=1}^{n} \frac{C_{medium,\,sub}}{AAL_{medium,\,sub}} > 1, \tag{3}$$

then the test fails, a sensitive biological receptor is considered to be at risk of an adverse impact and a risk management process should be initiated.

Environmental Fate and Risk Determination

The fourth component of the Decision Tree Process, Environmental Fate and Risk Determination, is designed to evaluate potential future risks associated with a particular site. The environmental fate and transport modules developed from data collected under the Site Assessment component are employed in the fourth step to project environmental impacts from current conditions associated with the site to future conditions on and distant from the site at points where sensitive biological receptors might be exposed to contaminants.

The three tests of the risk appraisal mechanism again are applied to evaluate whether sensitive biological receptors could be at risk in the future, utilizing projected concentrations in the various exposure media. Thus, the potential risks associated with contaminants on a waste site are evaluated for existing current exposures under the Risk Appraisal Component and for possible future exposures under this step, Environmental Fate and Risk Determination. If a sensitive biological receptor is evaluated to be at risk through either risk appraisal or risk determination, a risk management process should be initiated.

DEVELOPMENT OF MITIGATION STRATEGY AND SELECTION OF REMEDIAL ACTION

The first four components of the Decision Tree Process focus on evaluating risks associated with exposure to contaminants from hazardous waste sites. Once it has been determined that a sensitive biological receptor currently is, or will be at risk of being adversely affected, mitigation of that risk should be investigated. The development, evaluation and selection of remedial alternatives to mitigate that risk are discussed in this section. Although this component is presented as the final section of the Decision Tree Manual, activities associated with development, evaluation and selection of remedial alternatives actually should begin with the second component, Site Assessment, and run concurrently with the subsequent three components. In this manner, remedial alternatives can be evaluated and screened throughout the site assessment and characterization project as constraints and limitations of various alternatives become evident enough to justify exclusion from further evaluation. As the extent of contamination in each medium of exposure and the processes associated with transport and accumulation of contaminants along exposure

pathways become better understood, likely remedial strategies and alternatives can be selected for further evaluation, and unique data needs can be met concurrent with other site assessment activities.

The contents of the last component have been derived principally from those guidance documents available on the U.S. EPA's feasibility study process. The Decision Tree Process, therefore, is consistent with the U.S. EPA's specified process of selecting remedial alternatives for federal Superfund sites. The Decision Tree Process also is consistent with the remedial investigation process set forth in U.S. EPA guidance documents; site characterization activities are designed to develop the data base necessary for selecting the technically appropriate remedial action plan.

Risk Management and Risk Appraisal

The Toxic Substances Control Division (TSCD) of DHS is organized into a central headquarters and three regional offices. In general, those issues and problems that require uniform statewide solutions are referred to DHS headquarters. Those issues and problems that require solutions consistent with other regional operations are addressed by DHS regional offices, with technical support available from headquarters upon request. One example of this division of responsibility is in the area of hazardous waste management. The headquarters office of DHS is responsible for making determinations and classifications on a statewide basis as to which wastes are hazardous and which are non-hazardous. The regional offices of DHS are responsible for overseeing the management of those wastes, including issuance of waste disposal variances where mitigating factors such as volume and concentration justify disposal in other than a Class I facility.

With the passage of Proposition 27, the activities and responsibilities associated with mitigating hazardous waste sites also have been distributed between DHS headquarters and regional offices. Through the development of the Decision Tree Manual, the DHS headquarters office has provided a consistent technical approach to investigating, characterizing and mitigating hazardous waste sites. Through the ongoing development of AALs, DHS headquarters also provides statewide exposure criteria for toxic chemicals associated with waste sites. The DHS regional offices, on the other hand, are responsible for the day-to-day progress at waste sites. This includes developing working relationships with other state and local agencies whose jurisdictions include environmental monitoring and management as well as interacting with the interested public and their elected representatives.

On an organizational level, staff in DHS regional offices are responsible for risk management; staff in DHS headquarters offices are responsible for risk appraisal, as well as for providing technical support and guidance. Risk management includes project management to ensure collection of accurate and representative site characterization data, identification of sensitive biological receptors, identification of likely remedial alternatives based upon a working understanding of technical and cost considerations pertinent to each site and identifying non-technical considerations including demographics, land use, politics and public sentiment. Risk appraisal includes evaluation of risk associated with potential exposures not completely eliminated by remedial action. Thus, the DHS approach allows development of risk management decisions based upon a consistent risk appraisal process.

Finally, it is noted that consistency in the risk appraisal process does not equate to statewide uniformity in site mitigation criteria. For example, a level of residual contamination could be allowed to remain on one particular site and potential exposures to that contamination could be managed by engineering and legal controls such as capping and a notice on the title to the property. On another site where the environmental, economic, demographic and political factors are different, it might be unacceptable to allow that same level of contamination to remain on the site without physical control or management beyond that required for the first site. In both cases, statewide consistency is achieved by having a uniform exposure criterion to evaluate risk and by having a risk management process that addresses the same general technical and nontechnical considerations, though the relative importance of each issue may vary from site to site.

APPLICATIONS OF THE DECISION TREE PROCESS

Two representative examples of the application of the Decision Tree Process are presented below.

Arsenic Contaminated Site

This first example site had been a pesticide formulating facility for more than 40 years; it is located adjacent to a saltwater marsh. Extremely high levels of arsenic were measured in soils underlying former waste disposal impoundments and storage areas and near former loading and handling areas. Elevated levels also were measured across the site as a result of waterborne transport of contaminants by seasonal flooding.

Arsenic contamination also was observed in shallow, saline near-stagnant groundwater underlying this site. Deeper groundwater zones approximately 200 ft below the shallow zone are exploited for drinking water at a series of wells located hydraulically upgradient of the site. These deeper zones are separated from the shallow zone by approximately 100 ft of low permeability deposits.

As a result of site characterization studies, the site manager was able to identify human beings as the sensitive biological receptors of concern and contact with contaminated soils as the only significant exposure pathway. The remedial alternatives being considered included various amounts of excavation and capping in conjunction with notices attached to the deed on the property to limit potential usage of the land, thereby limiting future exposures to those associated with on-site activities that might disrupt the capping mechanism. At this site, the site manager had identified a likely remedial action plan. The Decision Tree Process was therefore activated to make an appraisal of the potential risks associated with a particular remedial alternative and to determine what level of contamination could be allowed to remain on-site.

Two exposure scenarios were considered for this site. In the first, exposures for on-site construction workers whose activities might disturb the capping mechanism were evaluated. The appropriate exposure criterion for this scenario was the 8-hour time-weighted occupational standard of 0.01 mg/m^3 for arsenic in the workplace rather than a long-term exposure criterion. The second scenario was to evaluate potential off-site exposure to windblown dust particles contaminated with arsenic.

The data necessary to evaluate these scenarios included characterization of on-site soils and pertinent meteorological information. In addition to environmental data, the literature and practicing industrial hygienists were surveyed to develop a reasonable estimate of dust levels that might result from on-site construction activities. An upper bound $25^{mg}/m^3$ of on-site dust and particulates was arrived at through review of survey results. Based upon this upper bound of $25^{mg}/m^3$, the level of arsenic allowable in on-site soils stays below the occupational exposure standard of $0.01^{mg/3}$ arsenic and was calculated to be 400 ppm of arsenic.

The second scenario required evaluation of the potential off-site exposures to wind-borne arsenic contaminated soils should the capping mechanism be disrupted. The particulate emissions from the site were estimated with standard air dispersion methods described in the Decision Tree Manual. With a residual level of 400 ppm arsenic in on-site soils, the level of arsenic in airborne particulates was undetectable and therefore would not represent a measurable risk to nearby residents. Thus, through the exposure assessments just described, a basis for setting site mitigation criteria was established for a site where the question "how clean is clean?" had previously seemed unanswerable.

Leaking Underground Fuel Tanks

In California, a statewide task force has been established to develop a guidance document on leaking underground fuel tanks (LUFT). Members of the task force include representatives of various State agencies, county health departments and water agencies. The format of the guidance document will follow that of the California Site Mitigation Decision Tree Manual and is expected to be available for distribution in the spring of 1986.

The LUFT task force is organized into subcommittees paralleling the five basic components of the Decision Treel Process. Thus, as with the Decision Tree Manual, a multi-disciplinary approach has been adopted that allows task force members to contribute in their particular areas of technical expertise.

Specific guidance will be presented on preliminary site appraisal and site assessment. Applied action levels for selected components of fuels are being developed, and the transport and environmental fate of fuels are being examined so that the risk appraisal and risk determination processes can be applied to leaking underground fuel tank problems. Remedial alternatives are being researched and evaluated with respect to their efficiencies and applicabilities under various site conditions. This application of the Decision Tree Process will fill a major need in California for developing a technical guidance document to address the investigation and mitigation of contamination from leaking underground fuel tanks.

CONCLUSIONS

The California Site Mitigation Decision Tree Process provides decision-makers with a consistent approach in investigating, characterizing and mitigating abandoned and uncontrolled hazardous waste sites. The Decision Tree Process provides a basis for appraising potential risks associated with alternative remedial actions at hazardous waste sites. The Decision Tree Process has been utilized by the Department of Health Services and other agencies within California and currently is being followed by a multi-agency task force to develop a technical guidance document on leaking underground fuel tanks.

Hazardous Waste Management: The Role of the Local Health Department

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ABSTRACT

The Columbus Health Department (CHD) has defined three functional areas for participating in the management of hazardous waste on a local level. These areas are: (1) coordination of local agencies, (2) emergency response and (3) review of hazardous waste facility permit applications. A core group of city agencies was formed at the Health Commissioner's request to review existing local responsibilities relative to hazardous waste management. Among the documents produced by this group for the city were notification procedures and functional responsibilities of agencies responding to a hazardous material incident and evacuation procedures and policies.

The CHD has identified its primary responsibility as the investigation of health effects from a hazardous material (HAZMAT) incident. A procedures manual for CHD was developed using the Centers for Disease Control document "A System For Prevention, Assessment, and Control of Exposures and Health Effects from Hazardous Sites" as a guide. The CHD manual later was used for the investigation of health effects from an accidental discharge of hazardous substances within the city by a chemical plant.

The CHD also has reviewed applications submitted by several industries for federal and state permits to store hazardous waste. These reviews have resulted in written agreements between the City of Columbus and the permittee that go beyond the federal and state statutory requirements.

INTRODUCTION

Since 1980, a national regulatory framework administered by the U.S. EPA has been in place to protect the public's health and safety from the improper management or illegal disposal of hazardous wastes. Under this federal legislation, states may exercise primary responsibility for administration and enforcement of a hazardous waste management program under state law in lieu of the federal U.S. EPA program provided the state program meets certain minimum federal standards.

On a local level, however, a combination of federal and state rules often precludes local authorities from passing laws and/or adopting regulations pertaining to the treatment, storage or disposal of hazardous wastes. Although such a preclusion exists in Ohio's hazardous waste laws,[1] the Columbus Health Department has attempted to initially define a role for our local government in managing hazardous wastes and materials.

REVIEW OF PERMIT APPLICATIONS

The CHD's initial involvement began with the review of a Part B Permit application for a local branch of a national independent distributor of chemical products. The company intended to collect spent solvents in 55 gal drums from its customers and store them at its Columbus location until an economic truckload could be arranged (this might necessitate storing the waste for longer than 90 days) for transfer to a reclaiming facility in an adjacent state. The Mayor of Columbus, as a statutory party to the judication hearing before the State of Ohio Hazardous Waste Facility Approval Board (HWFAB), requested that the CHD review the application and represent him at the hearing. Since the application had been reviewed previously by both the U.S. EPA and Ohio EPA for compliance with their respective regulatory standards, the CHD's task was to identify the potential hazards posed by the facility to the surrounding community and attempt to minimize any adverse environmental impact presented by these hazards. The CHD's first action was to form a committee of various city agencies to review the application.

The committee was comprised of representatives from the city's Fire, Police, Sewerage and Drainage, Water and Health Departments. Recommendations from each agency were recorded. Based upon these recommendations, a staff member of the CHD prepared testimony for presentation at a public hearing scheduled by the HWFAB.

Following the public hearing, a meeting was arranged between the statutory parties and applicant by the administrative law judge for this case. The goal of this meeting was to reach an agreement on those concerns raised at the public hearing. With the administrative judge acting as a facilitator, the CHD negotiated an agreement with the applicant. The negotiated agreement, or Memorandum of Understanding, incorporated the committee's recommendations and was to be included as a condition of the permit, if granted. The terms of this agreement included the following: (1) quarterly inspections of the hazardous waste storage area by the Division of Fire, (2) an alternative route for the transportation of hazardous materials and wastes entering and leaving the facility to bypass a nearby residential area, (3) the installation of a backflow device to prevent contamination by the hazardous waste of the public water supply and (4) payment of the performance of a community health assessment survey by the Columbus Health Department in the event of an incident at this site.

Two additional Columbus facilities have submitted applications for a Part B Permit to the U.S. EPA. Each application has undergone the same review process as described above. Although Memorandum of Understandings have been signed by each applicant and the CHD, each agreement addresses those concerns particular to that facility. For example, one company which failed to make familiarization arrangements with the Fire and Police Divisions as required in Section 264.37 of 40 CFR signed an agreement that such arrangements would be made. Another company agreed to permit the Division of Water to

conduct a cross connection survey of its facility and then correct any identified deficiencies. To date, only three of the 13 hazardous waste storage facilities in the City of Columbus have sought a Part B Permit; consequently, the Health Commissioner has requested the formation of a standing committee to review the remaining applications.

COORDINATION OF LOCAL AGENCIES

The CHD's role in the management of hazardous substances within the city expanded as a result of the application review process. Within a year, the CHD had initiated the development of three documents which became the backbone of the city's response to hazardous material incidents.

At the request of the Health Commissioner, a committee composed of representatives from Emergency Management Services, the Divisions of Fire and Police, the local chapter of the American Red Cross and the CHD was established to review and revise evacuation procedures to be taken during a hazardous materials incident. After months of discussion, the committee produced a document that contained a series of guidelines designed to serve as an assurance that every reasonable effort would be made to preserve life and protect property but at the same time recognizing that these policies and procedures could not be a governmental guarantee of absolute safety to area residents when it was necessary to withdraw from an area due to a hazardous materials incident. Highlights of this document include: (1) six basic premises that form the basis for the policies and procedures, (2) organizational responsibilities of these agencies responding to an incident, (3) key activities associated with each phase of an evacuation process and (4) planning considerations for facility administrators who manage large populations which generally are difficult to evacuate. The evacuation policies and procedures are not site-specific, but they apply to any fixed site or transportation incident which would require an evacuation of the surrounding area.

During the evacuation planning meetings, committee members were cognizant of the need to understand the role of each agency when responding to an incident. Consequently, a document was developed which formalized alert notification procedures and explained the functional responsibilities of responding agencies. The key to the notification chain is the Division of Fire. If, in the judgment of a responding Battalion Chief, a hazardous incident warrants the expertise or assistance of another city agency, the notification plan is initiated.

EMERGENCY RESPONSE

Since the CHD had taken the responsibility for investigating human health effects from exposures to hazardous materials which occur within the city, an intra-departmental procedures manual was formulated. The procedures within this manual were based upon the Centers for Disease Control guide, "A System for Prevention, Assessment and Control of Exposures and Health Effects from Hazardous Sites."[2] This response procedures manual outlines CHD's involvement in any response and describes the methodology for performing a health assessment study.

With internal response procedure in place, the CHD sought to improve the Environmental Health Division's response capabilities. To achieve this objective, access to a computer database was obtained and personnel protective gear and sampling equipment were purchased. With the acquisition of "Hazardline," an on-line, interactive, time sharing database, the risk assessment process was made more timely and efficient. "Hazardline" contains hundreds of pieces of data for approximately 4,500 chemicals. The information includes physical and chemical properties, needed personnel protective equipment, chemical toxicology, symptoms of exposure, and leaks and spills procedures.

A self-contained breathing unit, chemical splash suits, half-face respirators and a variety of other gear were purchased to protect the CHD's response personnel. For site assessment and investigation purposes, a high/low flow pump, charcoal collection tubes and a detection tube test kit were purchased.

A test of CHD's internal response procedures occurred 5 months after its initial involvement in spill response. On May 7, 1984, a chemical manufacturer accidentally released 2,000 lb of a phenol-formaldehyde resin into the air in less than 5 min. A slight northeasterly wind blew the resinous mixture over a residential area, although a great percentage of the material precipitated onto the company's ground. Sixty-eight individuals in 18 households were potentially exposed. The CHD collected water and soil samples within a 2-mile radius of the plant. Initial samples were analyzed for phenol and formaldehyde with subsequent samples analyzed only for phenol. Wellwater samples collected from the 18 households indicated no contamination from the incident.

The CHD's role within hazardous material incidents became more clearly defined with this incident. It was evident that OEPA and the Columbus Division of Fire were capable of handling the emergency response procedures during this incident. What was missing, however, was the evaluation of health effects on the area residents. Ohio EPA response teams have a natural tendency to worry more about the environment than the residents, while the CHD's training is based upon worrying about the residents first and the environment second. In this incident, the two agencies complimented each other's actions to the benefit of both parties.

Upon completion of a study of the incident, the CHD released a document that explained what was released, what amount was released, who was affected and whether any long-term health effects were expected. Furthermore, the CHD recommended that followup soil and water testing for phenol be continued for a definite period to ensure there was no contamination of the groundwater. The company which had the accidental release agreed to pay for any and all required testing using CHD guidelines as well as the cost of the complete CHD study. None of the information about health effects to the residents would have been available through any government agency other than the CHD.

CONCLUSIONS

Although local governments often lack the statutory authority to regulate hazardous waste facilities, much can be done outside the legal framework to ensure that local concerns about such sites are addressed. Without benefit of legislation, the Columbus Health Department secured voluntary agreements with local hazardous waste facilities which surpassed federal and state legal requirements.

In addition, the CHD coordinated the formulation of spill response procedures and evacuation policies which are implemented through interagency cooperation. The CHD believes that local governments have a role to play in the management of hazardous materials and wastes, notwithstanding the existence of formal regulations; it is the CHD's conviction that this involvement must complement, not duplicate, federal and state program efforts.

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U.S. EPA's Initiatives for Expanded Public Involvement in the RCRA Permitting Program

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ABSTRACT

The purpose of this paper is to provide an overview of the U.S. EPA's initiatives for public involvement in the permitting of hazardous waste treatment, storage and disposal facilities under RCRA. The authors first discuss the rationale for fostering early and expanded public involvement. They then describe the approach and main steps recommended by the U.S. EPA to facilitate public involvement in decision-making on a permit. The authors conclude with a brief discussion of some of the U.S. EPA's supporting activities in this area.

INTRODUCTION

In the 1970s, the potential threat to human health and the environment posed by hazardous wastes emerged as the nation's most prominent environmental issue. In scores of communities throughout the country, citizens banded together to press for the cleanup of abandoned hazardous waste disposal sites or to prevent new waste management facilities from being created. More often than not, these citizens had little prior experience with political activism and were far from being traditional environmentalists; their concern was over the direct personal health and economic effects of a particular hazardous waste facility. It usually made little difference whether the facility was inoperative and already the cause of extensive contamination or newly proposed and designed according to the strictest safety guidelines: hazardous wastes became perceived as potential threats under any circumstances and were regarded as generally intolerable in anyone's "backyard." The concerns raised at scores of localities led to national attention and, ultimately, major federal hazardous waste regulatory and cleanup legislation.

Public concern over hazardous waste has continued and, if anything, intensified through the 1980s. The primary source of the concern remains localized; that is, public concern over hazardous waste arises among citizens who consider themselves and their children to be directly affected by a particular disposal site or waste management facility. The U.S. EPA has recognized that to fulfill its legislative mandates to protect human health and the environment from the threat of hazardous wastes, an active, effective public involvement program is essential. There is no question of whether or not to involve the local public in the U.S. EPA's decisions. The question is how to involve the local public so that public participation is constructive and results in sounder environmental decision-making.

In the context of the permitting program conducted under RCRA, the U.S. EPA's answer to this question has taken the form of initiatives to foster early and expanded public involvement. These efforts are being pursued in accordance with the U.S. EPA's National Permits Strategy. They incorporate, but go beyond, public participation requirements in RCRA section 7004(b)(1) and in U.S. EPA regulations on procedures for decision-making in 40 CFR Part 124, Subpart A.

IMPORTANCE OF EARLY PUBLIC INVOLVEMENT IN RCRA PERMITTING

The U.S. EPA's initiatives for public involvement in RCRA permitting are aimed at enabling the local public to have meaningful and constructive input to decision-making on a facility's permit. For public input to be meaningful, it must occur early in the permitting process, before a permit has been drafted: that is, before all the major decisions on the permit and the actual conditions it is to include have been made. The public participation requirements in the regulations cited above, however, ordinarily would result in public involvement late in the permitting process, so the activities they call for must be supplemented. Thus, the U.S. EPA's National Permits Strategy calls for early and expanded public involvement.

There are several reasons why meaningful and early public involvement is important to the RCRA permitting program:

- Public involvement can yield information of value to decision-makers in evaluating a permit application and drafting a permit. For example, it can yield information concerning the facility's operational history and site characteristics.
- Public opposition often arises when citizens feel they are being excluded from decision-making that will have direct and long-lasting effects on their community; that they are being "railroaded" by a distant government agency. This kind of opposition is always unnecessary. It can largely be avoided by ensuring that the comments and concerns of the local public are considered throughout the process of debate and deliberation leading to decision-making. The result will be a permitting process focused on the technical merits of a facility rather than on the public's dissatisfaction with its lack of opportunity for participation.
- Public involvement from an early stage in the permitting process helps government staff identify areas of concern to the community before a permit has been drafted. When identified in advance, such concerns often can be addressed in the draft permit. Less time and energy will be spent developing permits that later provoke public opposition by failing to address community concerns.

Early public involvement in RCRA permitting is also important because of the enactment of the 1984 RCRA amendments. These amendments are a direct consequence of the increased public concern over the issues of hazardous waste management. In return, because of certain provisions in the 1984 RCRA amendments and

the debate over enactment of those amendments, public interest in the RCRA permitting program has broadened and public involvement in the program has become more complex. The following issues, in particular, are likely to be the focus of special public interest as the permitting program develops.

Groundwater Protection

There has been widespread failure to comply with RCRA's groundwater protection requirements. The removal of wastes from Superfund sites to RCRA facilities has intensified concern over the possibility of groundwater contamination and its effects on human health.

Protective Standards and Enforcement for Operating Units

Public interest is already strong on the question of whether RCRA's design standards and operating specifications (e.g., landfill liner requirements) are strict enough and are being met.

Exposure Assessments

RCRA section 3019 requires each final permit application for a landfill or surface impoundment to be accompanied by information on the potential for the public to be exposed to hazardous constituents released from the facility. Citizens also can submit exposure information. There often will be considerable local interest in this information.

Corrective Action

Significant public interest can be expected in all facets of corrective action requirements. Have releases occurred from a facility? How will releases be cleaned up? Will corrective action be sufficient to prevent future releases? What kinds of investigations will be conducted to determine the need for corrective action?

Permit Process Itself

The length of time involved in issuing a permit as well as the adequacy of public involvement opportunities are examples of issues related to the permit process (as opposed to the contents of permits) that can be of public concern.

Transportation of Hazardous Wastes

Many times the public's strongest concern centers on the transportation of hazardous wastes to or from a facility. The possibility of traffic accidents and the proximity of transportation routes to homes and schools heighten the public's concern over releases during transportation. Often, though, the sheer volume of traffic and the associated noise and congestion are of even greater concern.

Evacuation Plans

The very existence of evacuation plans implies that accidents can and will occur. Moreover, the public has shown interest in the adequacy of evacuation plans. Who will be evacuated? How will they be notified? Who pays? Fire and explosion emergency plans also acknowledge the potential for threats to the public's safety; despite their value, their existence may undercut assurances that such occurrences are unlikely.

Omnibus Provision

RCRA section 3005(c) states that "each permit . . . shall contain such terms and conditions as the Administrator (or the State) determines necessary to protect human health and the environment." The public may be inclined to read great flexibility into this provision.

Consequences of Permit Denial

Whether an operating permit is approved or denied, the consequences will be of interest to the public. The denial of a permit will cause special concern because of the potential impacts on employment, property values and the local tax base. Moreover, the public may not at first appreciate the environmental implications of permit denial. Denying a permit for incineration, for example, might mean that the applicant has to continue to landfill wastes.

U.S. EPA'S APPROACH TO PUBLIC INVOLVEMENT IN THE PERMITTING PROCESS

Guidelines

Early public involvement in the permitting process for a waste management facility means doing more than simply fulfilling the formal public participation requirements in federal regulations. How much more, however, is something that depends upon the particular circumstances of each case. Thus, the U.S. EPA's policy for public involvement in RCRA permitting does not include the addition of long lists of requirements. In fact, there are no new requirements. Instead, the U.S. EPA offers the following general guidelines:

- Public involvement efforts should be tailored to the distinctive issues and individual features of the facility and the surrounding community.
- The applicant and other responsible government agencies should have a role in public involvement efforts, especially to help clarify or resolve issues that may be related to the facility and its operations but cannot be addressed appropriately by the RCRA permit process.
- Small-scale, low-profile, informal communications techniques are preferred. Public meetings may be held in informal settings, before small audiences and without elaborate presentations (e.g., in living rooms). They need not be conducted by high-level staff.
- In general, public involvement actions should extend beyond providing information to the public; they should actively reach out to the public, encourage participation and provide an opportunity for public input on permit decisions made by EPA or the State.

Targeting

Following the above guidelines, public involvement efforts should be targeted to individual circumstances; the same program of activities will not be necessary, and would not be effective, in every case. Public involvement efforts also should be targeted in a second sense: the limited resources available to a U.S. EPA regional office or State agency for public involvement should be concentrated on those facilities where the need is greatest.

Targeting in this second sense means that certain facilities will have to be selected for special attention. The selection of facilities for early and expanded public involvement should be based not only on environmental significance (i.e., the potential to pose significant risks to human health and the environment), but also on social significance (that is, the extent of public interest already generated and the potential to arouse significant interest in the future). While the development of widespread interest as the permitting process unfolds cannot be predicted with certainty, the following are good indicators of the potential to generate public interest:

- The owner or operator of the facility lacks credibility with, or the trust of, the public or local officials
- The public perceives that the facility poses major health risks

- Major hazardous substance releases or accidents have been publicized recently in the area
- The type of technology proposed in the permit (e.g., incineration, underground injection, landfill, etc.) has a negative reputation in that particular area
- Facility non-compliance or violations have been highly publicized or will be made known by the permit process (in general, the more serious the continuing non-compliance, the more public interest likely to be generated)
- The facility has been or likely will become an election issue
- The permit could allow the transportation of Superfund hazardous wastes to or from the facility

Permit writers in the U.S. EPA regional offices and in State agencies have found that often there is little correlation between a facility's environmental significance and its social significance. It is not uncommon for an environmentally significant facility to meet an apathetic reaction from the local community, while a smaller facility creates intense public concern.

The Field Assessment and Public Involvement Work Plan

Two critical elements in a public involvement effort for a targetted facility are the "field assessment" and "public involvement work plan." Both help to ensure that public involvement efforts are well-planned and meet the distinctive needs of a particular community and a particular facility.

A field assessment consists of interviews, both in person and over the telephone, with local citizens and officials to obtain information on the following points:

- Major community concerns regarding a facility
- The citizens, community leaders and officials in the area who are especially interested in the facility and should be kept apprised of developments
- The best means to provide information to the public and, in return, to obtain public comment and input

To this end, the community interviews conducted for the field assessment address the following topics:

- The local history surrounding the facility (e.g., the circumstances under which it was built); any past or present opposition to the facility; previous relations between citizens, government agencies and the facility's owner or operator; and news stories about the facility. (For instance, it might be useful to know that the local newspaper has opposed the facility's operation for ten years and has just finished publishing a series on the facility's non-compliance with interim status requirements.)
- The negative as well as the positive economic impacts of the facility's operation on various segments of the community. This information is useful for anticipating and interpreting people's concerns and positions.
- The current level of information and understanding that the public (including local officials) has about the facility's operation. This information is needed to assess what additional information will be necessary to enable the public to participate intelligently.
- Other significant political or social events or circumstances that might affect the community's attitude or involvement with the facility's permitting. It would be imperative to know, for example, that the recently elected mayor campaigned on a promise to close the facility.

After two or three days of interviewing to gather such information, a public involvement work plan can be prepared. This plan will include the following elements:

- A capsule facility description
- An identification of major community concerns and leaders
- An outline of the minimum activities the U.S. EPA or the State will conduct to ensure both that the local public is well-informed about permitting decisions and also has meaningful input into those decisions
- An indication of the timing of these activities

The public involvement work plan provides a strategy for enabling the public to have meaningful input to the decision-making process for a permit. It also serves to coordinate the roles and responsibilities of the various participants in the public involvement effort: The U.S. EPA, the State, local officials, the owner or operator and the general public. And it reassures local citizens that there indeed has been some forethought given to providing opportunities for meaningful public involvement.

Public Involvement Activities

Public involvement activities will vary by facility and by the stage in the permitting process at which public involvement efforts are initiated. The following types of activities, however, will be conducted in each instance:

- Outreach activities, such as informal informational briefings and meetings, including public notice of the draft permit
- Dialogue and assimilation activities, such as work sessions, public meetings and public hearings (if appropriate)
- Response activities, including informal responses to questions, concerns and requests from the public during the permit process as well as formal, final responses to public comments

The only activities that are required are those specified in RCRA section 7004 and 40 CFR 124 Subpart A, the most important of which is the public comment period on the draft permit. These requirements hold for every determination on an RCRA final permit application, including those for facilities that are not targeted for expanded public involvement.

Often the most effective public involvement activities are very different from "textbook" information techniques. For example, a permit writer in Hawaii responded to citizen concern over the permitting of a waste management facility by serving as an intermediary between citizens and the owner, encouraging the owner to modify his operating procedures in a way that could not have been specified in the permit but that successfully addressed public concerns.

Roles and Responsibilities

Public involvement in the RCRA permitting process is a team effort, with contributions from the U.S. EPA and the State. And within each permitting agency, there will be roles and responsibilities for staff from a number of offices. For example, each EPA regional office, and each State authorized to issue final permits, should already have designated someone on its staff as the RCRA permitting program public involvement coordinator. The coordinator works with permit writers, enforcement personnel (both U.S. EPA and State), facility owner/operators and other appropriate individuals or groups to implement public involvement activities. Permit writers may take the lead in discussions of specific permit conditions on facility operations; they may be responsible for providing information to answer public inquiries.

In some cases, the owner or operator may contribute to public involvement activities conducted by the U.S. EPA or the State in addition to his own independent outreach or public information efforts. In fact, owners and operators are encouraged to take steps to inform and involve the local public, although in so doing, the distinction between the owner or operator's interests and the government's regulatory mission should be made absolutely clear to the public.

SUPPORTING INITIATIVES

The U.S. EPA's Office of Solid Waste is pursuing a number of supporting initiatives to advance the policy for public involvement outlined above. The goal is for local public involvement to become a regular feature of the U.S. EPA and State decision-making on each RCRA permit, with the extent of the public involvement effort for each facility and the scope of the activities conducted in the locality scaled to the need.

First, we are now providing a two-day training course in public involvement techniques for RCRA staff in each U.S. EPA regional office. State staff also are invited to these sessions, and we expect to offer the training in authorized States in the future. The training covers the rationale for early and expanded public involvement in RCRA permitting, the targeting of facilities for special attention, procedures for conducting field assessments and developing public involvement work plans, as well as techniques for conducting effective public meetings and handling relations with the news media. There is also instruction in basic skills for minimizing or resolving disputes and conflict between government and local citizens.

Second, we are preparing a variety of educational and informational materials for the lay public on the RCRA permitting program. Already in draft is a "Citizens' Guide to RCRA Permitting" that explains the steps in deciding whether to grant a final permit to a hazardous waste management facility, the conditions that may be included in a permit and the role of the local public in decision-making on the permit. We plan to prepare brief fact sheets on specific topics of widespread general interest (for example, corrective action requirements and exposure assessments). Fact sheets also will be prepared on individual facilities, when needed, to explain to the public the technical features of the facility, the operation and design standards to which it is subject and progress in reviewing the facility's permit application.

Finally, we are continuing to analyze the best approach to public involvement and community relations in special circumstances (for example, in siting new hazardous waste management facilities or in conducting exposure assessments). As the analyses reach completion, we will prepare guidance materials to assist the regional and State staff who will be on the "front line" in public involvement efforts. As noted, the U.S. EPA already has issued draft guidance on public involvement in RCRA permitting.

CONCLUSIONS

The discussion in this paper should serve to dispel any impression that the U.S. EPA's initiatives for public involvement in RCRA permitting will just "stir the pot," creating public opposition where there would otherwise have been none and ultimately forcing the closing of facilities that could treat and dispose of hazardous wastes in an environmentally sound manner. That is not, of course, the desired consequence of these initiatives. Instead, these initiatives are aimed at preventing needless public opposition, the opposition rooted in public distrust of government motives, rather than in the technical flaws of a facility or permit, and are precipitated by neglecting the local public in government decision-making. They are, moreover, aimed at ensuring that RCRA permits take local concerns fully into account and protect the local public's health, welfare and environment. Early and expanded public involvement in RCRA permitting can thereby facilitate the permitting process and lead to better environmental decision-making.

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Cleanup in the Sunshine: Florida DOT's Public Information Program at the Fairbanks Site

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ABSTRACT

A routine safety inspection of the Florida Department of Transportation (DOT) Bureau of Materials and Research Laboratory was conducted in November 1982. This inspection indicated that chemical waste generated at the laboratory was being disposed at a borrow pit located on DOT property in the rural community of Fairbanks, Florida, 7 miles northeast of Gainesville.

In January 1983, a number of private water supply wells in Fairbanks were tested for volatile organic compounds (VOCs). The results indicated the presence of VOCs in some of these wells.

In response to public health concerns, the well sampling program was intensified, and a comprehensive site investigation was initiated. The purpose of the investigation was to determine the source of VOC contamination affecting private wells to estimate the extent of VOCs in the groundwater, to develop immediate remedial procedures and to recommend a water supply alternative for the Fairbanks community.

The results of the site investigation indicated that the DOT borrow pit was the source of VOC contamination affecting private water supply wells. Laboratory waste materials which formerly were disposed of at the sand pit had seeped into a multiaquifer system. This contamination had entered the shallow aquifer in substantial concentrations within a limited area near the sand pit and had slowly leaked into the uppermost secondary artesian aquifer. VOCs that had entered the upper limestone aquifer spread to private wells through the natural flow system and in response to pumping.

Remedial actions were implemented to eliminate the source of VOCs and to cleanse the shallow aquifer. These actions included the removal of drums of buried waste from within the borrow pit and the installation of a recovery well system designed to prevent further movement of contaminated groundwater in the shallow aquifer, as well as to treat the groundwater by removing VOCs.

After the initial sampling, when it was determined that private water supply wells were contaminated, bottled water was distributed to the community. At that time, an understandably high level of anxiety existed in the community. For this reason, the DOT decided to initiate a public information program consisting of a newsletter, weekly public information meetings and liaison with the citizens' group. By the end of the crisis, it was apparent that the program was extremely successful.

INTRODUCTION

During a routine safety inspection of the Florida Department of Transportation (DOT) Bureau of Materials and Research Laboratory, the Second District Industrial Safety Manager noted that chemical waste generated by the DOT laboratory was being disposed at Fairbanks Sand Pit (FSP), located on DOT property approximately 7 miles northeast of Gainesville in Alachua County, Florida (Fig. 1).

Private water supply wells in the vicinity of the borrow pit were sampled, and the results of these tests indicated that 9 of the 18 wells sampled were contaminated with the same halogenated chemical solvents disposed at FSP or with the degradation products of these solvents. The DOT immediately began distributing bottled water to the residents of Fairbanks, the rural community which surrounds FSP.

On Feb. 4, 1982, Dames & Moore was retained by the DOT to work with the agency toward resolution of the Fairbanks problem. It was agreed that a detailed study of the Fairbanks problem was necessary and that this work should incorporate a comprehensive hydrogeologic investigation of the site.

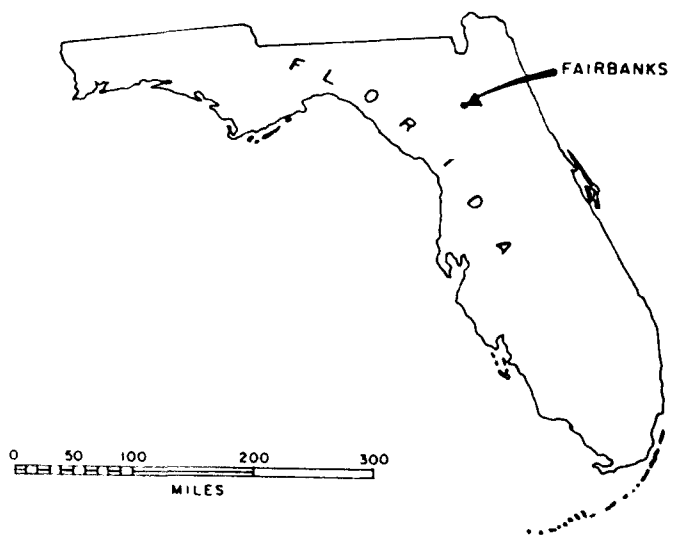

Figure 1
Site Location

Problem Definition

The initial objective of the project was to provide a comprehensive analysis of the nature, extent and transport mechanisms causing the observed groundwater contamination. Specifically, the work included:

- Implementation of immediate procedures to clean up and remove chemical waste contamination within the borrow pit
- Characterization of historical waste disposal at the borrow pit and adjacent areas
- Evaluation of adjacent off-site areas relative to potential contamination sources
- An estimate of the horizontal and vertical extent of contamination in the aquifer(s)
- Development of conceptual control/abatement alternatives for the zone of groundwater contamination

As the investigation progressed, the information developed led to expansion of the scope of work outlined in the plan of study to include: additional investigation of the extent and rate of travel of contamination in confined aquifers; logging of private water supply wells; toxicological analysis; design, installation and permitting of a recovery system; and an analysis of alternatives for providing potable water to the residents of the community.

PROGRESS OF THE INVESTIGATION

A major objective of the program was to establish the areal and vertical extent of the contamination affecting the aquifer system in Fairbanks.

Sampling

Sampling of private water supply wells had indicated that volatile organic compounds (VOCs) were contaminating one or more aquifers in the Fairbanks area. The first step was to determine if the Fairbanks Sand Pit was, in fact, a source of this contamination. In order to determine the types of waste present in the pit, as well as historical disposal practices, DOT laboratory personnel (the generators) and maintenance personnel (who had placed the chemicals in the pit) were interviewed.

Next, four clusters of two monitoring wells each were placed on the pit's perimeter (Fig. 2), sampled and analyzed for the chemicals on the U.S. EPA's Priority Pollutants List. The results indicated that the chemicals which were buried in the pit or their degradation products were contaminating the surficial aquifer and that among these chemicals were the same chemicals detected in the private water supply wells.

The next task was to construct eight clusters of two wells around the pit at a distance of 500 ft. Analysis of samples and water levels from these wells showed that the direction of flow in the surficial aquifer was to the north, towards Hatchet Creek, and that VOC contaminated groundwater was leaving the pit in this direction.

The next monitoring wells were placed downgradient of other borrow pits in the vicinity of FSP to determine if they were contributing to the contamination problem. They were not.

Other wells were placed into the semi-confining unit at the base of the surficial aquifer and north of Hatchet Creek. Analysis of samples from these wells indicated that the contamination was penetrating the semi-confining unit but was not crossing Hatchet Creek.

With this information, work shifted from the shallow to the deeper aquifers. First, borings were made to determine the position and continuity of water-bearing units in the Fairbanks area. When these units had been mapped, deep monitoring wells were placed so that each of the three aquifers identified could be sampled and aquifer characteristics could be measured (Fig. 3).

While the field program was underway, additional information on private water supply wells was being collected through a house to house well inventory and well logging.

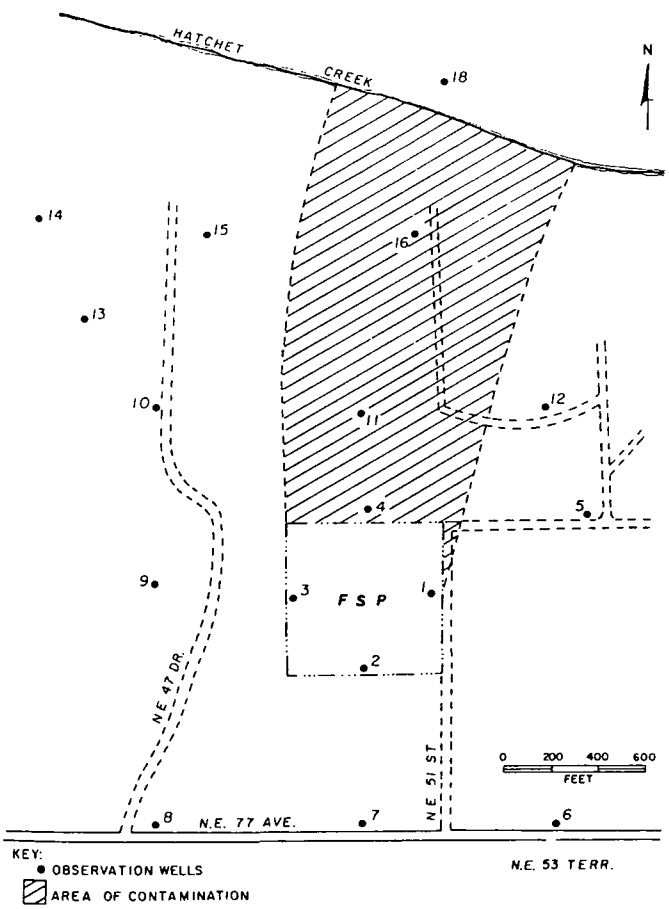

Figure 2
Monitoring Well Location and Approximate Lateral Extend of VOC Contamination in the Shallow Aquifer

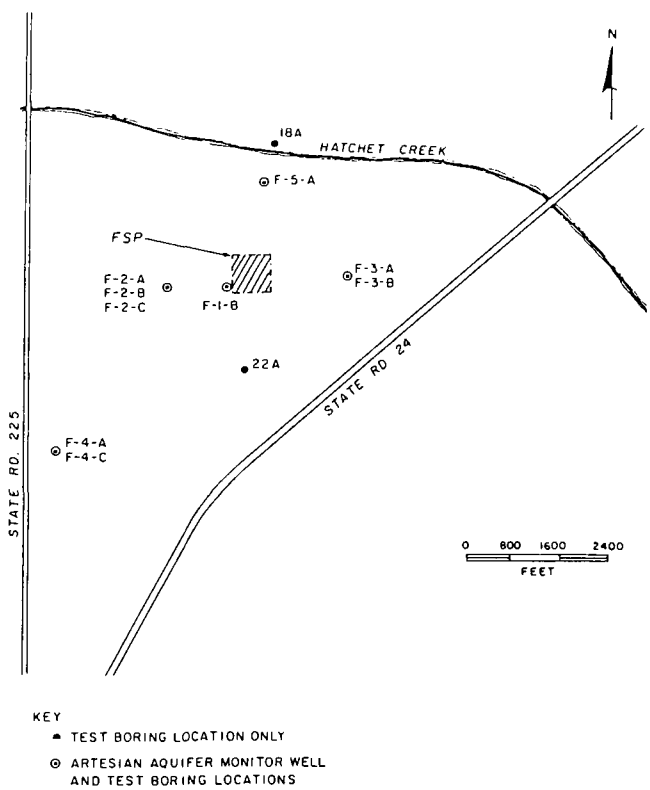

Figure 3
Location of Artesian Wells and Deep Test Borings

Pit Closure

Another of the project's objectives was to properly close, concurrent with the field investigation, the Fairbanks Sand Pit, eliminating it as a source of contamination. Closure consisted of a magnetometer survey to ensure that all buried drums had been located, excavation and proper disposal of the drums and installation of a recovery system to control the movement of contaminated water in the immediate vicinity of the pit.

Residents in Fairbanks whose water supply wells were contaminated were using bottled drinking water. A priority objective of the project was to restore potable tap water to the community as soon as possible. Thus, while the field program and pit cleanup were underway, an analysis of alternatives to provide potable water was conducted. Completion of this analysis was timed so that important information from the geohydrological program could be considered in deciding on the recommended alternative.

Although the residents were drinking bottled water, another issue of concern was whether or not they would be able to safely eat (1) fruit and vegetables in which contaminated water was used in the process of home canning or freezing and (2) meat from livestock which had consumed contaminated water before slaughter. To answer these and other health questions, a toxicologist was retained and samples of food were analyzed. The food samples were found to be free from contamination.

PUBLIC INVOLVEMENT

The need for public involvement was, from the outset, identified as vital to the successful resolution problem. When Department of Transportation (DOT) and Dames & Moore project personnel arrived on-site in February 1983, it was evident that the level of community concern was extremely high. Following an on-site review, a press conference was held to announce plans to initiate site investigation and cleanup activities. This press conference was the beginning point for a project which, from the start, focused local, state and national attention on public agency response to a serious groundwater contamination incident.

Development of the project plan of study proceeded with close coordination between all involved governmental agencies:

- Alachua County, Board of County Commissioners
- Alachua County Health Department
- Florida Department of Environmental Regulation
- Florida Department of Health and Rehabilitative Services
- City of Gainesville, Utilities Department
- St. Johns River Water Management District

The plan of study was publicly presented at an evening meeting in the County Commission board room in mid-March 1983. Public comment at that time made it clear that, although the Department of Transportation had done an excellent job of consulting with other agencies and local elected officials, members of the Fairbanks community felt excluded from the decision-making processes.

Community Group Formed

During this time, in response to the crisis, people living in the area joined together in a voluntary group known as the Fairbanks Community Association (FCA). They held meetings, elected officers, began to develop an agenda of concerns relating to the contamination and contacted a local legislator, Representative Sid Martin (D-Hawthorne), who was active in environmental and conservation issues. In late March, Representative Martin chaired a volatile and well attended, legislative committee meeting which provided a mechanism for DOT, Dames & Moore and local residents to begin the process of working together. From this point, an extensive community involvement program began which included the following key elements.

Community Involvement

- Daily contact between the DOT project manager, the FCA President, the Alachua County Administrator (acting for the Board of County Commissioners) and the County Health Department.
- At a minimum, weekly contact with legislative staff and the Department of Environmental Regulation. Other involved agencies were contacted regularly as the situation required.
- A series of evening community meetings (weekly during April and May 1983, then biweekly for the project duration) was conducted at the Fairbanks Baptist Church. The purpose of these meetings was to brief residents on project programs and provide an opportunity to air questions and respond to concerns. Prior to each of these meetings, face-to-face briefings were provided to FCA officers and their concerns were solicited.
- Site visits were arranged for interested residents.
- A newsletter was published and mailed to all community residents, not just to FCA members.
- Community members and agency representatives were invited to participate in all meetings involving major project decisions, including:
  - -Study design
  - -Monitor well construction
  - -Monitor well and test boring location
  - -Sampling protocol
  - -Borrow pit closure
  - -Water supply alternatives analysis
- Complete public and media accessibility of DOT project management personnel.

The cornerstone of the public involvement program was the open attitude and effort to maintain communication on the part of DOT personnel; from the beginning, all project operations were open to public scrutiny. Of the elements briefly reviewed above, the most critical to project success probably involved the meetings with the residents and the newsletters.

Public Meetings

At the outset, the FCA meetings were well attended with heated discussion. Residents were understandably scared, angry and frustrated. As the project progressed, DOT, Dames & Moore and community members began to work together to resolve issues of mutual interest. Examples include:

- Site excavation cleanup and progress
- Bottled water deliveries
- Site security
- Monitor well construction and testing progress
- Private water supply sampling
- Safety of foods grown and irrigated or preserved with contaminated water
- Provision of independent toxicological expertise for responding to health concerns
- Community well construction survey
- Rumor control
- Property values
- Long-term project planning
- Remedial action water supplies alternatives

REMEDIAL PLANS

The last item noted probably is most representative of the overall success of the public involvement program. A final project step required an analysis of possible solutions to the contamination problem, the election of a preferred remedy and implementation of an equitable settlement for the residents.

This remedial evaluation process, which examined drilling new wells, home filtration systems, a community water supply and connection to an extension of the Gainesville Municipal system, was jointly conducted by DOT and a citizens committee of 12 volunteer community members. Issues of fire protection and financial settlements also were considered. The result of this work was a decision to connect residents to the Gainesville water system, provide enhanced fire protection (hydrants) and include a water rate subsidy for a specified period of time.

COOPERATION ATTAINED

Toward the end of the site cleanup and contamination investigation activities, the remedial action decision for water system connection was announced at a well attended public meeting which received extensive media coverage. Unlike earlier meetings, the only hostility toward the DOT was evidenced by media representatives not familiar with the project. Residents and officers of the FCA voluntarily spoke in support of the different phases of project activities and on behalf of DOT.

The final few public meetings on this project clearly demonstrated the accomplishment of this multifaceted public involvement and educational program. A community, completely frustrated and angry at the state over the contamination of the water supply, eventually became totally involved in all phases of the project. The initial hostility gradually led to an active participation which resulted in a sense of satisfaction on the part of residents in having played an important part in the solution.

Public Involvement in the RCRA Permitting Process—A Facility Perspective

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INTRODUCTION

Few issues in America today generate more public concern than that of hazardous waste handling and disposal. By statute, regulation, policy and inclination, the U.S. EPA and the states encourage public involvement in permit decisions. While the principle is well established, there is little agreement on how best to accomplish the objective. There also is considerable debate on how best to evaluate, respond and act on issues raised by the public. As a result, regulatory agencies sometimes find themselves in the uncomfortable position of being sued on the same issue by industry for over-regulating and by citizen and public interest groups for under-regulating. Moreover, while the agencies have the ultimate responsibility for making and defending their decisions, they must consider issues raised by citizens even though those issues may not be germane to the subject or within the scope of the regulatory agency.

With this responsibility is also the reality that the regulatory agency does not have the staff, resources or ability to know the real community consensus and composition in depth. As is well known, those who attend public meetings and write comments are nearly always a very small minority of the population. The majority of citizens who are aware of the issues but do not make their opinions known are, more often than not, supportive of the applicant or the agency's professional judgment. Imperfect as the process is, it is a fact of life in major regulatory actions.

CITIZEN PARTICIPATION ENHANCEMENT

The primary variable available to improve the quality of citizen participation is the owner/operator working with citizens to promote a full understanding of the issues. Ideally, this is done at three levels of involvement—the company in the community, the company in concert with similar groups acting as an industry or trade group and the company coordinating its approach with the regulatory agencies.

Obviously, the industry can and should do more to generally educate the public about siting and permit issues; but even if this were to occur, the effects would be very limited on specific decisions. This approach is most widely and effectively used in legislative and rule-making activities.

A coordinated approach between government and industry is certainly a good idea but is fraught with problems. Aside from the regulatory resource limitations already mentioned, a cooperative effort often leads to the allegation that the agency and applicant are too close or "in bed with one another." It is, of course, the nature of a highly regulated industry to have a close relationship and intimate knowledge of operations and issues. While distance must be maintained, the agencies should do a better job of publicizing their responsibility and the need for close communication and coordination.

ROLE OF REGULATORY AGENCY

At a minimum, the regulatory agencies should plan and discuss the public involvement program with the applicant well in advance of implementation. An exchange of information should include citizen comments received to date, an exchange of any community relations or public involvement plans, suggestions for action by either party and joint informal meetings, workshops and information booths to identify issues in advance of a formal public hearing. The burden of this activity should be on the owner/operator/applicant, but the regulatory community can improve the effectiveness and "reach" of the program significantly through their participation. In so doing, the agency also will enhance the quality of public comment and its own image as a public agency.

In reality, however, there are severe limits to how much the government as a regulatory agency really can participate. Except in the case of the largest and most visible sites or permit issues, the agency will be able to provide little more than a cursory overview of the community dynamic. It is the local site that must take the lead for generating understanding that will give way to acceptance in the community. Guidance, participation and endorsement from government regulators of this local effort simply lend credibility and acceptance to the process. It is most assuredly a process and not an overnight sensation.

PUBLIC INVOLVEMENT PROGRAM

There are many considerations in planning a public involvement program. Among the most important is timing, and there are several key elements in that. It is not possible to start too early. There will be public involvement sooner or later; the earlier the public has an opportunity to become familiar with the process and the issues, the better. One common citizens' complaint is that there was no opportunity to be involved until after the major issues had been cast in a draft permit.

Public interest at this early stage may not be evident, so it usually is necessary to identify those who are potentially interested and solicit their participation. The ultimate objective in this effort is an exchange of information and ideas—a two-way dialogue. To set the stage for this two-way communication, the community members need to feel that it is early enough in the process to make a difference, that they are being dealt with openly and honestly and that they have access to information and to key regulatory and company personnel.

Communications

Some of this feeling of openness and availability can be communicated by the press; they, too, certainly need to have a regular and reliable point of contact and access to key people. It is very difficult for a complex and controversial issue to be consis-

tently well done by the press, but the press can convey the message that the company is open and invites honest inquiry. Discussing the public involvement strategy with the press or allowing coverage of a tour or meeting with citizens can be a good way to communicate that feeling of openness. Failing to generate that feeling of being open and responsive seems to make virtually everyone suspicious and undermines credibility.

Newsletter

Another means of communicating that open feeling and giving people information about the operation is through a newsletter or other general printed information. Although this is a one-way effort, it is a good precursor for a real exchange. The newsletter is also a good way for the operator to focus attention on issues of his choice. A newsletter also can be used to feature information about tours, meetings with environmental groups, question and answer columns and other two-way exchanges. The regular appearance of a newsletter is also proof that the facility has made an effort to communicate with and involve citizens. The longer the newsletter comes out, the more knowledgeable people become about the issues and people at the facility. Moreover, the readership seems to increase with each issue as the product and place become more familiar.

Documents Repository

Another important means of making information available is a local repository for documents, applications, permits and so forth. Traditionally, these documents have been kept at a courthouse or other government office (i.e., the local health department). Sometimes this "official" repository is not available to the public during evening or weekend hours or is not seen as a neutral location. A more appropriate location would be a public library or local school. The library has the added advantage of having other research resources available for serious inquiry. In addition to the required documents for review and inspection, other material should be placed on reserve. This reserve list might include: newsletters and other company publications; independent material such as state and federal regulations; and books and pamphlets on chemistry, industrial hygiene and safety, research reports and so forth. A summary of the important issues and the process for resolution of these issues also should be available. A good summary will be sufficient for many people and can offer a clear perspective and context for understanding the issues.

There are many other means of disseminating information that are, although basically one-way vehicles, good for educating citizens about certain activities and people and encouraging participation in meetings and other "feedback" opportunities.

COMMUNITY RELATIONS

The most important opportunity for generating community understanding and confidence is simply a presence in the community. The extent to which facility management and employees are integrated into the social fabric of the community is of critical importance. First, this means that personnel from the facility should live in and have roots in the area and be visible and active in the community. Employee community involvement programs and a recognition and incentive system are good tools for encouraging that presence.

Corporate involvement in community projects is also an important means of demonstrating a commitment to the community. Without being able to demonstrate that presence in the community and commitment to citizenship, other efforts are seriously hampered. It is important to understand, however, that the objective is citizen understanding and acceptance and, in the case of controversial facilities, much more than community involvement and a presence is required. The emphasis must be education and an exchange of ideas.

Tours

One of the best ways to accomplish this community presence is to give tours of the plant or facility with ample opportunity for questions about what is on the tour or any other issues that might arise. These tours should be personalized as much as possible to the particular tour groups. Involvement by senior management in these tours and question and answer sessions is very important to maximize credibility and commitment to public involvement. The importance of first-hand observations cannot be over-emphasized; often a facility will "sell itself" on such a tour, and the strong positive image from such an experience will make a lasting impression.

Speeches

Talks and speeches to interested audiences are another way to reach out to a particular group and encourage understanding and exchange of views. However, it is difficult to have enough time to cover the major issues and respond to questions as well. The question and answer session following a talk is probably the most important part of this kind of effort.

Meetings

The activities that can be expected to go the furthest in clarifying issues and settling disputes are the small informal meetings and one-on-one discussions. These meetings may take several forms but have several common characteristics: listening for key points, responding to questions and concerns and generally interacting as an equal.

While the exchange that occurs in these meetings is critical, it is also important that there be appropriate follow-up and evaluation. These meetings should be targeted for those people who clearly want to know more and are likely to vocalize their feelings.

Groups likely to be targeted are environmental organizations, elected officials, local community organizations, residents, ad hoc groups and public interest groups. While it is important to anticipate issues and prepare for them with an agenda and objective, it is equally important to make that agenda flexible if the group demands it.

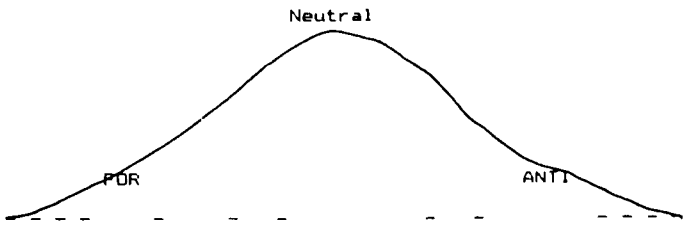
It is also useful to have such meetings for anyone willing to come rather than just targeting a particular group. Ideally, these meetings should be fairly regular, held in a neutral place and have a specific objective relative to the permit issue. These meetings are designed to explain the issue and draw out opinion on the subject. Once positions are disclosed, follow-up work is appropriate to influence or support the opinion.

Information Booth

A variation of this is an "information booth" approach that encourages local residents to ask questions or offer their opinions on a permit issue. Regulators have much more credibility in this role than operators, but it is an area where the two interests can work effectively together. This kind of open-ended small meeting can be unpredictable but may produce unexpectedly good results.

An exchange of information is the most powerful and useful communication that can be used to convince and persuade. Targeting the right audience for this dialog is very important since the process is very labor and time intensive. An even distribution of public sentiment might look like a "bell curve" with communication techniques overlain:

One way communication:
Community position, newsletter, press, handouts, perception



Speeches, personal contact, information booth, meetings, two-way talks.

It is the groups predisposed to be against a permit that a small meeting may be best able to influence. If these groups are identified and are willing to meet and discuss issues, some movement is possible. While these dynamic two-way exchanges are at the core of the objectives in a public involvement program, it is the static or one-way information program that educates, builds support and makes the opportunity for an exchange of information more meaningful and more difficult to resist.

Somewhat surprising to those concerned with this activity may be citizens who resist such small meetings and will not verbalize issues of importance to them. There may be several reasons for this including:

- Uncertainty about their grasp of technical issues
- Unwillingness to disclose their position because of a preference to "surprise" the applicant
- Unwillingness to believe anything that regulator or applicant says
- Unawareness of opportunity
- Personal embarrassment and other reasons

At any rate, many of these reasons become unimportant at a public hearing or in front of a television camera. It seems that nearly everyone wants to make his feelings known at that point. It is important to become aware of the feelings early so they can be identified, responded to and dealt with. Otherwise they represent "new" issues and come as a surprise. If there are no questions from the public, do not assume that there are no problems.

GENERAL TO THE SPECIFIC

As with most problems, work on the issue should move from the general (where some agreement and common ground can be identified) to the specific (where differences are most evident). Even with early identification of issues, good listening and analytical skills and a spirit of compromises, many problems may remain. However, if any semblance of a working relationship has evolved between the two parties, there will be room for some respect for the other's position and possibly an acknowledgement that there is some legitimacy to the position. If true, then the minimum outcome is the recognition of having acted in good faith—an important achievement in and of itself.

CONCLUSIONS

In chronological summary, the basic objectives of a public involvement program are to:

- Inform
- Educate
- Target
- Listen
- Respond
- Follow up

This movement and trend toward negotiation and mediation of environmental issues directly between citizen groups and corporations is clearly a positive development. Certainly it is more efficient than litigation and through early identification of the issues can go a long way to help prevent problems.

In the RCRA permitting process, however, it is especially important to begin this process of exchange and negotiation early enough to accomplish the major objectives before the public hearing process has run its course. The process needs to be open-ended to the extent that the agenda may include new issues raised during the process and may continue indefinitely past the hearing dates, but some priority for dealing with major differences should be established. Initially, those priorities should be outlined, ranked and agreed upon by both parties. Any area of agreement and common ground related to this issue should be used as a preface and introduction to begin talks.

If agreement fails to emerge from this process after a consistent, determined effort, the participants still are rewarded for having tried. Some of these benefits are:

- Respect from all sides, especially from press and public, for initiating a good faith effort
- Improved public understanding
- A narrower range of critical comments
- A lack of surprises in the hearing process

There is no substitute for an early start to educate, inform and involve the public in RCRA permit decisions. There is no magic recipe for success either. Each approach should be specific to the community involved and to the nature of the permit under application. The goals of a program generally are consistent and include such things as:

- Being open to inquiry
- Being responsive and flexible
- Making a real effort to inform and educate the public
- Anticipating issues and being prepared
- Being cooperative with the community
- Being innovative and creative with new techniques
- Being persistent in your efforts

While these are elements in a community based program, these elements also are applicable to working with the press.

A closing thought—not an afterthought. There is a natural tendency to concentrate on those who are contentious since that is where the conflict and the interest are found, but it may be just as important to work with those who are neutral or likely to be supportive of the application. There are several reasons for this position: (1) the neutral group frequently includes the majority of the citizens and hence usually is neither organized nor recognized; (2) this group can give the regulatory body a bigger "comfort zone" in which to make a decision; and (3) people often want to help, they simply do not know how to do it.

This neutral group may include customers, suppliers, employees, elected officials, industrial development groups and others. Many of them are your friends; at least let them know what you are going through and what they may be able to do to help. In the final analysis, we are all in this effort together and we need support and understanding wherever we can find it.

Public Participation in Siting Hazardous Waste Management Facilities in Alaska

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ABSTRACT

Hazardous waste management remains a major controversial issue in Alaska. The RCRA amendments provided impetus for immediate action on the issue of disposal of hazardous waste. The State of Alaska was directed by the Alaska Legislature, specifically the Committee Substitute for Senate Bill (CSSB) 503, in June of 1984 to address the problem of hazardous waste disposal.

Alaska Statute (AS) 46.03 assigns the Alaska Department of Environmental Conservation (DEC) the responsibility to study and identify a viable hazardous waste management and disposal facility for Alaska. This task is a large undertaking with considerable opportunity for controversy among various interested parties. One approach would be to address the issue actively with public participation from various groups including state agencies, local government, environmental groups and industries. The group could assist in the development of action plans and provide recommendations for the best options for in-state hazardous waste management facilities including disposal.

INTRODUCTION

The 1981 Alaska State Legislature passed a law (Chapter 93 SLA 1981) requiring the Alaska Department of Environmental Conservation (DEC) to develop hazardous waste regulations at least equivalent to the requirements of the federal RCRA. Such regulations would be the basis for a federally approved hazardous waste program in Alaska. In order for Alaska to be in a position to receive RCRA authorization, the U.S. EPA determined that the original state legislation must be changed to provide civil and criminal penalties of at least $10,000 per day. This legislation was introduced in the 1984 Alaska Legislature, and several bills affecting the DEC hazardous waste program were introduced as a result. Eventually, the chair of the Senate Resources Committee proposed merging the bills into one compromise bill (CSSB 503) to address the diverse positions of the parties. The compromise legislation, which was passed into law, included the following three points:

- DEC shall develop and implement a program to educate businesses and the general public about their responsibilities under the regulations.
- DEC shall evaluate and select in-state sites for hazardous waste management.
- DEC shall track the transportation of hazardous waste through the state.

These points were based on input from the Hazardous Waste Advisory Work Group (HWAWG), an advisory committee to the state. The HWAWG group was originally formed in 1982 and met throughout the year to address the 1981 legislation and provide input for developing regulations. In addition to the DEC staff, the group included representation from the Associated General Contractors, the Alaska Oil and Gas Association, the Alaskan Air Command, the Alaska Center for the Environment, the Sierra Club, the League of Women Voters, the Alaska Federation of Natives, the Alaska Truckers Association and the Alaska Public Health Association. The new Alaska legislation and accompanying funding renewed the process for a comprehensive hazardous waste program. New mandates address not only the problems of hazardous waste generated by businesses, but also those of household waste, tracking waste shipments and hazardous waste disposal facilities.

The ability of the states to implement and enforce the RCRA program adequately is the subject of controversy. Until and unless a state is authorized by the U.S. EPA to implement RCRA, the U.S. EPA is required to implement the RCRA regulations, including the issuance of permits for waste storage, treatment and disposal facilities in that state.

RCRA regulations primarily address the permitting and operating of hazardous waste management facilities. RCRA does not specify the process for selecting a hazardous waste management site. However, RCRA does state that certain regulatory requirements must be met before hazardous waste management activities may be performed legally at the site. Several states have established programs for siting hazardous waste management facilities. These programs generally specify the process to be followed in selecting a site, provide for public participation and determine the role of state and local government in site selection and permitting.

Many hazardous waste management facilities may require state and federal permits or approvals in addition to the RCRA facility permit(s). These permits may govern: facility construction, air pollution emissions, water usage, wastewater discharge, underground injection or disposal, highway rights-of-way and leasing of state lands.

The 1984 Amendments to RCRA have further forced the siting issue to the forefront. The 1984 Amendments address the phase-out of land disposal for hazardous wastes, greatly increase the number of hazardous waste generators by lowering the regulated quantities, require the study and listing of additional materials as hazardous waste, add a citizen's suit provision and increase the penalties for violations. The amendments increase the costs and decrease the options currently available for disposal in the lower 48 states. Currently, no disposal site is available in Alaska; however, many generators exist, and a site is needed.

An evaluation of a proposed facility should include an assessment of the need for hazardous waste management facilities of some sort (what's generated, where and how much). Additional

concerns to be addressed include whether the proposed facility represents the most appropriate technology for handling the particular wastes generated and whether the location proposed for such a facility is suitable given environmental, social and economic concerns in Alaska.

There are three basic types of facilities which may provide independent or complementary management:

- Storage—holding the waste prior to treatment, disposal or transportation to another state
- Treatment—turning the waste into something less hazardous or reducing its volume
- Disposal—final placement of waste

The siting process should:

- Be well thought out by government agencies, the Alaskan public, industry and potential site developers
- Provide for early and full public information and participation
- Be understandable to the public
- Provide the public with accurate information concerning the benefits, risks and alternatives to a proposed facility
- Address the legitimate concerns of all parties
- Be a shared consultative process among site developers, facility operators, communities, government agencies and other affected parties
- Provide opportunities for all concerned to negotiate areas of dispute

Hazardous waste management sites are needed within the state boundaries. Landfills, injection wells and process facilities all are becoming more strictly regulated. Proper design, siting, permitting and construction of a hazardous waste disposal facility could take more than 10 years. Alaska must start now and not plan to send its wastes to other states.

COMMUNITY INVOLVEMENT IN FACILITY SITING—THE PROBLEM

Environmental and health problems resulting from some improper hazardous waste management practices have caused people to raise legitimate concerns about the nation's ability to manage hazardous wastes effectively. Appropriate technologies should be applied at environmentally acceptable storage, treatment and disposal locations for hazardous waste. Public information and participation programs that include the public early in the siting process are increasingly viewed as necessary steps for addressing public concerns and for public acceptance of the technologies. The fact that hazardous wastes can be dangerous and that the management of hazardous waste is a highly technical area has been well documented.

Another problem with the siting of hazardous waste facilities is the "not in my back yard" syndrome—which has stopped the permitting of many otherwise acceptable sites. The fact that no one wants to live near a hazardous waste facility further emphasizes the need for public participation in the siting process.

THE PROCESS

Components of public information/participation programs that facilitate negotiation, cooperation and dispute resolution can help overcome mistrust and skepticism and avoid legal conflict. Once a facility has been proposed, there may be only a short time to institute dialogue before polarized viewpoints are established. Dialogue should be based, among other things, on credible information about the environmental integrity of a site, the need for the facility, the performance characteristics of the facility and the financial stability and competence of the facility operator. The real challenge to industry and government is to provide the public early in the planning process with non-adversarial points of contact that can reduce polarization and provide an opportunity for addressing questions and concerns with candor and clarity.

What is being suggested is the need for consensus building through an innovative process of private and public cooperation. This is an important starting point which will:

- Foster positive involvement and dialogue among the interested and affected parties
- Help focus the issues and narrow the areas of real disagreement
- Provide ideas and information that may improve the quality of solutions and facilitate decision-making

For hazardous waste management facility siting in Alaska, the 1984 legislation mandated the consideration of several factors including: economic feasibility, intrinsic suitability of the site, pollution control regulations, the risk and effects on local residents, consistency of a facility with local land use planning and potential adverse effects on agriculture or natural resources.

The design of a public information/participation program communicates how much the public's involvement is valued or desired. Providing information and avenues of response to public concerns may earn public approval of the facility, result in changes that make the facility acceptable or justify disapproval of a proposed facility. Regardless of the outcome, the actions will help the community and the state to make decisions which ensure that new facilities will be as safe as possible.

RCRA has established the following procedure for public participation after the notice to issue a draft RCRA permit is established:

- The intention to issue a draft RCRA permit must be published in major newspapers or broadcast over local radio stations
- This notice of intent must be sent to each unit of local government that has jurisdiction over the area where the facility is proposed and to each state agency with authority over the construction or operation of the facility
- At least 30 days must be allowed for comments on a draft permit
- Hearings are required, if requested, within 45 days of public notice of intent to issue a draft RCRA permit
- Public notice of a hearing must include, whenever possible, the date, time, location and nature and purpose of the hearing. The hearing must take place in a location convenient, whenever possible, to the population center nearest to the proposed facility.
- A fact sheet for every draft hazardous waste permit must be prepared by the chief officer for the state's U.S. EPA-approved program, if the officer finds that the permit application is of widespread public interest or raises major issues.

Since the State of Alaska has not yet promulgated siting regulations, conditions for confrontation rather than cooperation are enhanced. It is important for individuals and groups to meet with appropriate State officials to encourage the development of a siting process and to open up the decision-making process in a way that seeks public involvement, keeps the public informed and incorporates viable suggestions about decisions that may affect public health and the environment.

State and local government officials and potential site developers should recognize the planning and providing opportunities for all concerned to participate in a proposed project will facilitate timely siting decisions that are supported by the community. An important aspect of the process involves assuring the public that its concerns will be considered, and, when appropriate, will influence decisions on whether or how to proceed with the siting and operation of a hazardous waste management facility.

THE PARTICIPANTS

Participants in the siting process range from the general population to community leaders to those who may have a particular interest in or may be affected by siting decisions. Serious efforts must be made to inform, involve and respond to these sometimes overlapping groups during different phases of a public information/participation program. Possible participants are:

- Public representatives:
  - -Public officials, both elected and appointed
  - -Federal, state and local government agencies
- Generators and Users:
  - -Businesses and industries
  - -Hazardous waste generators
  - -Site developers and facility operators
  - -Property owners in the vicinity of the site
  - -Consulting scientists, engineers and other experts
- Public and Interested Parties:
  - -General public
  - -Public interest groups
  - -Environmental and conservation groups
  - -Local scientists and engineers
  - -Ad hoc citizen groups
  - -Civic associations
  - -Community and religious groups
  - -Consumer groups
- Other Organizations:
  - -Trade, industrial, agricultural and labor organizations
  - -Public health, scientific and professional societies
  - -Educational institutions
  - -Media, including editorial boards

THE TECHNIQUES

The use of early and broad public information and consultation techniques will inform interested parties about the facts of a proposed facility and may help to narrow areas of potential conflict and promote understanding. Many fears about sites are based on unknown factors or concern that another "Love Canal" will result without the people having any input, therefore extensive public education and input programs are essential. Whether information and participation programs are designed by government regulation or by community/developer interaction, numerous techniques may be used to encourage understanding and evaluation of a proposed siting project:

- Information Dissemination:
  - -Fact sheets
  - -Agency and interest group newsletters
  - -Education of the media for proper use of use of print, radio and TV education
  - -Letters to people on mailing lists
  - -Information centers and public libraries
  - -Spring Cleanup (agency-sponsored hazardous waste collection)
  - -Hotlines
- Consultations:
  - -Advisory committees drawing on major interest groups and representatives of the affected local community
  - -Technical advisors
  - -Public workshops for large and small group discussion
  - -Public opinion surveys
  - -Small group meetings covering specific concerns
  - -Use of models
  - -Public tours and walk-throughs of facilities

The critical influence of the facility's type and location on the potential for adverse environmental impacts makes it important to have comprehensive state or regional siting criteria and management plans for hazardous waste facilities. These criteria and plans should be developed with public participation and should identify, based on hazardous waste management needs and environmental sensitivity, the most environmentally acceptable type of facility and location for the state.

The plans must be realistic in evaluating what is technically feasible and economically supportable given the type, quantity and generation rate of hazardous waste. The Alaska DEC recently has initiated such a plan for Alaska. The first part of this plan includes a "Waste Disposal Study" to be completed by January 1986, and a second study, "A survey of Approaches by Other States in Establishing Criteria for the Location of Hazardous Waste Facilities," also to be completed in January. Both of these studies are in support of the draft regulations to be issued in early 1986.

COSTS AND BENEFITS

A community may experience increased costs as a result of the new facility. One major concern is the remote possibility of health and environmental injuries that may arise if there are releases from the facility. Other increased costs may be related directly to the site: security patrols, fire equipment and new tasks for fire and police personnel. For example, a small local fire department or hospital might need new equipment and different or additional training to handle emergencies related to the facility.

While the developer and/or operator of a hazardous waste facility is interested in a profitable investment as well as a safe and effective business, the community's prime concerns relate to health, quality of life and property values. If the proposed facility is viewed as a threat to these values, the community may want some sort of community benefit in return for accepting the facility.

The community may request the operator to provide funds for services related to the facility including additional fire-fighting or hospital equipment or improved roads in the vicinity of the site. Alternatively, the developer or operator could contribute a fixed sum to the local government for needs that may arise in connection with the project. Another solution could be a type of sales tax whereby the operator would pay a fixed percentage of operating revenues to the local government.

These additional costs, whether a part of the initial investment or a part of higher operating costs, will add to the general economic feasibility of the project. As such, it is very important in studying the project economic viability to address all costs at the very beginning. In some cases, the state may assist the local government in mitigating potential community impacts, especially if they encompass a larger area or population such as would be the case in Alaska.

CONCLUSIONS

The key to developing a good program which involves the public in the siting process must:

- Provide adequate information to the community
- Provide a means to listen to and address the community's concerns
- Develop sound methods of interaction among all interested parties

Communities have developed their own task forces, advisory committees, information systems and other educational and communication methods. Volunteer leaders have been used to work with site developers, facility operators and the government. Potential sources of funding for community participation programs are government, civic, industry and other groups. The goal is to develop a program which will work effectively toward a disposal

answer for the state while enhancing the cooperation and directing the efforts of all interested parties toward the right answers.

Introduction of the public to hazardous waste management facilities and siting options could create a greater appreciation and knowledge of the complexity of properly managing hazardous waste in Alaska. Several objectives would be accomplished including bringing more affected entities into the discussions, educating the regulators to practical application and focusing the hazardous waste issue on an area of common ground. This process should lead to a viable hazardous waste disposal option in Alaska.

The Hazardous Waste Advisory Work Committee should be reestablished to work with the DEC in developing a plan of action for disposal option(s) and site(s) in Alaska. The committee would include representatives of state agencies, local governments, environmental groups, industries and the state legislature. The draft regulations currently being developed should be shared with this group to get early input prior to the legislative deadline of July 1986 for the adoption of regulations. The State DEC should continue its current effort to use newsletters, fact sheets and spring cleanups to promote the local education process.

A balanced picture of the hazardous waste threat to the Alaskan environment and its people is an important perspective for the State to consider. The current DEC study will help answer this question. A strong emphasis on the conservation and recovery aspects of the Resource Conservation and Recovery Act (RCRA) program will provide direction for the Alaskan agencies, public and industry to educate each other about the hazards involved and to minimize the hazards (by reduction and treatment) to the maximum extent possible. And last, but not least, one should recognize that this is not a one-time education process, but one that is required on a continuing basis for all of us to live in our world, together.

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Developing a Comprehensive Public Affairs Policy for New and Existing Industrial Operations

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ABSTRACT

The primary public affairs policy problem faced by most industries involved in the handling of hazardous wastes/materials is simply devising specific programmatic approaches to the desired audiences. This paper offers specific program suggestions for five groups defined as the most important audiences for an industrial public affairs program: the Media, the Community, Government officials, Customers and Employees. The focus of the suggested strategies is the constructive dissemination of unbiased, technically sound information to all these groups.

INTRODUCTION

Your secretary buzzes your office. You detect a note of trepidation in her voice. Suddenly, the dread words waft over the intercom..."Mr. Johnson—there's a Morley Safer here to see you... and Mr. Johnson, he wants permission to film while he talks to you...Mr. Johnson?...Mr. Johnson!...."

There are four possible outcomes at this point:

- With luck, you will wake up.
- You will refuse comment and be made to look like Attila the Hun on next week's Sunday night broadcast.
- You will go into the interview unprepared and watch yourself be battered by the reporter who has already researched the entire story, who has made up his mind about the guilty party (undoubtedly you) and who is only in your office to fulfill his "ethical" duty to get your rebuttal.
- You will be prepared for the interview since one of your community contacts will have alerted you days earlier that the "60 Minutes" crew was in town. Your staff will have approached the crew and offered them access to your facilities and personnel. Your interview will be your opportunity to make a coherent and well researched statement about the issue at hand.

To many of you, this final outcome seems unlikely at best. Yet, it is my firm belief that structured, organized and well-directed public affairs policies can produce a positive scenario such as that I have recounted.

To most industries, the advantage of anticipating the inquiries and needs of their public has been ignored or overlooked in favor of adopting reactive public affairs postures. We allow the story on our new waste incineration process to be "uncovered" by the media and thereby sensationalized without benefit of fact or our own point of view. We meet our community in a forum of litigation rather than negotiation, thereby immediately casting ourselves as the uncommunicative, overbearing industrial warlord.

I would like to recommend several very specific program strategies that can be implemented to begin to change our public response posture from reactive to anticipatory and constructive. I have had the opportunity to design and administer many of these programs for one of the major waste disposal companies, CECOS International. I have since designed similar programs for other clients and have seen the positive impact that a well designed outreach program can have on industry's image in the community.

INTERNAL STRATEGIES—THE FIRST STEPS

The focus of your public affairs policy should be sharply and clearly delineated prior to structuring the actual programs. New projects will require different strategies from existing projects. Although this may seem obvious, it is extremely important to understand that while you may have the opportunity to shape and direct perceptions about a new project, you will have to acknowledge and accept perceptions about existing operations.

I suggest that a small (no more than four people) committee be formed and given one full day to:

- Describe the project
- Describe the need for the project
- Outline any community impact (positive and negative)
- For a new project, describe the desired perception of the project by the community.
- For an existing project, describe present perceptions of the project and desired perceptions.
- Select a Public Affairs Representative for the project.

Above all, it is important to be realistic in your goal setting with regard to the project. For example, you will never get 100 people to turn out at a public hearing to voice their enthusiasm for a new hazardous waste site. However, you may be able to minimize the number of opponents to the project by disseminating clear, straightforward project information to the public.

Once a Public Affairs Spokesperson has been chosen, resource people should be selected. It is important to have at least one management and one technical contact for the Spokesperson. These people will be kept continually informed by the Spokesperson and will be prepared to handle special interview situations (press conferences, technical journal interviews, etc.). Conversely, these resource people will serve as conduits to the Spokesperson for new project information.

After the foregoing has been established, the Spokesperson can begin to develop a Comprehensive Public Affairs Policy. I will outline some specific ideas for such a program in the remainder of my presentation.

IDENTIFYING THE AUDIENCE

You will note that I have selected five target audiences for my policy archetype: Media, community, government officials (elected and non-elected), customers and employees. I would like to comment briefly on specific suggested contacts within these general groups.

Media

- National Media: National magazines, national newspapers (*USA Today, Christian Science Monitor, Wall Street Journal*), network news, CNN News (they will cover what others do not), national radio shows (Talk Net, Larry King, National Public Radio)
- Local Media: Local television (contact all local talk and interview shows—do not forget PBS), newspapers (do not forget Pennysavers, small community tabloids), local magazines (especially Chamber of Commerce and business oriented tabloids), local radio (especially all-talk and all-news formats),
- Trade Media: National and local trade journals (Chem-week, various industrial/regulatory newsletters)

Community

- Citizens within your immediate community or some specified radius of your facility. Address lists can be purchased by zip code.
- Professional Groups and Societies
- Fraternal Groups: Lions, Rotary, Kiwanis Clubs, Garden Clubs, PTAs
- Schools

Government Officials

- Elected and Non-Elected (the Sewer Board, the Planning Commission, the Health Inspector, etc.)

Employees

- The most valuable and most under-utilized resource that you have. Certain programs also should include your employees' families.

SUGGESTED PROGRAMS

Programs for the Media

Facility Tour and Press Conference

This obvious and tremendously valuable strategy is almost never implemented in an organized fashion by industries. It is most important to familiarize media personnel with your facility and/or project. By conducting a tour, you are allowing access to the press as well as getting an opportunity to tell your company's story. Without sanctioned access, the media will portray your company as a series of locked gates and employees hiding their faces. By arranging constructive photo opportunities with a subsequent press conference, you will be able to direct the image of your company/project as it is fashioned by the media.

I suggest that a tour-related press conference be conducted and directed by the Spokesperson. The CEO and technical resource should be available for specific press inquiries as directed to them by the Spokesperson.

At the time of the Press Conference, a carefully constructed Press Guide should be distributed. This Press Guide should contain:

- A company history
- Brief biographies of top management
- Economic impact of the project
- Description of the project
- Reproducible diagrams or charts
- Name of contact person (with home and office telephone numbers)

Press Releases/Story Opportunities

Press releases should be an on-going part of any Public Affairs Program. All research programs, promotions, earnings reports and new technologies should be subject to press releases. Story opportunities should be presented to individual media members as they occur. Story opportunities can present anything from interesting employee/public interest stories to exclusive information on acquisitions or new technology breakthroughs. Reserve your "story opportunity" approaches to the media for especially interested cases.

Individual Relationships with the Media

One of the first responsibilities of any Project Spokesperson should be to develop an individual relationship with those members of the media with which he/she most frequently interacts. Personal facility tours and meetings enhance not only the reporter's knowledge of the facility, but also serve to foster a personal acquaintance between the reporter and the Spokesperson. It is much more difficult to write a totally biased story about a company when you have had personal contact with its employees.

Meetings with Editorial Boards

Each large newspaper has a select group of personnel who comprise the Editorial Board. The Board selects the topics and viewpoint for the papers' editorials. I have found meetings with Editorial Boards to be the single most helpful tactic in receiving positive press coverage. Editorial Boards should be briefed on the project/company by the CEO and the Spokesperson.

In the case of existing projects and facilities, samples of unfair coverage by the paper should be assembled and discussed. A succinct but professional presentation on the project should be made. Full contact information for any future inquiries should be readily available.

Technical Resource Center

The media should be made aware that all the company personnel are available for technical consultation or project or related technical issues. At CECOS, we were able to have several of our staff used as experts by the media in articles relating to general hazardous waste issues. All company reference and research materials also should be made available to the media.

Both of these programs lend technical credibility to your personnel and organization as well as giving your company stature as an expert in the field.

No, No Comment

It is my policy to advise clients against ever adopting a "no comment" stance except in cases under litigation. The public perceives "no comment" responses as one of three things:

- You do not know the answer and are uninformed about your company's affairs
- You are hiding something
- Both of the above

You cannot benefit from a "no comment" response. I recommend that if anyone is faced with a question he does not feel qualified or inclined to answer at the moment, he should get the reporter's name and number and give him a response at a later (but definite) time. Do not be afraid to tell the press that you do not have the facts with you, but that you will assemble them and respond later. Another alternative is to offer a full interview the next day rather than an answer to a single question. Be resourceful—but always comment.

Programs for the Community

Facility Tour and Open House

Most people who vehemently oppose a project or facility have no idea what such a facility looks like or what takes plate at one. Therefore, the first community program that should be implemented is the facility tour and open house. The tour should be

held on a Saturday and always should be preceded by a full presentation on the company, its history and facilities. The tour should be followed by an open question and answer session with company personnel. The names and addresses of all attendees should be recorded and kept for future activities and mailings.

The Open House should be advertised in all local papers, and all local media should be invited to cover the event.

Openline

A toll-free number of citizen inquiries should be established. I resist the title of "hot line" because I feel it is associated with some type of disaster—"openline" has a more informational overtone. All inquiries received on the Openline should receive a written followup response.

Directed Mailing Program

A program of directed mailings to the community should be implemented either immediately after the announcement of a new project or to address specific issues related to an existing project.

Examples of topics for directed mailings might include:

- Economic impact of the facility on the community (taxes, payroll, vendors, etc.)
- New technological developments
- Industries dependent on this facility—service performed for industries

Community Newsletter

This newsletter should be published quarterly for distribution to the targeted citizens and citizens' groups in the community. Some suggested topics include:

- New facility development
- Profiles of employees (spotlight personal and professional interests)
- New technological developments at your facility
- Recent community events
- Community contributions by the company

There should be some response mechanism in the newsletter —a prepaid card for comments, requests for tours or speakers, etc.

Speakers' Bureau

Employees with specific expertise should be identified and involved in a Speakers' Bureau. A brochure listing all available topics should then be distributed to all professional, fraternal, civic and educational organizations in the community. Be certain to include employees vocational and avocational interests.

Financial Contributions to Community Causes

In most organizations, contributions to community causes are made without thought to their overall impact. In many instances, $100 and $200 contributions are made without being part of a larger focussed giving program. For example, at CECOS we were able to identify over $10,000 per year in contributions that were being distributed without an overall giving strategy. Once this amount was identified, we selected one major, visible community project for funding. We provided matching funds for a project to buy a new fire truck for the community in which one of our disposal sites was located. This single contribution had a much more far-reaching and visible impact on the community than a series of $100 and $200 contributions.

School Programs

Secondary schools, colleges and universities always welcome speakers from local industries. Contact department chairmen as well as placement and guidance counsellors with Speaker's Bureau information.

For secondary schools, a company sponsored essay contest on the environment will highlight the company's involvement in the community and provide an excellent media coverage opportunity.

Household Chemical Disposal Days

For industries with disposal facilities, a day for the free disposal of household chemicals will highlight the pervasive problem of hazardous materials in our society.

Programs for Government Officials

As discussed previously, tours and open houses are one of the most effective mechanisms for removing the mystique surrounding your operation.

In general, major elected officials should have personal tours of the facility while others, such as a Town Council, can receive group tours. Meetings with top management officials always should follow these tours. Special emphasis on the economic contributions of the company to the community should be made.

A systematic program of followup contacts should be established following the tours. A contact person in the organization should be selected and identified for all governmental inquiries.

The personnel and reference resources of the company should be detailed for government officials and made available to them for legislative research. Expert witnesses also should be made available.

Programs for Customers and Vendors

Customers and vendors can be an important source of support within the community. Customers, in particular, can be valuable resources at public hearings and can help focus attention on the importance of your facility/project to the community. Many of the aforementioned programs (Open Houses, Tours and Newsletters) would have obvious benefit to your customers. I also would suggest that you distribute periodic legislative updates to your customers. The development of structured lobbying organizations in response to specific legislative proposals will augment the credibility of your leadership within the industrial community.

Programs for Employees

Tour of Your Facility

A survey conducted at CECOS revealed that over 70% of our office personnel had never visited our disposal site—despite the fact that it was only 20 min away. After a full day of tours and presentations for our employees, we got a universally enthusiastic response. An extensive period of questions and answers followed the tour and presentation. Afterward, people commented that they felt much better equipped to act as advocates for the company.

Newsletter for Employees

A newsletter can serve as a vehicle for developing company morale as well as a tool for disseminating information about new technological or financial programs for the company.

Employee/Legislative Liaison Program

All employees living in the immediate area of the facility should be asked to make contact with their various legislative representatives. When specific legislative issues arise, employees can be asked to write or call their legislators.

CONCLUSIONS

I hope this paper has convinced you to take the first step toward establishing a comprehensive public affairs program for your organization. If you do not, you will condemn yourself to repeating the same reactive posture you always have taken with the press and the community—with the same unsatisfactory results.

And, who knows, this time Morley really may be outside the door.

Behind the "F" in Public Education for Hazardous Waste Management: A Case for Special "Tutoring"—Plus Some Tips for Better Grades

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ABSTRACT

In recent years, engineers and waste management companies have been winning the battle of technology but losing the war of public opinion. Hundreds of waste management projects have been scuttled in the face of overwhelming public opposition traceable to the waste management industry's inability to communicate its side of the story with any real impact or credibility. Engineers and waste management technicians have some built-in limitations in this regard, but they can learn to do better—with some professional help and some practical tips contained in this article.

Where public acceptance is concerned, an ounce of prevention is worth a pound of cure.

INTRODUCTION

It's an alarming fact that, despite the critical shortage of sound hazardous waste disposal facilities throughout the United States —and hundreds of efforts to site new ones—only a bare handful of new facilities has been permitted in the past four years. Most of the proposed facilities that failed to come to fruition were technically feasible and incorporated advanced environmental safety features. They were not aborted because of engineering and safety considerations or even because of regulatory agency intervention. Instead, they died of public opposition.

Something has gone very wrong when experienced, conscientious waste management experts cannot convince the public that it, too, has a responsibility to help solve the waste treatment and disposal problems that threaten this country. Something is wrong when the very people who use the products whose manufacture generates hazardous industrial wastes refuse to allow sound waste management facilities anywhere near the communities where they live.

And something is very wrong when the news media in one city after another continue to report on waste management issues with such widely varying accuracy that it is hard to know when the facts are right.

POOR COMMUNICATORS AND EDUCATORS

Some would have us believe that the media deliberately set out to misinform the public and discredit even the most responsible, well-intentioned hazardous waste management initiatives. Don't believe it; with few exceptions, the news media make a conscientious effort to report truthfully on these matters—regardless of how distorted the end result may seem at times.

What is wrong, from our perspective, is that the waste management industry has done, and continues to do, a terrible job of communicating with, and educating, the American public, including the news media. If the medical world had communicated as ineffectively as the waste management industry, we'd still be using leeches and mumbo-jumbo to treat cancer.

No one is arguing that this is the only reason our communities have been so slow to learn the facts about waste management. Love Canal, Times Beach and hundreds of present-day Superfund sites have left America with a cynical mindset. Even the best teachers would find it tough to convince people that today's sophisticated technology isn't going to pose similar problems 20 years from now. The failure of U.S. science education in general has made it very difficult to resolve any kind of science-centered public policy dispute in an intelligent manner. Widespread mistrust of governmental competence in regulating environmental matters is yet another complication, as is the public's belief that

American industry doesn't care how many wells it poisons or what it does to the air we breathe.

These sizeable handicaps notwithstanding, the hazardous waste management industry is still the leading culprit in the failure of public education. Talk about "slow to learn!" Over and over again, companies in the waste management field have invested huge sums of money in feasibility studies, geologic surveys, property acquisitions and design and engineering fees, only to have their projects fail the test of public acceptance. But while bemoaning the fortune that keeps going down the drain, and knowing full well that public relations and politics, not technology, is the problem, the industry still refuses to spend any real money for professional public relations and marketing help. Instead, it has tackled the highly specialized task of public acceptance on its own. Countless companies turn to outside help only after community opposition already has become so impacted that the project is doomed to failure.

Judging from its abysmal record, one would think the industry would finally admit that the engineers, scientists and other experts who are so knowledgeable about the technology of hazardous waste treatment have a lot to learn about how to sell the public on their plans. Not only do they have a lot to learn, most of them are constitutionally ill-equipped to do the job themselves. Here's why the technical experts can't hope to succeed without a massive infusion of expert tutoring and direct, ongoing assistance from specialists skilled at persuading the public.

Winning over the public can be the key to a winning project.

WHY PROFESSIONAL PUBLIC RELATIONS EXPERTS ARE NEEDED

Engineers and Scientists Naive

Sheer naivete is at the heart of the industry's problem. Engineers and scientists are rationalists. They tend to believe that facts are—or should be—as persuasive to others as they are to themselves. They have a hard time seeing things from the perspective of the general public. If they make a logical case for a project, then back it up with solid facts and research, they think the public should react favorably. They forget that there are a lot of other ways to look at waste management problems than from a technical, engineering perspective.

Operations-, Not Marketing-Oriented

A second, closely related, issue is that engineers and engineering-based companies, including large waste management firms, traditionally have been very operations-oriented, not marketing-oriented. Even some of the biggest firms have been slow to develop anything more than the most rudimentary marketing communications and public relations efforts.

This tendency is consonant with the personality type of the engineers and waste management specialists Fanfare Communications has come to know (and respect) in more than seven years of dealing with environmental issues. They are generally uneasy wrestling with subjective judgments. They prefer to avoid situations calling for salesmanship and the manipulation of other people's feelings. They are more comfortable dealing with tangible, quantifiable things. How much? How many? What weight? How high?

Even the professionals who do spend a fair amount of time selling rarely have much experience dealing with the general public. Engineers don't sell their services to the man-in-the-street; they sell to other engineers or to technocrats, who see the world as they do.

Technicalese

A third factor compounding the communications problem of many science and engineering types is that they don't even talk the same language other people do. Even when they're trying their level best to communicate with a lay audience, they talk in "Technicalese" without realizing it. "Leachate collection zones" and "low-permeability soils" are simple enough terms to a waste management specialist, but they don't communicate much to an untutored citizen.

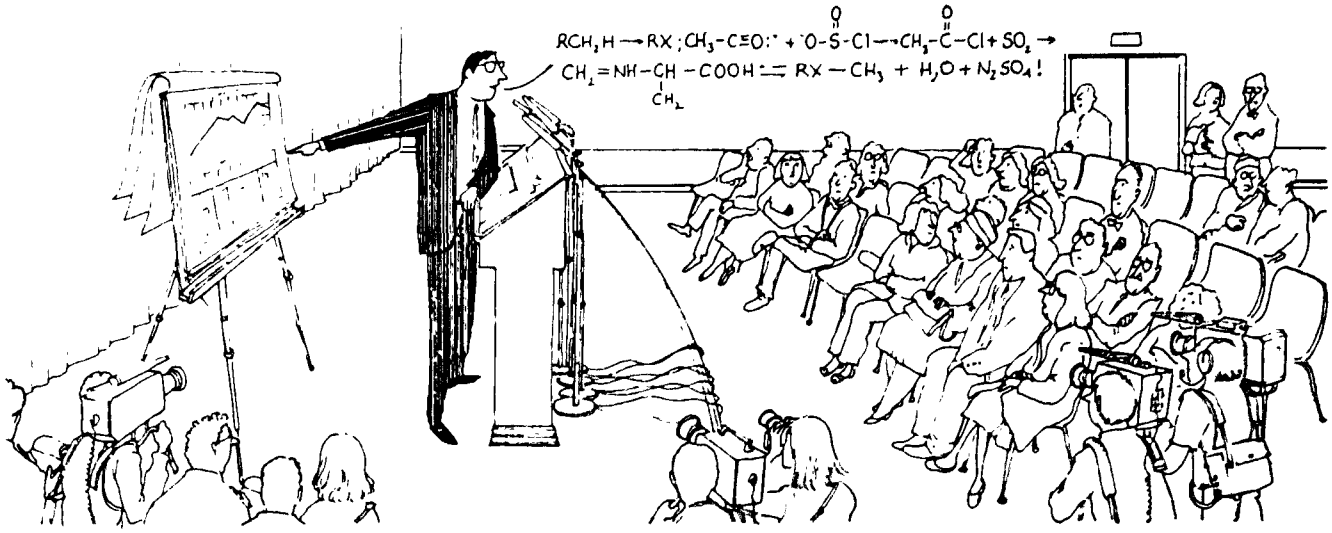
For example, one of the country's largest waste management firms last year published a "Fact Sheet" aimed at clearing up public misconceptions about hazardous waste management. "PCBs: What Are They?" said the fact sheet, implying that the answer which followed would clear up this mystery once and for all. That possibility was quickly dashed. What would your nontechnical friends or spouse make of this explanation?

"The name stands for polychlorinated biphenyls, and contrary to popular belief, PCBs are not one chemical but a class of compounds. These compounds are two benzene rings joined together at one carbon on each ring. The rings are then substituted with one to ten chlorine atoms."

Too Expert to Communicate?

Fourth, as specialists in demanding technical fields where depth, not breadth, of knowledge is the common measurement of true expertise, engineers and scientists are prone to write off their inabilities as public communicators with such rationales as, "I'm an engineer, not an actor." As a consequence, they invest little effort in improving their skills and may simply avoid situations that highlight weaknesses in this area. Like most people, if given a choice, they'll define their jobs and responsibilities to emphasize their strengths, not their liabilities.

Finally, in organizations that traditionally have rewarded personnel for their engineering and operational know-how, and which recruit new professionals by those same criteria, qualified professionals are often reluctant to make marketing and com-



Too often, engineers talk "technicalese" that confuses the public.

munications a central part of their job. Is it surprising that those organizations not only do a poor job of communicating with the public, but also don't even recognize that they need help?

Because of these and other factors, many of the public presentations for environmental and waste management projects recently have been handled by lawyers, not engineers. Lawyers are supposed to be comfortable in the world of words. They are trained in the art of verbally manipulating facts into convincing legal arguments.

But convincing legal arguments do not often sway the public. Lawyers may present some inherent public relations liabilities of their own. For one thing, they aren't scientists, technical experts or engineers; they don't—except in rare instances—have an in-depth knowledge of environmental engineering and the scientific disciplines related to waste management. And, when all is said and done, the public doesn't care whether a waste management firm has a solid, likeable lawyer. They'd rather see proof that the company's waste treatment expert, its chemist, its hydrogeologist, its construction engineers, laboratory technician and weigh station operator are competent and trustworthy. The lawyer is just a "mouthpiece" for the company, and the public knows that.

Second, lawyers often are oriented toward the adversarial approach to conflict resolution, one reason why they often win the battles but lose the wars. They pick arguments apart; they marshal facts and cite precedents. But do they win the public? Not necessarily. That's because, in the arena of public opinion, there is no burden of proof, and precedents seldom hold much weight. The public doesn't even have to make sense to win. All it has to do is make its feelings felt—strongly enough, long enough and in the right places—to make it very difficult for the "right side" to win.

IF THEY CAN'T DO IT, WHO CAN?

Having eliminated the technical experts and the lawyers, who CAN be counted on to handle the responsibility for winning public acceptance for a major waste management project?

Experience indicates that the best bet is a team approach. It is headed by top company management to ensure that the team's decisions and public statements aren't going to be subject to reversal by higher-ups—something that can cripple any public acceptance effort. The team includes a public relations consultant experienced in public participation programs for environmental projects. This consultant generally serves as chief tactician, communications director and exclusive conduit to the news media. He or she may double as, or be associated with, a political strategist to steer the project through partisan politics and/or public referenda.

The team also includes—Surprise!—a lawyer specializing in environmental law and, finally, by far the most important member of the team, a knowledgeable project engineer or scientist who is, first and foremost, a superb public communicator. He is, in fact, THE Communicator, the prime ongoing spokesperson for the project. Other technical specialists may round out the team as needed.

"The Communicator"

The Communicator is the kind of person who conveys complete credibility and personal honesty. Generally low-key, pleasant looking and unpretentious, he is readily likeable to a broad cross-section of people. He most likely has a fine sense of humor. More important,he has the explanatory skills and patience of a first-rate teacher. Finally, he has a sound grip on the subject matter, although he does not have to be a leading expert.

One of the best examples of how effective such a Communicator can be without actually being a true expert was the late, great John A. ("Shorty") Powers, who was the voice of the National Aeronautics and Space Administration during the crucial days of the U.S. space program from 1959 to 1964. Often referred to as "The 8th Astronaut," Powers was an Air Force Lt. Colonel who never flew in anything more orbital than a Korean War bomber and wasn't even a college graduate.

Shorty Powers led the American public and the news media through an instructive introduction to the science of space exploration. It was he who originated the phrase "A-Ok," and to whom hundreds of reporters turned for authoritative information about Project Mercury. Committed to the importance of honesty in dealing with the public ("You gotta tell people," he insisted), he did much to build public confidence in the space effort. Could there be a better Communicator model for the waste management industry today?

If all of these qualities seem to add up to an unattainable ideal, rest assured that it IS possible to find someone—preferably someone already employed by the waste management firm—who fills the bill reasonably well. If it's necessary to hire someone to assume this role, then do so and give him a title appropriate to his task and the talents he brings to it.

Some Practical Suggestions

These, then, are the key participants for a successful public acceptance effort. But how should they proceed, and what mistakes should they be careful to avoid?

Whole books and lengthy manuals have been written on the subject of public participation programs for waste management projects, but they pay far more attention to the rules and regulations for formal hearings and proceedings than to the more fundamental issue of winning public acceptance. Space doesn't permit a full exploration of all key components of a sound public acceptance program, but here are some practical suggestions gleaned from the experience of Fanfare Communications and its clients in the waste management industry.

In General

- Think carefully before trying to go around the public. It rarely works. Have a good public acceptance program ready to put into place even though you think it won't be necessary.
- It's usually easier to control public reactions if you take the initiative instead of being forced to react.
- Communicate a sense of full disclosure. Better that YOU tell people the bad news than for the public to hear it from another source and think you've been deceiving people.
- The bottom line is not to be declared "right"; it is to get enough people in the community to believe enough of your story to allow your company to do what it hopes to do.
- "Walk in the public's shoes" if you want to understand a community's concerns. If you do not understand its concerns, you will never gain its acceptance.
- Never lie to the public or "shoot from the hip" with a statement you might later have to retract.
- Never make up an answer and then try to support it later.
- Communicate in such a way that people who know absolutely nothing about the environmental sciences, chemistry or engineering can understand what you say. It makes people nervous, worried, embarrassed and angry to be confused.
- Even if you can't win outright public acceptance, try to establish an atmosphere calm enough to permit regulatory agencies to do their jobs free of public hysteria and excessive political pressure.
- Public acceptance programs do not succeed because of what YOU know, but because of what the public FEELS.
- Internal communication is critical. Develop a consistent project narrative and description, and make sure all parties stick to it.
- Do not think of "the public" as a single entity. Think of community residents in terms of "active, intractable opponents," "passive opposition," "disinterested neutrals," "persuadable neutrals," "allies" and "latent allies." There are also opinion leaders, special interest groups (labor, churches, business, environmental groups, the PTA, ethnic concentrations, etc.), the news media, elected officials, regulatory agencies and civic groups. "Target" messages appropriate to each sub-group, but never make contradictory statements.
- Have specific, detailed objectives for all the communication tools you employ, including: the official project spokesperson (The Communicator), speeches to specific groups of people, public information meetings, printed brochures and booklets, audiovisual presentations, individual meetings with officials and opinion leaders, radio and TV commercials, posters, targeted mailings, publicity releases, news conferences and announcements, official hearings, public debates and news media interviews.
- Tap the resources and trade associations of waste generators in a community to participate in general education efforts about the importance of sound waste management.
- Line up friends. Harness their self-interest and provide them with the materials and support to make it easy for them to help.

Spokespersons

- Insist on having one official project spokesperson. Many mouths make hard work, lots of headaches and embarrassing contradictions.
- It is essential to level with the media as much as possible, establish trust and not be seen as pro-company zealots. Give them the freedom to succeed for you.

At Public Meetings

- Urge all company speakers and respondents to questions to be "real people" and let (the good sides of) their personalities show. Humor, at the proper time, can be a real trust-builder.
- Your personal manner and appearance communicate at least as much information about your project as what you say about it. Look confident and relaxed. If you cannot, do not appear in public meetings.
- Use standard persuasion techniques, including always starting where your audience is, not where you are or where you want them to be.
- Insist on getting professional training in public speaking and responding to hostile questions for all company representatives likely to make public appearances.
- Use videotape cameras to record the way company representatives look and sound at public meetings and to help them practice their presentations beforehand. There is no better way for people to learn than to see themselves as others see them—especially if they are going to be seen on television.
- Address the intent of people's questions, not just the specific wording, which is often inarticulate. It makes you appear to be more forthcoming.
- Always schedule ample time for give-and-take with the public and for clarifying questions and answers. Do not put this crucial component of public meetings on an "if there's time" basis.
- Be clear about what you want to convey in all public utterances. Have simple, modest goals for your statements. Complexity bewilders. Bewilderment breeds anxiety.
- Avoid jargon and "technicalese." It separates you from the audience just when you want them to be with you.
- The purpose of public meetings is to generate credibility and better feelings, not to flood people with a vast quantity of information. It is not your message that matters; it is how the public feels about you and your project.
- Do not disengage from the audience by constantly staring down at a prepared speech and reading in a monotone. Master the material so that you can look up frequently. Engage the audience. Be expressive.
- Learn to tolerate people directing their angry comments and concerns at you. It is seldom truly personal, and it usually helps to defuse public hostilities when people are allowed to spout off at someone—unpleasant as that may be.

Audiovisual Programs

- Unless they are accompanied by a skilled speaker or are designed to allow interaction with the audience, one-projector slide shows without a soundtrack can be pretty static and boring. The best format is a technically uncomplicated, not overly slick, two-projector program with a pre-recorded, synchronized soundtrack. Numerous studies have shown that it sustains interest better and produces much fuller information recall.

- Try to put only one idea on each slide. Detailed charts, lengthy lists and wordy graphics are a staple of engineering presentations, and they are almost worthless as communication devices.
- If the eye cannot quickly grasp and easily "hold on to" the visual information in a slide, it is a bad slide.
- The use of all capital letters tends to be less readable than capital and lower case letters combined—the way they are in 99% of the things we read every day.
- The typography in many slides resembles "The Lord's Prayer" written on the head of a pin. Keep type clear and large enough to be quickly legible.
- Audiovisual programs that present information only and fail to address and affect people's feelings are failing to use the full potential of the medium.

News Media Relations

- Educate the news media patiently. Keep giving them clear, informative information and their coverage will improve.
- Establish your company as a dependable source of information about waste management in general, not just as it relates to your company. It makes reporters more knowledgeable and builds useful bridges with the news media.
- See every potential story about your project as the press might see it. Your perspective is not a reliable index of how the media will, or should, deal with news about your company and its projects.
- Keep your cool when "correcting" the news media for erroneous stories. Mistakes rarely are intentional, and you will benefit in the future from not insulting a reporter who gets things wrong. Never "demand" retractions unless you have firm legal grounds for doing so. A firm request often gets better results.

Booklets and Brochures

- Good printed materials should adhere to the same communications guidelines stated for other media. They should avoid "technicalese," be clear and understandable to non-experts with only a high school education and address the readers' interests and concerns, not simply hammer home the company's message.
- Printed materials should communicate well on several levels: they should use boldface or color-emphasized headlines, subheads that add details and interest to the headlines, photographs and illustrations that convey visual information, and caption material that expands on them. All of these elements help "pull the reader in," and at a time when people are being bombarded with a vast amount of printed matter, every readership encouragement helps.
- Generally, waste management companies should avoid using excessively slick and sophisticated publications that may convey too strong a "big business"/"big money" impression to people in a particular community. Sometimes, however, it is important to convey a very substantial image, in which case the graphic presentation and paper quality can signal your company's ample resources.
- Consider using targeted mailings to direct specific messages to specific audiences. It is expensive, but effective.

Radio, TV and Print Advertising

- If you are frustrated by repeated failures in getting the news media to pay sufficient attention to your side of the story, consider using advertising to communicate a message that you and you alone control. But get professionals to create the copy and graphics. Advertising that misses the boat from a message standpoint, makes no strong impression or fails to get people's attention in the first place is a terrible waste of precious communications resources.

Now get out there and start educating!

Recycling of Dust from Electric Arc Furnaces—An Experimental Evaluation

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ABSTRACT

Dust generated from electric arc furnaces (EAFs) employed in steelmaking plants currently is listed as a hazardous waste. Disposal of the waste at a controlled landfill is becoming expensive as disposal sites become more scarce and remote from the point of origin. Even with current standards of environmentally acceptable disposal, long-term liability is a concern. This has led the steelmaking industry to look to other viable options for handling the dust.

The dust from carbon and low-alloy steel plants represents a potential source of heavy metals such as iron and zinc, the recovery of which appears to be a logical alternative to disposal. In addition to providing a dust management option, material conservation would result from this approach. Centralized recovery facilities do not appear to be economically attractive for EAF dust because it is generated in small quantities at a large number of locations distant from industrial centers. Recycling to the furnaces to achieve additional iron recovery and produce a zinc-enriched blowdown dust stream for sale appears to represent the most sensible route for managing the dust. This paper discusses the approach and presents results of an experimental program for investigation of key issues pertaining to EAF dust pellet recycling. These issues are the fate of zinc and other volatile elements in the dust, electrical energy consumption in the furnace during recycling, effect on steel quality and the economics of recycling. The research was conducted under a grant from the U.S. EPA's Small Business Innovation Research Program.

INTRODUCTION

Each year the electric arc steelmaking industry generates approximately 650,000 tons of dusts containing valuable metals such as iron, zinc, lead and chromium. These electric arc furnaces (EAFs) are becoming increasingly popular for the production of carbon and low-alloy steels and currently account for about 35% of total steel production. Although only a relatively small amount of dust is generated from the furnaces at any one steel plant, the cumulative quantity from all plants is large and represents a significant loss of heavy metals and scarce alloying elements.

More importantly, EAF dust currently is listed as a hazardous waste because of the leachability of its toxic constituents; its U.S. EPA-assigned hazardous waste number is KO61. Disposal is becoming costly as disposal sites become more scarce and remote from the point of origin. Disposal costs (including transportation) of $100 per ton of dust are quite common. Furthermore, even with current standards of environmentally acceptable disposal, long-term liability is a concern. This has led the steelmaking industry to look to other viable options for handling the dust.

Alternatives to the landfilling option for EAF dust management include chemical fixation, regional recovery processes and on-site recycling. The major shortcomings of the various processes suggested for recycling metallic values from EAF dust (e.g., SKF Plasmadust process, AMAX Caustic Leach—Electrowin Zinc process) have been the high capital cost of the equipment and the need for large quantities of dust for the processes to be economical. Furthermore, the processes require dusts with zinc contents greater than 20%. EAF dust generally is not amenable to these processes because it is generated in small quantities at a large number of locations distant from industrial centers where regional recycling might occur.

Recycling to the furnaces is a logical alternative for managing EAF dust. The recycling operation should result in the generation of a dust enriched in volatile elements such as zinc and lead; this blowdown dust stream could be removed for sale to zinc smelters. The main advantages of the recycling process are its low capital cost, relative insensitivity to EAF dust composition and applicability to both minimills and large mills. This process can be applied to carbon and low-alloy steel plants in both the basic steel and steel foundry industries to recover contained mineral values in the dust and thus avoid costly disposal of this waste in hazardous waste landfills.

Plant Experience in Recycling

Several steel plants including Bethlehem Steel, Babcock & Wilcox, Empire-Detroit Steel, LASCO in Whitby, Ontario and Armco at their Kansas City Works have conducted trials of recycling with either pellets (of dust and water) or briquettes. On balance, there appears to be no clear consensus on the effects of EAF dust recycling in the steel industry. Although some dissatisfaction with recycling exists, it appears to offer the most immediate, lowest-cost alternative to disposal at this time.

Experimental Research Program

Based on the results of a feasibility study by PEI and the experience of previous researchers, PEI designed an experimental program to obtain data under controlled conditions for investigation of several critical issues for the commercial application of recycling: (1) the partitioning (upon recycling) of heavy metals such as zinc, lead and cadmium between the slag and the dust generated; (2) the effect of recycling on energy consumption; (3) the effect on steel quality; and (4) the economics of recycling. The tests were conducted at the Green River Steel EAF shop in Owensboro, Kentucky, during the summer of 1985.

Green River's Owensboro site has two 65-ton electric arc furnaces rated at 24,000 kVA each (370 kVA/ton). The furnaces produce low-alloy and specialty carbon steels that are sold to the forging industry for use in the aerospace, bearings, defense, en-

ergy exploration and production, machine tool, power transmission and generation, mining and transportation industries. Oxygen is injected with hand-held pipes; lime is injected pneumatically. Three to four charges of scrap are used per heat. The furnaces are equipped with side-draft hoods, which semi-surround the electrodes and canopy hoods in the roof. Both furnaces are vented to a 14-compartment baghouse that discharges into screw conveyors. These conveyors ultimately join into one cross conveyor that discharges into a flexible tube. The dust then falls about 6 ft through the tube into a large sealed rolloff box situated on the ground. After being filled, this box is hauled to a hazardous waste facility.

EVALUATION OF PELLETIZING EQUIPMENT

Prior to plant selection, fresh dust was obtained from two operating EAF shops representing low-alloy medium carbon steels (Plant A) and plain carbon steels (Plant B). Manufacturers of pelletizing equipment were contacted for conducting pelletizing tests. (The agglomerating of EAF dust with water is often called "greenballing." In this paper, however, we refer to the product as pellets and the process as pelletizing.) Teledyne-Readco of York, Pennsylvania, was selected to run laboratory-scale and bench-scale tests on these dust samples.

Based on the bench-scale test results, the following equipment was selected for conducting the pilot-plant studies:

1. 3-ft-diameter disc pelletizer and hopper
2. 8-in-diameter pin mixer
3. 3-ft³ live bin feeder
4. Heavy-duty base supports for pelletizer, pin mixer and feeder

Two feeder tubes were also used to provide the flexibility to bypass the pin mixer. Even though the bench-scale pelletizing tests did not warrant the use of a pin mixer, one was included to provide preslaking of lime in the event that this was required.

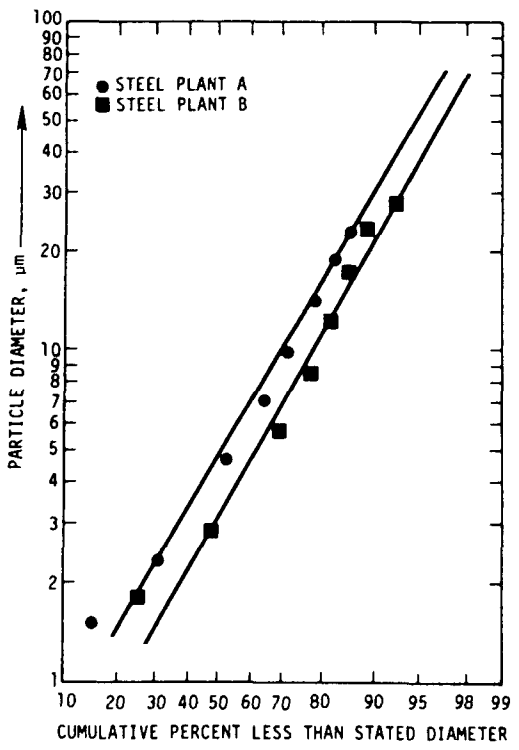


Figure 1
Particle Size Distribution of Electric Arc Furnace Dusts from Two Steel Plants

Table 1
Elemental Concentrations in Electric Arc Furnace Dusts (% by Weight)

Element	Steel plant A	B	C	D
Ca[a]	9.17	3.18	2.81	14.71
Fe[a]	16.7	32.1	32.9	28.2
Zn[b]	26.9	20.9	20.6	12.9
Pb[b]	2.24	3.85	5.08	0.83

[a]Analyzed by ASTM Reference Method 3682
[b]Analyzed by ASTM Reference Method 3683

CHARACTERIZATION OF EAF DUSTS

As part of the preliminary activities for the experimental research program, PEI conducted physical and chemical characterization tests for EAF dusts.

PEI performed Bahco analyses for analyzing particle size distribution of two EAF dusts (Fig. 1); the Bahco analyses were performed on minus-100-mesh material, which represented 98.8% (by weight) of the sample for dust from Steel Plant A and 65.5% of the sample for dust from Steel Plant B. The results show that the EAF dusts were composed of fine particles and that approximately 50% of the dust was below 5 microns.

Table 1 illustrates the variability of important metallic constituents in the dust. The EAF dust analysis varies from heat to heat and during a heat, depending on the materials charged, stage of the heat and other factors. Consequently, the recycling technique must be relatively insensitive to changes in both the chemical and physical characteristics of the dust.

Some of the pellets produced during the bench-scale tests were subjected to weatherability tests. These pellets were kept in the open for a period of 5 months. Ninety-five percent of the pellets retained their shape without any breakage. All the pellets retained a strength of over 50 lb. Although the weatherability tests indicated reasonably good weathering characteristics without any impact on pellet strength or breakage of pellets, in an ongoing recycling operation, pellets would not be stored for more than a few days.

Tests were conducted to measure the temperature change of EAF dust/water mixtures over time. The dust contained 20.6% lime. For one test, the dust/water mix was formed into pellets 3/8 in. to 1/2 in. in diameter; for the other, the mix was left as a solid cake. The mixtures were held in insulated cups and the temperature was measured by imbedded thermocouples.

Figure 2 shows the time-temperature curves for the pellets and the solid cake. Maximum temperature reached in the solid cake was higher than in the pellet test; however, the more important observation is that in both tests, temperatures increased quickly at first and then gradually rose to a maximum sometime after the dust and water were mixed. The time required to reach the maximum temperature was 80 and 105 min, respectively, for the solid cake and pellets. The thermal mechanism demonstrated in these tests indicates the lime slaking and curing phenomenon taking place.

PELLETIZING OPERATION

Figure 3 illustrates the pelletizing process flow diagram for the Green River installation. The temporary storage hopper, which is completely enclosed, receives the EAF dust from the baghouse. The pelletizing operations were enclosed in a temporary shelter.

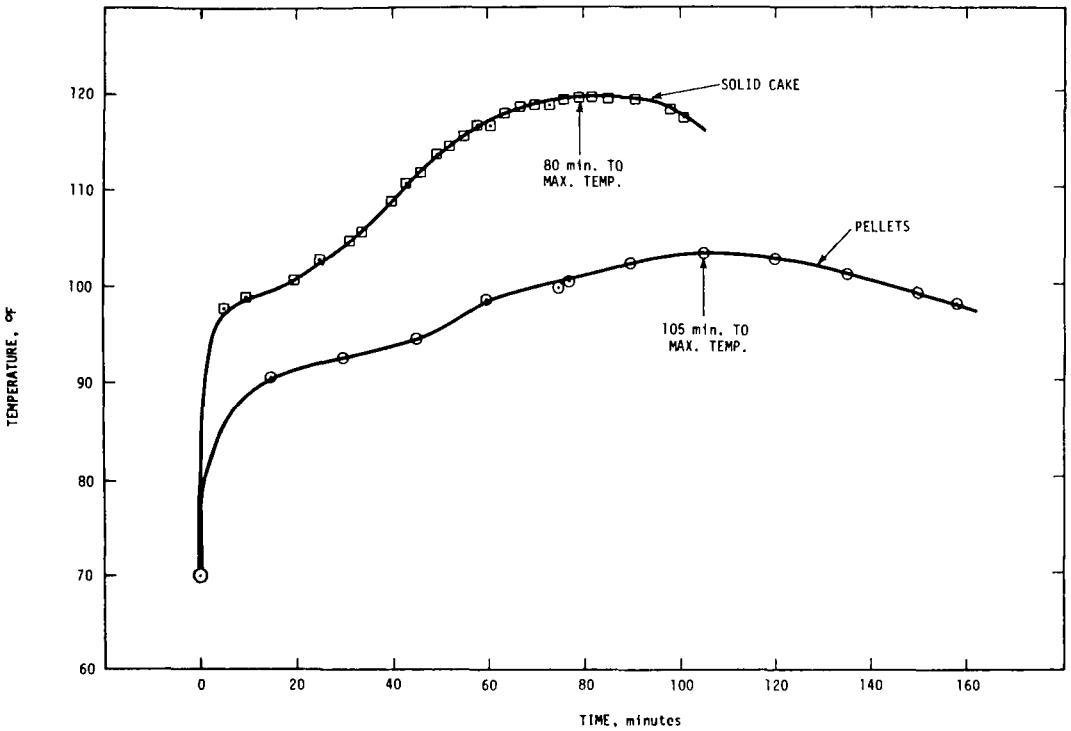


Figure 2
Results of Time-Temperature Tests on EAF Dust Pellets

The pellets produced were stored either in cardboard drums or wooden boxes lined with polyethylene. All the pellets produced were transferred and stored in a covered warehouse before charging into the furnaces. These arrangements met the necessary regulatory requirements. Figure 4 shows the temporary enclosure and the auxiliary facilities for the pelletizing system.

The test pelletizer unit was a pilot model and, as such, was open to allow adjustment of water spray or dust feed locations. During pilot model operation, some dusting occurred around the machine; this would be circumvented on a production model as it would be covered and vented to the baghouse.

Dust composition appears to be the most important parameter affecting pellet quality. Fortunately, variations in size ($< 1/4$ in to $> 3/4$ in.) did not affect the efficacy of recycling.

The initial arrangement of the system included the pin mixer, which was believed to offer the advantage of premixing water with the dust to start the slaking of the lime before the dust entered the pelletizer. After several trials, however, the pin mixer became clogged with wetted dust, which hindered the process; therefore the mixer was removed. Even though the Green River EAF dust varied from 10 to 20% lime, the pellet quality without the pin mixer was not noticeably different from the pellet quality with the pin mixer.

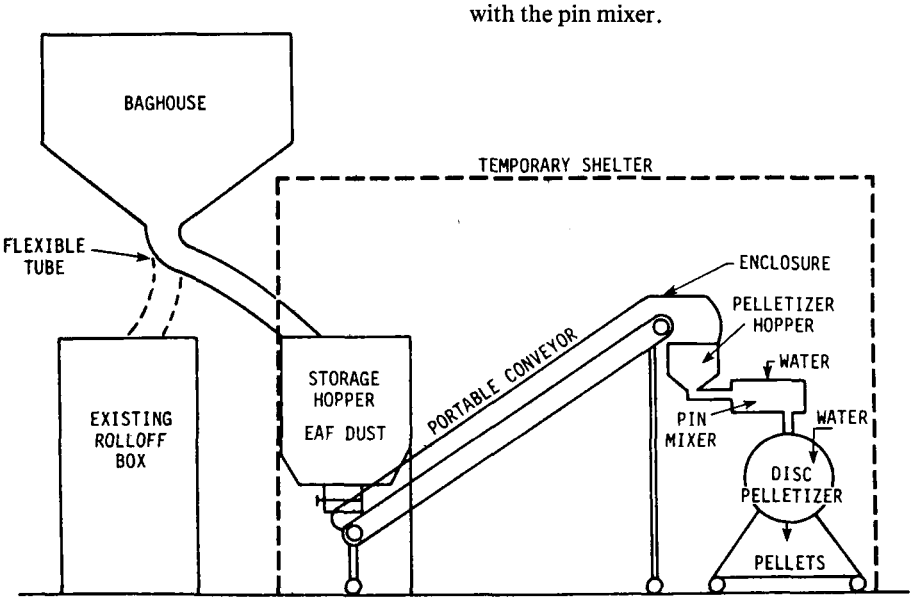
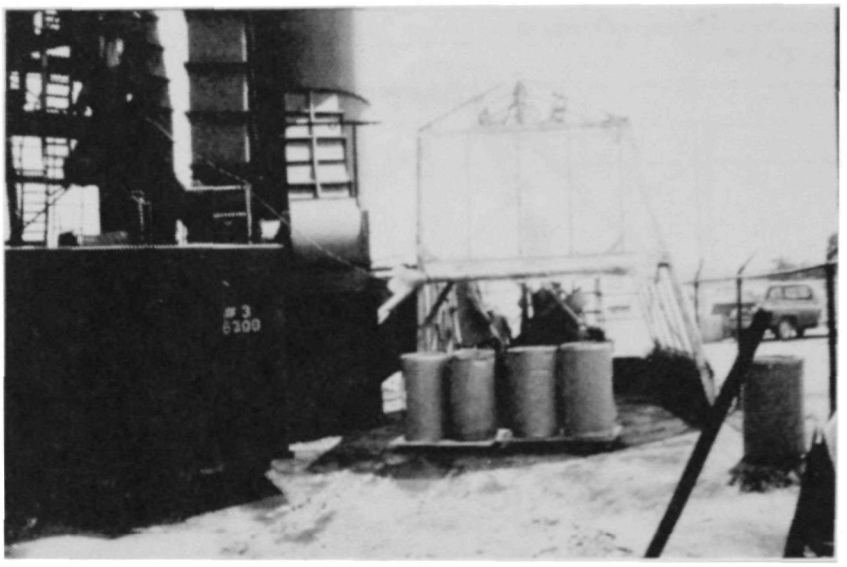
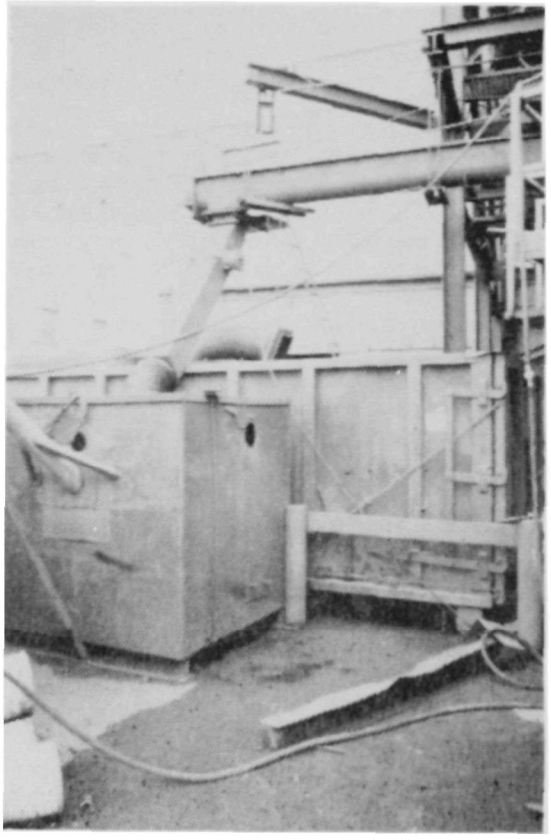


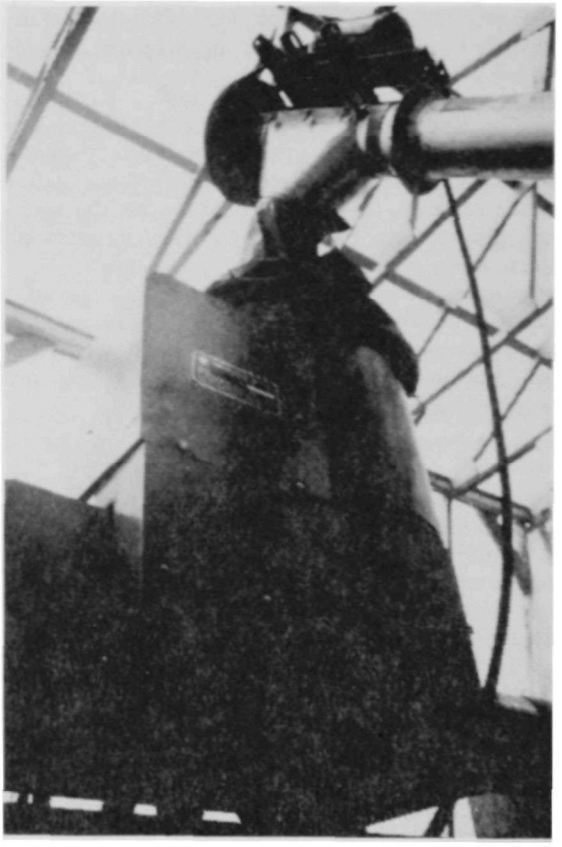
Figure 3
Dust Pelletizing Process Flow Schematic for Green River Steel Installation



Temporary Weather Enclosure Over Pelletizing Equipment
at Green River Steel EAF Shop, Owensboro, Ky.



Day Bin Constructed by Green River Steel
for EAF Dust Storage



Auger Supplying Pelletizer Feeder

Figure 4
Pelletizing Facility at Green River Steel Co.

Pellet Quality

Pellet strength tests were mostly qualitative, i.e., the pellets were squeezed by hand. In some cases, however, a flat strip was used to press the pellets on a scale, and the pellets showed breaking strength of 9 to 10 lb (green strength). Pellets from the pelletizer as made were strong enough to withstand shoveling and/or dropping into the container.

After aging for 24 hr, the pellets increased in strength. Tests on three different batches (of different sizes) showed a crush strength of 18 to 25 lb. The same batches showed a crush strength of 35 to >80 lb after 48 hr of aging.

RECYCLING OPERATION

Transportation of pellets to the furnace and the timing of their charging are important for a successful recycling program. Preferably, the pellets should be charged into the furnace through the use of a separate box or skip pan. They should be charged while a slag layer is present on the molten metal from the meltdown of scrap charged earlier. This facilitates quick assimilation of the pellets into the bath and reduces flash off as dust. The scrap backcharge can take place immediately after the pellets are charged. Another variation in charging consists of "sandwiching" the pellets between the scrap in the charging bucket.

At Green River, the recycling operation involved moving the drummed or crated pellets by a forklift to a warehouse area and then to the melt shop floor, where they were dumped into a skip pan. The skip pan was weighed and emptied into the furnace by crane. The pellets were charged prior to the second charge of scrap (first backcharge). Figure 5 schematically illustrates both methods of charging.

RESULTS

Results of pellet recycling were analyzed by comparison with collected baseline data to determine:

- Effect on heat time and productivity
- Effect on power consumption
- Effect on yield
- Effect on quality of the steel
- Effect on carbon and electrode consumption
- Effect on lime and ferroalloy consumption

The tests were conducted in two blocks. The main objective of the Block I tests was to determine the effect of recycling fresh pellets on power consumption and other furnace variables, whereas the primary objective of the Block II tests was to determine the fate of heavy metals under continuous recycling conditions. Table 2 summarizes the data for the heats with pellet charging in Blocks I and II. Because the shop operation was not continuous during the experiments, some heats were made after the furnace had sat idle for an entire turn, whereas others were made immediately after the previous heat. This situation affects apparent power use in kWh/ton and heat time regardless of pellet use. The heats are therefore divided into these two categories ("first heat," i.e., cold furnace, versus "not first heat," i.e., continuous operation) for more accurate analysis. Table 3 summarizes similar data for baseline heats, i.e., heats without pellet charging. The data for these heats were obtained largely from the plant's heat log sheets.

During the Block I test period, both furnaces operated 16 hr per day. Later, one of the two furnaces was shut down for repairs and only one furnace remained in operation. During the night turn, the furnace roof was kept open and the furnaces were allowed to cook down. The data collected during the Block I and Block II tests include a variety of heats representing the normal product mix. The operators paid no special attention to, nor implemented any changes in, the steelmaking practice (other than adding extra carbon) because of the testing program.

The Block II tests were limited to 4 days of continuous recycling because of the plant operating schedule. During this period, pellets were made directly from the baghouse catch and

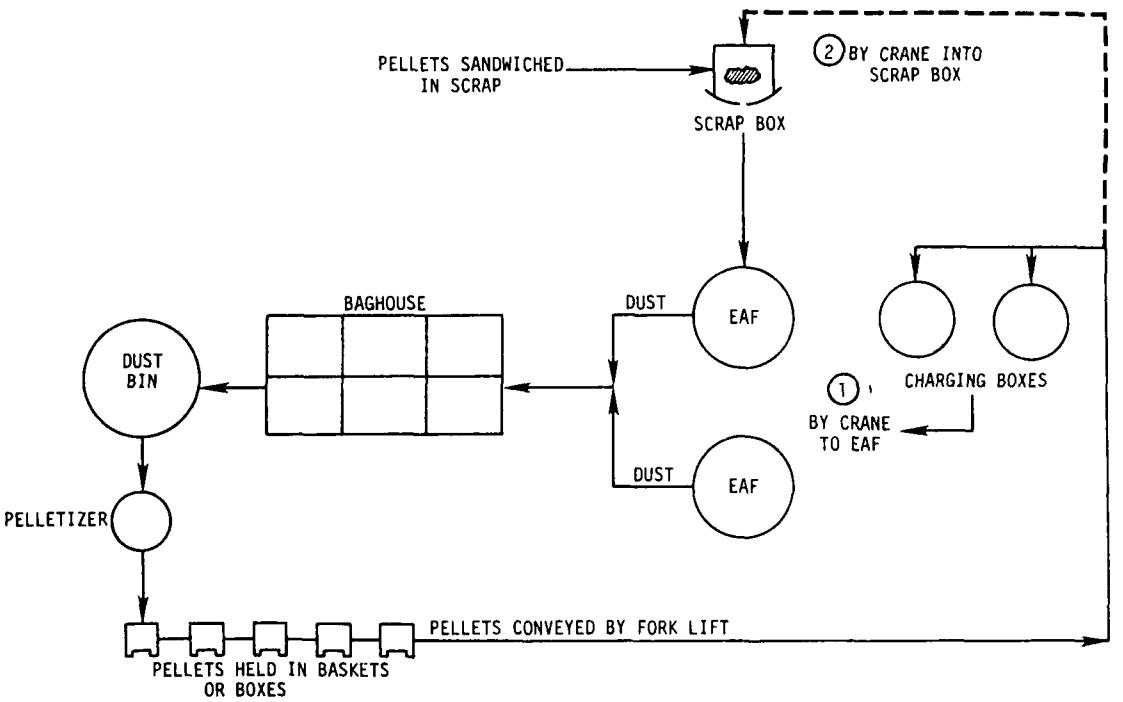


Figure 5
Schematic of EAF Dust Pelletizing/Recycling Operations

Table 2
Comparison of Data for Heats with Pellet Charging in Blocks I and II

HEATS WITH PELLET CHARGING (FIRST HEAT ON FURNACE AFTER DOWNTURN)

TOTAL OBSERVATIONS: 14

	TAPTAP HRS	PWRUSED KWH/TON	TOTYIELD %	NETYIELD %	OPENCRBN %	FNALCRBN %	COKECHRG LBS	PLLTCHRG LBS
N OF CASES	14	14	14	14	14	14	14	14
MINIMUM	4.830	536.960	86.550	79.500	0.070	0.150	0.	910.000
MAXIMUM	9.670	670.740	93.800	93.600	0.471	0.480	3200.000	2180.000
MEAN	7.319	616.919	89.909	86.693	0.270	0.352	1132.143	1129.286
STANDARD DEV	1.217	40.442	2.752	3.734	0.120	0.113	799.425	322.090

HEATS WITH PELLET CHARGING (NOT FIRST HEAT)

TOTAL OBSERVATIONS: 24

	TAPTAP HRS	PWRUSED KWH/TON	TOTYIELD %	NETYIELD %	OPENCRBN %	FNALCRBN %	COKECHRG LBS	PLLTCHRG LBS
N OF CASES	24	24	24	24	24	24	24	24
MINIMUM	4.500	493.830	82.500	65.500	0.050	0.160	100.000	100.000
MAXIMUM	8.000	672.500	98.900	93.900	0.860	0.470	2000.000	2155.000
MEAN	5.872	560.903	91.231	85.788	0.349	0.338	1050.000	1083.542
STANDARD DEV	0.953	37.725	3.656	5.494	0.203	0.112	521.703	328.019

Variable names are as follows:

TAPTAP	Tap-to-tap heat time (in hours)
PWRUSED	Power used (in kilowatt-hours/ton).
TOTYIELD	Yield of steel as tapped as percentage of total metallic charge including scrap, ferroalloys, and pellets.
NETYIELD	Yield of prime steel as poured (in percentage).
OPENCRBN	Opening carbon in both (in percent).
FINAL CRBN	Final tap carbon in both (in percent)
COKECHRG	Coke charged (in pounds).
PLLTCHRG	Pellets charged (in pounds).

Table 3
Comparisons of Data for Baseline Heats

BASELINE HEATS (FIRST HEAT ON FURNACE AFTER DOWNTURN)

TOTAL OBSERVATIONS: 28

	TAPTAP HRS	PWRUSED KWH/TON	TOTYIELD %	NETYIELD %	OPENCRBN %	FNALCRBN %	COKECHRG LBS	PLLTCHRG LBS
N OF CASES	28	28	28	28	27	27	28	28
MINIMUM	4.670	483.220	83.400	73.000	0.060	0.110	0.	0.
MAXIMUM	9.083	766.090	97.100	96.600	1.170	1.070	2500.000	0.
MEAN	6.777	592.898	90.118	87.172	0.348	0.381	1078.571	0.
STANDARD DEV	1.211	74.942	3.438	4.799	0.295	0.271	654.532	0.

BASELINE HEATS (NOT FIRST HEAT)

TOTAL OBSERVATIONS: 35

	TAPTAP HRS	PWRUSED KWH/TON	TOTYIELD %	NETYIELD %	OPENCRBN %	FNALCRBN %	COKECHRG LBS	PLLTCHRG LBS
N OF CASES	35	35	35	35	35	35	35	35
MINIMUM	4.083	466.440	85.000	71.000	0.090	0.100	0.	0.
MAXIMUM	9.250	634.440	96.500	96.600	1.040	1.060	2300.000	0.
MEAN	6.093	540.882	91.180	87.397	0.336	0.350	788.571	0.
STANDARD DEV	1.204	37.959	2.712	4.290	0.257	0.203	545.447	0.

Variable names are as follows:

TAPTAP	Tap-to-tap heat time (in hours).
PWRUSED	Power used (in kilowatt-hours/ton)
TOTYIELD	Yield of steel as tapped as percentage of total metallic charge including scrap, ferroalloys, and pellets
NETYIELD	Yield of prime steel as poured (in percentage).
OPENCRBN	Opening carbon in bath (in percent).
FINAL CRBN	Final tap carbon in bath (in percent).
COKECHRG	Coke charged (in pounds).
PLLTCHRG	Pellets charged (in pounds).

Table 4
EAF Dust Analysis in Block I and Block II Experiments
(% by weight)

	Sample No., date (1985), and type[a]														
	1 06/12 C	2 06/13 C	3 06/14 C	4 06/14 G,S	5 06/14 G,S	6 06/17 C	7 06/17 G,S	8 06/18 C	9 06/19 C	10 07/02 G	11 07/02 G	12 08/26 C	13 08/27 C	14 08/28 C	15 08/29 C
Constituents	Block I											Block II			
Phosphorus	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.03	0.03	0.04	0.02
Sulfur	0.50	0.47	0.44	0.47	0.47	0.43	0.47	0.55	1.0	0.41	0.40	0.50	0.47	0.63	0.58
Cadmium	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02
Calcium oxide	15.3	15.5	15.5	14.4	13.9	13.4	13.8	14.3	17.5	21.1	12.0	19.0	15.1	18.1	16.1
Chromium (+3)	0.32	0.26	0.23	0.25	0.22	0.25	0.26	0.32	1.8	3.1	0.42	0.58	0.44	0.57	0.62
Chromium (+6)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.01	0.004	0.004	0.002	0.006	0.003	0.002
Copper	0.1	0.09	0.08	0.08	0.07	0.07	0.08	0.09	0.08	0.1	0.05	0.09	0.08	0.13	0.1
Iron	18.4	18.7	18.2	17.3	15.5	16.7	16.1	16.9	21.1	25.6	14.8	24.4	21.2	26.7	28.5
Lead	0.76	0.67	0.70	0.68	0.63	0.56	0.52	0.47	0.59	0.65	0.45	0.66	0.58	0.65	0.65
Magnesium	1.87	2.02	1.96	1.91	1.79	1.88	1.87	1.79	1.76	1.03	2.36	3.63	2.29	2.64	2.77
Manganese	3.0	3.3	3.3	3.0	3.0	3.0	3.1	3.2	2.6	2.0	3.0	5.0	3.5	4.5	4.4
Molybdenum	0.14	0.1	0.8	0.1	0.07	0.09	0.10	0.12	0.05	<0.01	0.09	0.14	0.16	0.37	0.33
Nickel	0.17	0.13	0.12	0.13	0.11	0.12	0.11	0.13	0.14	0.16	0.12	0.29	0.24	0.27	0.27
Potassium	0.8	0.8	0.9	0.9	1.0	0.8	0.9	1.0	0.7	0.3	1.0	1.0	1.0	1.2	1.1
Silica (SiO_2)	1.8	1.9	1.6	1.6	1.6	1.5	1.6	1.8	3.2	4.1	1.9	3.1	2.8	3.0	3.1
Sodium	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.4	0.6	0.5	0.5	0.7	0.7
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	24.4	23.0	27.9	26.9	25.0	26.6	26.1	20.1	24.6	12.0	32.7	9.0	12.4	12.3	14.7

[a]C = composite sample, G grab sample, S = pellet size change.

recycled to the furnace. Two furnaces operated 16 hr per day during this period. Slag and dust samples were collected to evaluate the fate of zinc. Table 4 presents the analytical results for dust/pellets, and Table 5 presents the results for slag analysis.

A long shutdown occurred at the plant prior to the Block II experiments. Because of uncertain business conditions, inventory was reduced by consuming all available scrap in the plant during the Block II tests without regard for a balanced scrap mix. The zinc content of this cleanup scrap was significantly lower than that of the scrap usually used. No high-zinc scrap was observed during the Block II testing; consequently, the zinc content of the recycled dust was lower than in Block I despite the recycling. An increase in the zinc content of the dust from 9% to approximately 15%, however, was observed during the continuous recycling period.

Several area samplers with AA millipore membrane filters were located in the shop to measure heavy metal concentrations in the shop atmosphere—two at 5 ft above the ground level and two above the furnace level and just below the crane runway. Table 6 presents the analytical results for these samples. Although zinc, lead and cadmium were all detected on the filters, the concentrations were very low. These results indicate that general loss of zinc and other heavy metals through fugitive concentrations is not a significant factor in the zinc balance during recycling operations.

During Block I testing, the zinc content of the dust was fairly constant, varying between 20 and 25% based on composite samples. On the other hand, two grab samples taken within 30 min of each other showed a marked variation in zinc content (12 and 32.7%). The zinc content of the slag was less than 0.01% in almost all samples.

Table 5
EAF Slag Analysis in Block I and Block II Experiments
(% by weight)

	Sample No., date (1985), heat No., and type of sample[a]													
	1 06/26 69568 FS	2 06/26 69569 FS	3 06/27 69571 FS	4 06/27 69570 IF	5 07/01 69575 IF	6 07/02 69576 IS	7 07/02 69577 IS	8 07/02 69578 IS	9 07/03 69579 IS	10 08/28 50028 IS	11 08/28 50028 IF	12 08/29 50030 IS	13 08/29 50031 IF	14 08/29 69616 IF
Constituents	Block I									Block II				
Al_2O_3	7.21	7.79	7.48	4.96	4.99	5.47	5.59	5.89	5.78	2.66	3.30	3.93	4.22	5.54
CaO	41.2	41.0	42.4	41.7	40.3	39.8	42.3	42.0	42.4	36.1	39.5	31.1	33.0	36.2
FeO	6.87	3.96	3.25	18.1	15.4	11.0	17.9	15.5	22.4	27.5	18.1	39.5	26.7	18.4
MgO	10.7	15.3	11.6	10.6	6.86	9.31	6.40	9.39	7.49	2.61	5.31	5.89	5.81	5.99
MnO	9.36	4.49	4.98	6.15	6.69	7.60	8.09	4.55	4.52	7.40	10.6	5.49	8.86	7.68
SiO_2	16.8	17.1	20.3	7.32	13.9	17.1	13.1	13.0	8.80	7.42	9.13	5.86	10.3	15.1
Cr	1.22	0.29	0.48	0.67	0.87	1.13	0.9	0.6	0.64	2.72	2.22	1.07	1.67	1.25
Cu	0.01	0.04	0.02	0.02	<0.01	<0.01	0.05	0.02	0.01	0.02	<0.01	0.02	0.02	0.01
Pb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06

[a]FS = final slag, IF = inside the furnace (in-site sample, IS = initial slag.

Table 6
Analysis of Contents of Area Samplers Located Inside the EAF Shop During Block II Experiments

Constituents	Sample Nos. (date)							
	1[a] (8/26/85)		2[b] (8/28/85)		3[c] (8/29/85)		4[d] (8/29/85)	
	µg (gr)[e]	µg/liter (gr/scf)[f]	µg (gr)	µg/liter (gr/scf)	µg (gr)	µg/liter (gr/scf)	µg (gr)	µg/liter (gr/scf)
Total particulates	$<2.0 \times 10^{1}$ ($<3.1 \times 10^{-4}$)	<0.75 ($<3.3 \times 10^{-5}$)	2.72×10^{3} (4.2×10^{-2})	3.49 (1.5×10^{-3})	1.57×10^{3} (2.4×10^{-2})	5.23 (2.3×10^{-3})	3.4×10^{2} (5.3×10^{-1})	0.8 (3.5×10^{-2})
Cadmium	<0.2 ($<3.1 \times 10^{-6}$)	<0.00075 ($<3.3 \times 10^{-7}$)	<0.2 ($<3.1 \times 10^{-6}$)	<0.0003 ($<1.14 \times 10^{-7}$)	<0.2 ($<3.1 \times 10^{-6}$)	<0.0007 ($<2.9 \times 10^{-7}$)	<0.2 ($<3.1 \times 10^{-6}$)	<0.0005 ($<2.1 \times 10^{-7}$)
Lead	<4.0 ($<6.2 \times 10^{-5}$)	<0.015 ($<6.6 \times 10^{-6}$)	10.0 (1.55×10^{-4})	0.013 (5.7×10^{-6})	<4.0 (6.2×10^{-5})	0.013 (5.8×10^{-6})	<4.0 ($<6.2 \times 10^{-5}$)	<0.009 ($<4.1 \times 10^{-6}$)
Zinc	7.7 (1.2×10^{-4})	0.028 (1.3×10^{-5})	281 (1.26×10^{-3})	0.36 (4.6×10^{-5})	281 (1.26×10^{-3})	0.93 (1.2×10^{-4})	60.7 (9.4×10^{-4})	0.14 (6.3×10^{-5})

[a]Sample 1—Total volume, 267 l; duration, 133 min; location, 5 ft. above ground
[b]Sample 2—Total volume, 770 l; duration, 390 min; location, above furnace and below crane girder
[c]Sample 3—Total volume, 300 l; duration, 150 min; location, above furnace and below crane girder.
[d]Sample 4—Total volume, 425 l; duration, 210 min; location, 5 ft above ground.
[e]Two types of units are indicated: micrograms (µg) and grains (gr).
[f]Two types of units are indicated: micrograms per liter (µg/liter) and grains per standard cubic foot (gr/scf).

Results of pellet charging on heat time are inconclusive. Heats with pellets on a cold furnace took longer, while heats with pellets during continuous operation were shorter. In neither case, however, are these differences statistically significant.

Power consumption for heats on a cold furnace was about 10% higher than during continuous operation where pellets were used or not. The use of pellets caused an increase in power use of about 4%; this was consistent for both cold furnace heats and continuous operation, but the test of statistical significance is conclusive only for continuous operation. This increase in power consumption is consistent with results reported by some other investigators.

Average total yield for the heats to which pellets were added did not differ significantly from the base line heats (no pellets added). It should be noted that several factors other than pellet addition affect yield. If all the iron contained in the pellets were recovered, an improvement in yield of 0.2 to 0.3% could be expected. Net yield is not a significant parameter in this analysis because it is affected by physical factors such as spillage, short ingots and off-product unrelated to metallurgical yield.

Green River produces quality steels in medium-carbon and low-alloy grades suitable for forgings in several industries, including the aircraft industry. The quality and internal cleanliness of steel are extremely important in meeting the stringent specifications for this use. To assess the effect of recycling on steel quality, the plant metallurgical department kept a special vigil and followed all the heats charged with pellets from the ingot stage through the dispatch of semifinished products (bars, rods, etc.) to various customers. Recycling had no deleterious effects on the steel quality. This assessment is based on 38 heats (with pellets) in different specifications.

Although not apparent in Tables 2 and 3, comparison of aim carbon and opening carbon data for heats with pellets and baseline data showed a higher percentage of heats using pellets were closer to aim carbon; 28% of the baseline heats opened with carbon higher than aim carbon compared with 44% of the heats with pellets. Because operators were concerned about carbon loss with pellets, they compensated for this by making carbon additions exceeding the theoretical requirements for the pellet recycling trials. Coke consumption during continuous operation was about 33% (260 lb) higher for heats with pellet charging although the difference does not meet the test of statistical significance (at the 5% level). A large portion of this additional carbon was recovered in the bath. Electrode consumption data were collected for the period when pellets were used in the Block I experiments and were compared with the electrode consumption of the previous month. Electrode consumption increased slightly during pellet recycling (by about 0.26 lb/net ton of steel produced).

In the Green River operations, pea size lime is blown into the furnace pneumatically near the top of the furnace, above the bath line. Lime is required to produce slag that assimilates the gangue materials charged in the furnace, thereby maintaining the required basicity. Although not presented in Tables 2 and 3, comparison of the baseline data with the heats charged with pellets showed a slight increase in the lime consumption when pellets are used. An average of 1.2 lb of extra lime was consumed per ton of steel produced.

Comparison of ferroalloy consumption data did not indicate any significant differences between heats with and without pellets after adjusting for differences in aim specifications.

During the tests, the Green River baghouse operated normally. Dust was discharged from it periodically; i.e., when sufficient dust had accumulated in the hoppers, it was conveyed to the day bin for pelletizing. No abnormal baghouse operation was noticed.

Observations did not reveal any noticeable change in dust or slag generation rates due to the addition of pellets.

In summary, the observations and the results of the experiments indicate that an acceptable quality of pellets can be made by pelletizing, and that recycling to the furnace can be conducted without any operational or air pollution problems. Recycling at the rate of dust generation had no deleterious effects on steel quality at Green River Steel.

ECONOMICS

Table 7 summarizes the design and operating parameters for three EAF units of different sizes. Table 8 presents the capital and annualized costs developed for each of these three units. These economic analyses are preliminary in nature and must be refined for each specific plant site. When compared to landfilling costs of $100/ton dust, the economic analysis indicates recycling to be attractive, especially for larger plants.

Table 7
Base Units for Economic Evaluation of Recycling

	Units		
	Small	Medium	Large
EAF plant size (tons steel/yr)	70,000	200,000	600,000
Dust quantity processed (tons/yr)	1,000	3,000	9,000
Recycle plant capacity (tons/h)	0.5	2.75	6.5
Recycle plant operating rate (tons/h)	0.5	1.50	4.5
Operating hours per year	2,000	2,000	2,000
Onsite operators/supervisors	1	1	2

Table 8
Capital and Annualized Costs for Selected EAF Recycling Units

	Costs per Operating Unit, $		
	Small	Medium	Large
Capital (Installed) Costs			
Fixed capital costs	70,000	130,000	200,000
Working capital (15% FC)	10,500	19,500	30,000
Total capital	80,500	149,500	230,000
Annualized Costs			
Manufacturing costs			
Raw material	0	0	0
O&M labor (includes onsite supervision & clerical) (2080 h/y/person @ 16/h burdened)	33,280	33,280	66,560
Utilities			
Electricity	2,000	6,000	18,000
Water	250	750	2,250
O&M supplies (10% of FCI)	7,000	13,000	20,000
Lab charges ($1/ton)	1,000	3,000	9,000
Total Manufacturing Costs	43,500	56,000	115,800
Fixed charges			
Equipment payments (5 yr loan @ 14%) includes working capital	22,500	41,700	64,220
Local taxes & insurance (3% of FCI)	2,100	3,900	6,000
Plant Overhead (15% of mfg. costs)	6,500	8,400	17,370
Home Office Management and Administration (25% of mfg. costs)	10,900	14,000	28,950
Other			
Credit for sale of high zinc material ($10/ton dust)	(10,000)	(30,000)	(90,000)
Freight	10,000	30,000	90,000
Total Annualized Cost	85,500	124,000	232,500
Unit Cost for Dust processed, $/ton	85.50	41.33	25.83

CONCLUSIONS

This research has proved that EAF dust can be pelletized with water only and recycled to the furnace. The following original objectives underlying PEI's philosophy for EAF dust management have largely been met:

- Use of a simple process design
- Use of existing, proven, low-cost equipment
- Use of EAF dust only, with no additives other than water
- Use of a process with no residual pollution streams
- Use of a process with a high turndown ratio and capable of processing widely varying dust compositions

Thus far, PEI's experimental research has included an evaluation of pelletizer performance parameters and the effects of recycling on electrical energy consumption, raw materials consumption and steel quality. Future research programs should focus on the longer-term verification of EAF operation with dust recycling and the fine-tuning of the process economics. In the research conducted, it was not possible to include sufficient heats to obtain the desired amount of process data to close the material balance. The objectives of longer-term testing are:

- To establish the material balance for continuous EAF dust recycling, with particular emphasis on the partition of zinc between various phases
- To determine the optimum rate and composition of the blowdown stream from recycling
- To finalize the economic model for the process to determine the net cost per ton of dust recycled

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Trends in Used Oil Composition and Management

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ABSTRACT

In 1983 Franklin Associates, Ltd. prepared a major technical report for the U.S. EPA's Office of Solid Waste. This report developed baseline data on the composition and management of used oil generated in the United States.

Traditionally, a significant fraction of the used lubricating oils generated in the United States have been environmentally mismanaged. Contaminated used oils with little or no processing commonly have been used for dust suppression or burned in boilers without pollution controls. As a result, the hazardous contaminants present in the oil have been dispersed into the environment, and health impacts may have occurred.

The U.S. EPA has attempted to minimize the health risks associated with improper used oil management by promulgating regulations under the authority of RCRA and the Used Oil Recycling Act. While the U.S. EPA has been developing and proposing regulations for used oil, the quality of oil has been improving due to the decrease in the lead content of gasoline. This paper examines the changes occurring and expected to occur in used oil composition and management practices resulting from U.S. EPA regulations and changes in lead levels in gasoline.

INTRODUCTION

Over the past decade, there has been widespread and growing interest in used oil issues. Used oil management practices of the late 1960s and early 1970s were criticized as being wasteful of a valuable resource and harmful to the environment. In general, the concerned parties, which included industry, government agencies and environmentalists, contended that used oils could be handled wisely or unwisely. Wise handling included reuse practices such as re-refining and carefully controlled burning with energy recovery. Unwise handling included such wasteful practices as dumping and even land disposal. Oiling roads with used oil to suppress dust was considered more desirable than dumping or land disposal, but less desirable than re-refining or burning as a fuel.

Studies completed in the early 1970s showed that more than 50% of the generated used oil in the United States was being managed in what were generally considered to be undesirable ways. Less than 10% was refined into new lubricating oil. A larger fraction was burned as fuel, but often without the necessary monitoring to assure that the public was not being exposed to any potentially hazardous substances. Over the next decade, additional studies indicated that most unwise management practices continued to occur at significant levels.

The U.S. EPA has attempted to minimize the health risks associated with improper used oil management by promulgating regulations under the authority of RCRA and the Used Oil Recycling Act. Final rules governing burning were issued on Nov. 29, 1985. On the same day, the U.S. EPA proposed an overall regulatory program that covers all aspects of used oil management. The regulations provide generators, collectors, transporters, processors and end-users with requirements related to storage, testing with a specification, recordkeeping and other administrative requirements.

While the U.S. EPA was developing and proposing legislation, used oil quality was improving; it will continue to improve in 1986. This change in waste oil quality is due not only to a decrease in the lead content of gasoline, but also to behavioral changes in anticipation of the new regulations. Since lead is one of the major contaminants in used oil and since most lead comes from gasoline, this change will influence used oil quality significantly in the future.

This paper presents data on baseline used oil contamination levels and used oil flows as developed for a 1983 Franklin Associates, Ltd. (FAL) study for the U.S. EPA Office of Solid Waste.[1] The 1985 regulations are then briefly summarized followed by a discussion of the changes in oil composition and flows that are expected to result from the new regulations.

BASELINE CONDITIONS

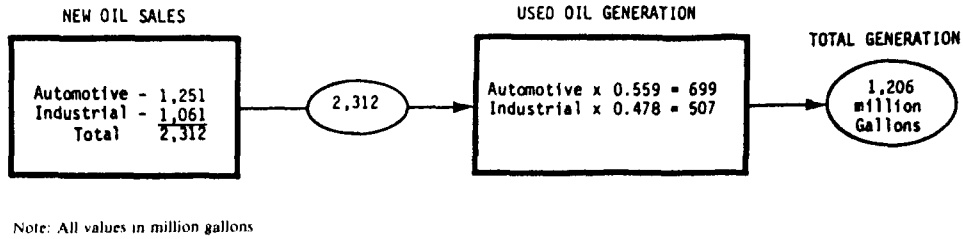
Two data bases were developed as part of the 1983 FAL study for the U.S. EPA: one data base characterized used oil flows through the management system and the other data base characterized contaminant levels in used oil. The flow characterization was accomplished by a literature search, hundreds of telephone interviews and 25 site visits to facilities involved in commercial used oil management.

Much of the information regarding the flow of used oil is undocumented because of the unstructured nature of the used oil management system. Federal regulations prior to 1985 did not require participants in the used oil industry to report their collection procedures or reuse practices.

The used oil composition characterization is based on a series of fairly simple statistical parameters that characterize over 1,000 used oil samples. The concentrations of 19 potentially hazardous constituents were determined, including several heavy metals, chlorinated solvents, aromatic solvents, polynuclear aromatics, PCBs and total chlorine.

Used Oil Generation

In 1983 approximately 1.2 billion gallons of used oil were generated in the United States. The 1.2 billion gallons were generated from the sale of over 2.3 billion gallons of new oil. A summary of the automotive and industrial used oil sales and used oil generation is shown in Figure 1. Approximately 54% of automotive oils enter the used oil market compared to about 48%



Note: All values in million gallons

Figure 1
Used Oil Generation in the United States in 1983

of industrial oils. Generation rates for various used oils take into account losses due to leakage, spillage, combustion, disposal with equipment and incorporation into finished products such as paint, putties, etc.

Used Oil Management System

The used oil management system (UOMS) is comprised of companies that collect, process and sell used oil into several markets. There are three basic types of companies involved in the industry: (1) independent collectors, who only collect and sell the oil; (2) minor and major processors, who collect, process and sell an improved product oil; and (3) re-refiners, who collect, process and sell a refined lube base stock. Many variations exist for each basic type of company.

Figure 2 shows the flow of used oil from the point of generation through the management system to reuse or disposal for 1983. Also included is a description of the reuse practices for generated oil that does not flow through the system. This oil is reused or disposed of directly by the generators. Only 55% (669.1 million gallons) of all generated used oil entered the used oil management system. The remainder was reused, dumped or disposed of by the generators (e.g., those who change their own automobile oil).

The total number of companies involved in the used oil management system in 1983 (excluding 500 to 1,000 independent collectors) was 253. There were only 13 companies involved in re-refining used oil; however, approximately 15% of the oil that entered the management system was re-refined. There were approximately 115 minor processors and 125 major processors.

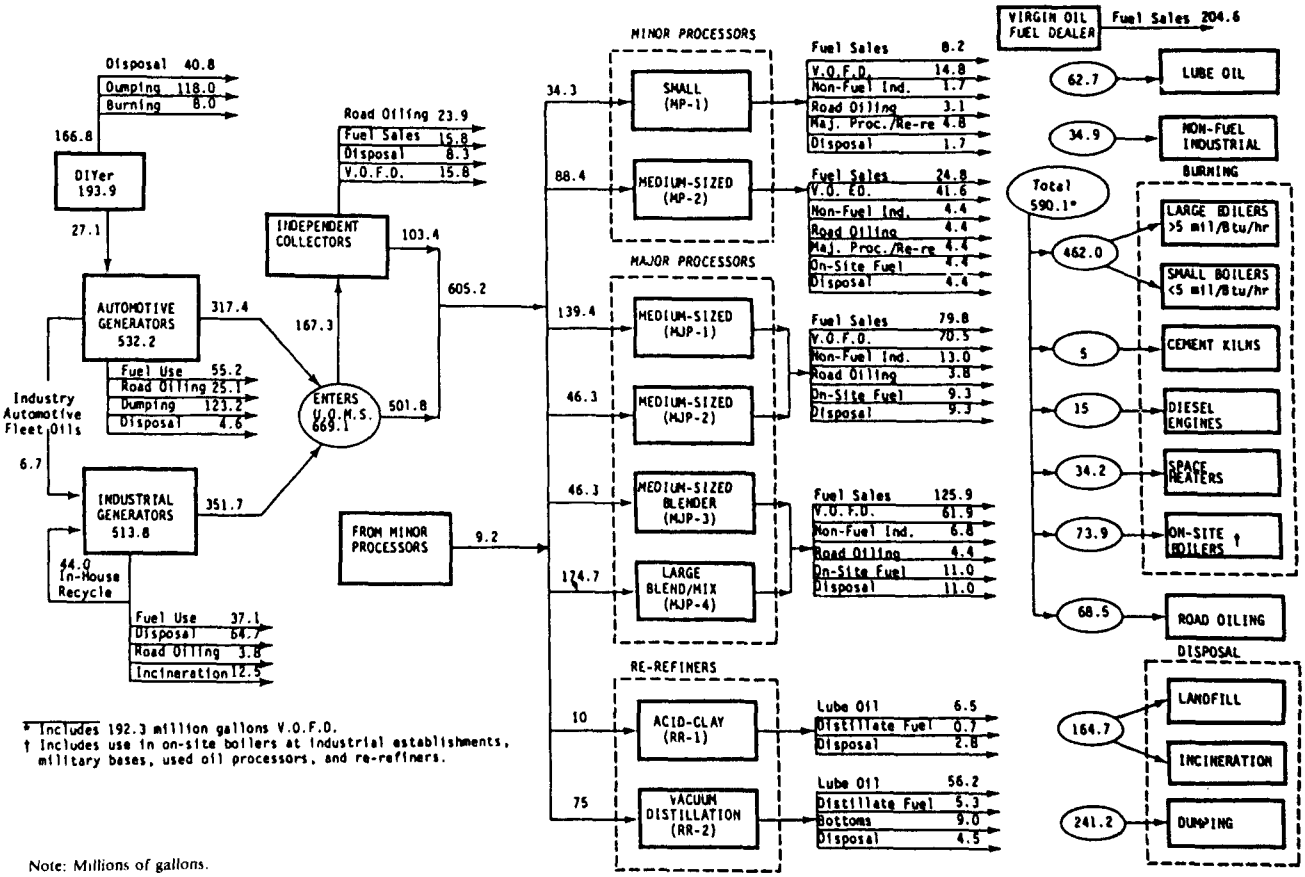


Figure 2
Used Oil Flow Description in the United States in 1983

The fuel oil market clearly dominated with respect to end-use applications. About 590 million gallons of used oil (nearly 50% of all used oil entering the used oil management system) was burned as fuel in 1983. Approximately one-half of the burned oil was blended with virgin fuel oil before being burned. The industrial market was and is the largest for burning; however, significant quantities also were burned in commercial, residential and institutional boilers.

Comparable quantities of used oil were re-refined and applied to roads for dust control in 1983. Approximately 83 million gallons were received by re-refiners and nearly 74 million gallons were used for roal oiling. Approximately 70% of the oil received by re-refiners became new lube stock, and the remainder was recovered as lighter distillates or was lost during processing.

Approximately 35 million gallons of used oil were marketed for industrial purposes other than fuel. The major application in this category included flotation oils, asphalt extenders and form oils.

In 1983 over 400 million gallons of used oil, out of the total of 1.2 billion gallons generated, were disposed of by landfilling, incineration and dumping. Nearly 50% more oil was dumped than was disposed by landfilling and incineration combined. Most of the dumped oil is automotive oil generated by do-it-yourselfers and large off-road equipment operators such as farmers, moving companies, construction companies and the military.

Used Oil Composition

Analytical data that quantify waste oil contamination in 1,071 samples were obtained from 50 sources for the baseline study. The majority of the results were obtained from state and federal government agencies in unpublished form. Because of the variety of data sources, there is considerable variation in: (1) the constituents that were measured; (2) the precision of the tests; and (3) the detection limits of the equipment. These differences in technique complicate any procedure used to combine the data into summarized statistics.

Table 1 summarizes used oil contamination with respect to 19 specific constituents, 17 of which are included on the U.S. EPA's published list of hazardous constituents. The results are summarized according to percent detection (mean, median, 75th and 90th percentile concentrations), and range of measured concentrations.

The data in Table 1 indicate high levels of contamination for many constituents including lead, chromium, cadmium and several chlorinated solvents. The mean concentrations are badly distorted by a few very high values. The mean concentration for each contaminant is much higher than the median. PCBs were detected in approximately 18% of the samples analyzed.

The data in Table 1 have been categorized according to source and end use with the following generalizations:

- Automotive used oils tend to have higher concentrations of potentially hazardous heavy metals; industrial oils tend to have higher levels of chlorinated solvents and PCBs. No significant differences were noted in the concentration of aromatic solvents or polynuclear aromatics.
- Used oils from gasoline engines have much higher lead concentrations than those from diesel engines due to the presence of leads in some gasoline additives.
- Metalworking industrial oils have higher levels of heavy metals and chlorinated solvents than other industrial oils including hydraulic, compressor, turbine, electrical and others.
- Approximately 30% of the oil samples had a measured flash point below 140 °F,* which is a criterion for classifying a waste as hazardous. Since the flash point for virgin fuel oils is above 350 °F, contamination with low flash points such as gasoline or chlorinated and organic solvents is indicated.
- Used oils do not appear to differ significantly in contamination levels according to end-use markets. Similar levels of contamination were measured in used oils that were burned, road oiled and re-refined.

* The new used oil rules are somewhat more lenient. Used oil is subject to the full hazardous waste rules due to the ignitability characteristic only if the flash point is less than 100 °F (see Table 2).

Table 1
Concentration of Potentially Hazardous Constituents in Waste Oil[1]

	Total Samples Analyzed	Samples with Detected Contaminants		Mean Concentration 2/ (ppm)	Median Concentration 3/ (ppm)	Concentration at 75th Percentile 3/ (ppm)	Concentration at 90th Percentile 3/ (ppm)	Concentration Range (ppm)	
		Number	Percent					Low	High
Metals									
Arsenic	537	135	25	17.26	5	5	18	<0.01	100
Barium	752	675	89	131.92	48	120	251	0	3,906
Cadmium	744	271	36	3.11	3	8	10	0	57
Chromium	756	592	78	27.97	6.5	12	35	0	690
Lead 4/	835	760	91	664.5	240	740	1,200	0	21,700
Zinc	810	799	98	580.28	480	872	1,130	<0.5	8,610
Chlorinated Solvents									
Dichlorodifluoromethane	87	51	58	373.27	20	160	640	<1	2,200
Trichlorotrifluoroethane	28	17	60	69,935.88	160	1,300	100,000	<20	550,000
1,1,1-Trichloroethane	616	388	62	2,800.41	200	1,300	3,500	<1	110,000
Trichloroethylene	608	259	42	1,387.63	100	200	800	<1	40,000
Tetrachloroethylene	599	352	58	1,420.89	106	600	1,600	<1	32,000
Total Chlorine	590	568	96	4,995	1,600	4,000	9,500	40	86,700
Other Organics									
Benzene	236	118	50	961.2	20	110	300	<1	55,000
Toluene	242	198	81	2,200.48	380	1,400	4,500	<1	55,000
Xylenes	235	194	82	3,385.54	550	1,400	3,200	<1	139,000
Benzo(a)anthracene	27	20	74	71.3	12	30	40	<5	660
Benzo(a)pyrene	65	38	58	24.55	10	12	16	<1	405
Naphthalene	25	25	100	475.2	330	560	800	110	1,400
PCBs	753	142	18	108.51	5	15	50	0	3,800

1. Results determined for the analyses of 1,071 used oil samples.
2. Calculated for detected concentrations only.
3. For purposes of determining median and percentile concentrations, undetected levels were assumed to be equal to the detection limit.
4. Used samples collected after 1979 only.

Source: Reference 1.

U.S. EPA REGULATIONS FOR USED OIL

In 1985 the U.S. EPA issued three proposals and one final rule for the regulation of used oil. On Jan. 11, 1985, U.S. EPA proposed under Subtitle C of the RCRA regulations[2] that prohibit the burning of non-industrial boilers of used oil that does not meet specification levels for certain hazardous contaminants and flash point. Final rules were issued on Nov. 29, 1985.[3] The regulations also provide administrative controls to monitor marketing and burning activities. These controls include recordkeeping requirements and U.S. EPA notification of used oil activities, including an invoice system for shipments. The specifications for used oil that may be burned in non-industrial boilers without regulation are listed in Table 2.

Table 2
Used Oil Fuel Specification for Oil that May Be Burned in Non-Industrial Boilers

Constituent/Property	Allowable Level for Burning without Regulation
Arsenic	5 ppm maximum
Cadmium	2 ppm maximum
Chromium	10 ppm maximum
Lead	100 ppm maximum
Total Halogens	4,000 ppm maximum
Flash Point	100 °F minimum

Source: Reference 3, p 49181

Also in the Nov. 19, 1985 *Federal Register*,[4] the U.S. EPA issued a proposed rule to establish standards for used oil that is recycled, or "recycled oil." These standards apply to generators and transporters of recycled oil and owners and operators of used oil recycling facilities. The standards would include tracking requirements when used oil is shipped off-site for recycling and facility management requirements when used oil is stored prior to recycling. Recycled oil used as fuel would be subject to certain regulations except that fuel meeting the specifications listed in Table 2 for toxic contaminants and flash points would be exempt from regulations. Uses of recycled oil that constitute disposal would be regulated as land disposal, and road oiling would be prohibited.

The third proposed rule, also issued in the Nov. 29, 1985 *Federal Register*,[5] would list used oil as a hazardous waste. The effect of the listing, if promulgated, would be to control the treatment and disposal of used oil (as well as its transportation, accumulation or storage prior to treatment or disposal) by subjecting it to full hazardous regulation under Subtitle C of RCRA. At the same time, most used oil that is recycled would be subject to the special management standards of the previously mentioned proposed standards for recycled oil.

In the following sections, expected trends in used oil composition and management practices resulting from the proposed and final rules are summarized.

CHANGES IN USED OIL COMPOSITION

The burning regulations include specifications for metals, total halogens and flash point for oil burned as fuel. Because of these regulations, the concentrations of hazardous materials in used oil will be reduced, thus reducing the risk to human health and the environment.

Most of the contaminants in used oil are the result of normal oil usage. However, significant quantities of some contaminants sometimes are introduced as a result of carelessness or intentional mixing.

Chlorinated solvents make up a major group of contaminants in used oil. They are not a normal component of automotive oil but often are introduced by careless practices. For example, automobile mechanics may pour solvents into tanks used primarily for storing used automobile oils.

Measuring total chlorine is one method for assessing the presence of chlorinated solvents. The 1983 baseline data indicate typical chlorine concentrations range from 1,000 to 5,000 ppm. However, the total chlorine content of some samples that were identified as oil were as high as 40%. It is probable that these materials were not oils at all, but rather solvents. It is expected that many industries, when faced with higher disposal costs because of mixing solvents with used oils, will modify these practices to keep oils and solvents segregated to the best of their ability and therefore continue to manage the oil under the special used oil rules rather than the full hazardous waste rules.

Most metals in used oil are the result of the oil's original use. Metals concentrations in oil can be reduced only by blending. Even with blending at a 9:1 ratio, many oils will not meet specifications.

One of the major heavy metal contaminants in used oil is lead. In the baseline study, the lead concentration in used oil ranged from 0 to 21,700 ppm. The high levels were most common in crankcase oils in samples taken in the early 1970s or from oils taken from leaded gas-burning engines. Samples taken in the 1980s generally had levels between 100 and 1,200 ppm. As stated earlier, the major source of lead in automobile oil is the lead in gasoline. As the lead in gasoline continues to decrease (a tenfold reduction from 1983 is expected in early 1986), the lead level in used oil is expected to decrease almost proportionately.

CHANGES IN USED OIL FLOW THROUGH THE WASTE MANAGEMENT SYSTEM

Several changes are expected in used oil flows through the management system. The U.S. EPA has prepared a Regulatory Impact Analysis (RIA) of its proposed standards for the management of used oil.[6] The estimated total national annualized cost of regulation is $168 million. The U.S. EPA predictions of how these costs (and regulatory constraints) affect supply and demand for used oil in different markets are shown in Table 3. A total increase in recycling of 100 million gallons is expected. The establishment of fuel standards is expected to shift recycled oil to controlled burners. Although the U.S. EPA study does not predict any burning in hazardous waste incinerators, information obtained from industrial sources indicates that significant quantities also may be managed in this way, particularly oils recovered from treatment facilities and various types of oil/water separators

The use of used oil as a dust suppressant is banned by the proposed rules. This displaced oil (currently 69 million gallons per year) is expected to be used as both re-refining feedstocks and fuel. Re-refining, which generally is considered a wise reuse practice by most segments of society, is expected to increase from 85 to 135 million gallons per year. There is, however, some question about whether re-refiners can economically survive in a tight lube oil market and with higher operating costs than the fuel oil processors who compete for the same oil.

The RIA has estimated impacts on used oil generation, collection and processor facilities. For industrial generators, used oil management costs are usually very minor when compared to the industry's production processes. It is expected that used oil still will be sold to collectors and processors but for a lower price because of the collector and processor costs of regulatory compliance. The generation from industrial generators is not expected to change significantly as a result of the regulations.

The impacts of regulations on non-industrial (automotive) generators are expected to be greater. The U.S. EPA has assumed that since automotive oil changes will cost more, more homeowners will change their own oil. This impact could result in more oil being dumped. The U.S. EPA estimates that full implementation of the rules will increase these homeowner oil changes by 12 million gallons per year.

Table 3
Effect of Regulation on Market Flows of Used Oil
(Million gallons per year)

	Baseline	Regulatory Impact
Burning		
Industrial Boilers	249	185
Asphalt and Cement Kilns	94	309
Non-industrial Boilers	121	117
Diesel Engines	15	15
Space Heaters	34	34
On-site Boilers	73	48
Total Burned	586	708
Re-refining		
Lube Oil	59	101
(total re-refined)	(85)	(135)
Non-fuel Industrial	36	40
Road Oiling	69	0
Disposal	405	305
Total	1,155	1,155

Source: Reference 4, p. 49247.

Collectors (particularly small collectors) are expected to experience the most significant changes in the industry structure resulting from the U.S. EPA regulations. It is estimated that approximately 473 small and medium-sized collectors will find it uneconomical to continue operating as small independent businesses. Although these 473 collectors represent approximately 50% of the used oil recycling industry, they currently handle only approximately 10% of the volume of oil entering the recycling system. Initially, some oil may not be collected as facilities adjust to the changes imposed by the regulations. In the long run oil will be collected, but the nature of the collection function is likely to be very different after regulation.

Some of the small collectors (an estimated 155) are expected to grow or become part of larger businesses and thus be able to absorb the costs of the U.S. EPA regulations.

The U.S. EPA has optimistically estimated that the flow of used oil to re-refiners will grow by 59% as a result of the new regulations. This means the equivalent of six new facilities will be opened (there are now 13).

Minor and major processors are not likely to change drastically as a result of the used oil regulations, although it is estimated that 12 out of the current 115 minor processors and two of the current 25 major processors may be involved in closures.

CONCLUSIONS

The expected trends in used oil composition and management following the promulgation of the 1985 proposed regulations are summarized as follows:

- Reduction of lead in automotive oils as a result of the removal of lead from gasoline
- Reduction of chlorinated solvents in waste oil because of improved handling practices
- Reduction in the quantity of used oil burned in industrial and non-industrial boilers
- Increase of burning in asphalt plants and cement kilns
- Elimination of road oiling with used oil
- Large potential increase in re-refining of used oil
- Increase in total used oil burned because of constraints on placing liquids in secure landfills
- Decrease in total disposal of used oil, but with probable increase in dumping by do-it-yourself automobile oil changers

The overall used oil regulations and allowable lead level in gasolines will result in a significantly better used oil management system from an environmental perspective. Burning will be more closely controlled, and the oils burned will be of much higher quality.

In the past, generators were very careless and often purposely mixed hazardous wastes into oil. The new rules should modify this behavior substantially, resulting in more oils that are contaminated only through normal use. With the planned lead reduction, these levels of contamination are quite low compared to earlier levels of contamination resulting from purposeful mixing.

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Used Solvent Elimination Program

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ABSTRACT

This paper will discuss the manner in which the Naval Energy and Environmental Support Activity (NEESA) is supporting the Navy in the implementation of the Used Solvent Elimination (USE) Program.

The Hazardous and Solid Waste Amendments of 1984 mandate that industrial dischargers minimize hazardous waste generation at their facility. These amendments to RCRA provided an impetus for launching the Department of Defense (DoD) USE Program. The purpose of this program is to reduce the present and future risks and cost associated with the disposal of used organic solvents by eliminating disposal as far as possible. This program demonstrates DoD's conscientious efforts to conserve energy and protect the environment.

INTRODUCTION

The Navy generates a large amount of used oil and solvents (UO&S) in accomplishing its mission. As an occupant of prime coastal properties, the Navy is in a very precarious position of maintaining a delicate balance between fleet readiness and preservation of environmentally sensitive areas. In support of the Department of Defense's (DoD) Solvent Elimination System (USE), the Navy set a goal to eliminate as far as possible the disposal of used organic solvents. Means to achieve the goal include, but are not limited to:

- Process changes
- Material substitution
- Recycling/reclamation

The initial thrust of the Navy's USE Program is the recycling/reclamation of solvents. Process changes and material substitution will be investigated further under the Navy's Hazardous Waste Minimization Program. Recycle/reuse of these by-products can reduce fuel consumption, save energy and provide monetary savings to the Navy. Naval installations classified as major generators of solvents (shipyards, ship repair facilities, air rework facilities, etc.) have been identified and instructed to implement a USE Program no later than Oct. 1, 1986.

All other activities that generate over 400 gal of used solvents per year must implement a USE Program by Oct. 1, 1987. Activities can receive technical assistance from their Engineering Field Division (EFD) and Naval Energy and Environmental Support Agency (NEESA) as they start their USE Program. This assistance includes feasibility studies, equipment and training.

Studies were initiated at six large industrial naval bases in Fiscal Year (FY) 1985. In FY86, USE studies are scheduled to be started at approximately 50 naval installations.

NEESA studies include used oils since the U.S. EPA soon may classify used oils as hazardous wastes and used oils often are mixed with used solvents.

The study focuses on developing a recycling program that is environmentally sound, cost-effective, simple to implement, requires little training, has low labor requirements and uses solvent distillation equipment that is commercially available.

PLANNING

Prior to initiating the UO&S study at an activity, an ad hoc committee is organized to ensure maximum participation of personnel who will be directly affected by this program. The committee members will provide input on which recycling alternatives they prefer for implementation at their shops. In addition, the committee will be involved in the review of the interim reports and decision-making process during the course of the study.

UO&S STUDY

The UO&S recycling study consists of three steps:

- UO&S Inventory
- Evaluation of Alternatives
- UO&S Recycling Program Development

Step 1—UO&S Inventory

A site visit is conducted to obtain the following information as a minimum:

- Annual generation rates of UO&S in gal/year
- Location (building number, ship type and hull number, etc.)
- Common name, chemical compound name and MILSPEC of product
- Usage information (brief description of how UO&S are generated)
- Probable contaminants and the corresponding chemical and physical properties
- Current disposal procedures
- Anticipated variations in above findings
- Purchasing and Disposal Records
- All UO&S in accordance with U.S. EPA, State and local regulations and requirements

Previous studies related to UO&S are reviewed and the relevance of their findings to this effort indicated.

In determining annual generation rates, maximum and minimum values as well as average values are obtained. Where average values are not available, as may be the case for solvent disposal, estimates based on process knowledge and characteristic losses (i.e., solvent evaporative losses) are estimated.

The information obtained is tabulated and reviewed by the ad hoc committee for accuracy.

It is preferable to conduct the inventory by visiting the shops and interviewing shop personnel. This process takes only a few minutes of shop personnel time and gives the investigator a first-

hand knowledge of the operations. Questionnaires should not be sent to shop personnel. More than likely, they will not be able to provide all the information needed. Shop personnel should be notified at least 1 month in advance of the site visit.

Step 2—Evaluation of Alternatives

The key to a successful recycling program is to keep it simple and to maintain the degree of segregation required.

The most practical UO&S recycling program options are:

- On-site/Off-site reclamation of solvents
- Closed loop recycling of high value hydraulics and lubricants with manufacturers
- Burning of appropriately segregated UO&S in Navy boilers
- Sale of UO&S through Defense Reutilization and Marketing Office (DRMO)

On-Site Recycling

On-site recycling of used solvents located as close to the source of generation as possible usually will yield the most cost-effective results. Accordingly, on-site recycling is emphasized as the primary USE program option. On-site recycling of used solvents involves use of distillation equipment (stills). There are many types of stills commercially available in sizes ranging from 5 gal to over 200 gal. Stills are available which can be run on a batch or automatic mode. In addition, some are explosion-proof and have optional features for easy operation and maintenance.

On-site recycling currently is being practiced at the Norfolk Naval Shipyard Paint Shop utilizing a small still for recycling used paint thinners with impressive results. A savings of approximately $17,000/year is realized due to reduced consumption of virgin paint thinners and less volume of paint sludge for disposal. Presently, 10 stills are being ordered for four naval installations and the Navy expects to procure more than 15 stills in FY87.

Off-Site Recycling

Where on-site recycling may not be cost-effective or may be difficult to implement, off-site recycling by commercial contractors offers a viable solution for recycling UO&S. As in the case of on-site recycling, proper segregation of used solvents must be maintained. Costs for recycling by commercial contractors vary as a function of virgin material costs, volumes, handling and transportation costs and ease of recycling. Overall savings for naval installations of about 20-30% can be achieved using reclaimed solvents instead of virgin material for parts cleaning.

There are some companies which provide equipment and solvents for parts cleaning under a lease agreement. When the solvent gets too dirty, it is replaced by the supplier. Because the solvent essentially is leased out to the customer, this type of operation becomes very attractive for smaller Navy facilities because the supplier assumes all responsibility for the solvent, including ultimate disposal. Presently, the Construction Equipment Department at Naval Construction Battalion Center (CBC) Port Hueneme is utilizing off-site recycling for Dry Cleaning Solvent. Shop personnel are very satisfied with the operations.

Closed Loop Recycling

Closed loop recycling of high value hydraulics and lubricants with manufacturers is another recycling alternative worth investigating. This option may be employed when large volumes of contaminated high value hydraulics and lubricants are being generated by an activity located near major industrial centers where the manufacturers' processing facilities are available for reclamation. Under this option, the manufacturer contracts with the activity to perform either of the following tasks:

- Reclaim the used petroleum product and return it directly to the activity. A per gallon fee is charged which generally depends on the handling, transportation and processing costs.
- Accept the contaminated petroleum products and give the activity credits on its purchase of virgin materials. This option is not likely to be cost-effective for lubricants which have complex and diverse additive packages and which would require costly requalification testing.

Burning

Burning of appropriately segregated UO&S in Navy boilers has been practiced at some Naval installations. CBC Port Hueneme has burned contaminated oil at 5% blend with fuel oil #5 at the Thompson Boiler Plant without any boiler modifications.

Among the waste solvents being generated at Navy shops, only PD-680 Type II is recommended for blending with fuel oils. Halogenated solvents must be kept segregated and must not be mixed with used oils intended for use as boiler fuel. Halogenated solvents combine with water to form a corrosive mixture that would attack the boiler tubes and result in untimely breakdowns. Likewise, to avoid explosion, high flash solvents (having a flash point greater than 140° F) must not be mixed with low flash solvents.

Sale

Sale through DRMO is the least favorable option because, before this sale can be completed, it may go through a reuse, transfer, donation and sale cycle which makes the UO&S available to any federal, state or local government agency upon request and at no economic benefit to the generating activity. Furthermore, approval by knowledgeable personnel from a higher command is required before this option could be implemented.

Recently, the DoD added an impetus to recycling used solvents. The DoD directed naval activities to implement a directive that immediately prohibits landfill disposal of certain used solvents. This ban made recycling of used solvents even more desirable since the amount of certain used solvents to be ultimately disposed of (by incineration) after recycling will be reduced by 70-80%, thereby drastically reducing the disposal cost.

The ad hoc committee is consulted to assist in identifying which of the four alternatives provides a combination of practicable UO&S recycling programs that is in full compliance with applicable environmental regulations. For each recycling alternative, the following information is provided:

- Present worth cost
- Expected annual cost
- Savings
- Payback period

Cost includes one-time and recurring costs associated with collection, transportation, segregation, recycling and disposal of non-recyclable UO&S. An interim Step 2 report incorporating the above information is presented to the ad hoc committee for review and concurrence.

Step 3—UO&S Recycling Program Development

Once the ad hoc committee decides on the preferred recycling alternatives for implementation, a recycling program is developed. This program contains instructions, detailed operational procedures and identification of key personnel to implement the program. The UO&S recycling program consists of two parts.

Part I—Recycling

The Part I program includes:

- Identification of the UO&S sources with annual volumes by oil type or group.

- Identification of the selected recycling alternative for each group/source and the corresponding manpower requirements.
- Schedule for implementing the recycling program and delineation of respective command responsibilities.
- Identification of interim practices/improved management procedures that can be implemented immediately until the recommended recycling program can be fully implemented and required facilities can be constructed.
- Identification of shop practices which will result in the reduction of UO&S generation.

Part II—Recycling

Part II of the recycling program delineates specific procedures and provides design parameters and specifications for necessary facilities/equipment for the selected recycling alternative. In addition, a description of the selected alternative for each group/source is presented. This description includes, but it not limited to:

- A description of the source, recycling group and corresponding disposal program
- A description of the responsibilities and identification of personnel required to implement the selected recycling program; a description of the training program that will be required of the personnel who will implement the selected recycling program
- Procedures for segregating UO&S in accordance with respective recycling alternative
- Procedures for establishing collection points, frequency of collections and transfer centers where required
- Development of design parameters for facilities and/or equipment specifications for collection/transfer and recycling and its respective location
- Development of design criteria for special equipment required for blending, grouping or mixing chemically compatible UO&S. Establishment of procedures for blending, handling and disposal of UO&S in accordance with the HSWA requirements.
- Identification of existing collection, transfer, treatment, disposal/reuse procedures that are implementable within the framework of the proposed program.
- Identification of disposal procedures for UO&S sources that are not suitable for recycling
- Development of procedures or operational improvements and providing design parameters and specifications for required support facilities or equipment for sources where reduction of UO&S generation is viable

The completed UO&S Recycling Management Program is reviewed and approved by the ad hoc committee. Once the program is finalized, it is included in the base hazardous waste management plan. Instructions for implementing this program are outlined in the base instruction.

CONCLUSIONS

NEESA UO&S studies showed that:

- Maintaining the degree of segregation required in UO&S is very important to ensure a successful recycling program.
- On-site recycling using small capacity stills at the source of generation is the most cost-effective and simple way to recycle used solvents.
- For used oil, blending with virgin fuel oil and burning in the boiler is practical.
- The estimated annual savings from recycling of UO&S at Navy and Marine Corps bases is $30,000-$200,000 depending upon the type of industrial operations.
- Recycling of UO&S has proven to be an effective program for conserving valuable resources and preventing environmental degradation without sacrificing the Navy's mission.

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Waste Reduction Audit Procedure— A Methodology for Identification, Assessment and Screening of Waste Minimization Options

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ABSTRACT

This paper describes a waste reduction audit procedure, a management tool designed to generate a comprehensive set of waste minimization options for a specific process and rank the options to evolve those deserving either immediate implementation or an in-depth evaluation. The procedure relies on a programmed systematic approach and is described in detail along with the actual case example.

Additionally, waste minimization definitions are provided together with: a discussion on why waste occurs, a characterization of factors inhibiting waste minimization activities and a checklist to help identify waste reducing measures.

INTRODUCTION

The Waste Reduction Audit Procedure (WRAP) described in this paper is a management tool intended to help achieve the following objectives:

- To generate a comprehensive list of waste minimization measures or options applicable to a specific industrial process
- To rank all identified waste reduction options and use these rankings to allow management to focus on options deserving further in-depth consideration

The ultimate outcome of a WRAP is a report to management that contains concrete recommendations concerning which options to pursue and/or implement.

BACKGROUND

In 1981, it was estimated that nearly 80% of all the hazardous waste generated in the United States ended up in landfills, pits or ponds.[1] Landfilling has been the most popular form of disposal chiefly because of its low cost and simplicity. However, this situation has been changing since the Federal government adapted The Hazardous and Solid Waste Amendments of 1984 to RCRA.

The major goal of the 1984 RCRA Amendments is to minimize both the generation of hazardous waste and the practice of land disposal. Achievement of this goal currently is being promoted by at least two factors:

- Increased land disposal costs, which are the result of new regulatory requirements for mandatory groundwater monitoring, leachate collection and treatment, installation of double liners and solidification of liquid wastes
- Waste minimization certification requirements demanding that generators of hazardous wastes certify that the volume or quantity and toxicity of the hazardous wastes they generate has been reduced to the degree economically practicable

Land disposal costs have been increasing significantly and will continue to do so. According to estimates over the last year, the cost of landfilling drummed waste has increased more than 50%, bulk solids 60 to 70% and bulk liquids 100%. The cost impacts of waste minimization certification requirements cannot be evaluated easily since the requirements are recent (Sept. 1, 1985). However, hazardous waste minimization already has been recognized by many companies as a desirable goal, and there is strong evidence indicating considerable interest, activity and progress in this area.[2]

WORKING DEFINITIONS

What is "waste minimization"? At the time of this writing, the U.S. EPA had not issued a formal definition. In lieu of a formal definition, the following working definitions are used:

- Waste minimization—any source reduction, recycling or treatment activity that reduces the volume or toxicity (through means other than dilution) of any hazardous waste that is land disposed;
- Treatment (as part of waste minimization)—any activity or series of activities that results in reduction of the volume and/or toxicity of the hazardous waste without attendant generation of a valuable material that is subsequently employed in the manufacture of a commercial product (example—an incinerator for disposal of spent chlorinated solvent with scrubbing and neutralization of hydrogen chloride from the flue gas);
- Recycling (as part of waste minimization)—any activity that reduces the volume and/or toxicity of the hazardous waste with attendant generation of a valuable material subsequently employed in the manufacture of commercial product (example—distillation of spent cleaning solvent with subsequent reuse of the recovered clean solvent;
- Source reduction—any activity that reduces or eliminates the generation of a hazardous waste within the industrial process (example—replacement of chlorinated solvent by a biodegradable, water-based cleaning detergent solution).

Of the three components of waste minimization, recycling and source reduction can be subdivided further (Fig. 1). It is useful to distinguish between reclamation and use/reuse as two separate recycling activities.

Source reduction, the most prominent component of waste minimization, consists of product substitution and source control. Product substitution means the replacement of an original product and use of another product suitable for the same end use, or the alteration of an original product use which results in a decrease or elimination of hazardous waste generation associated

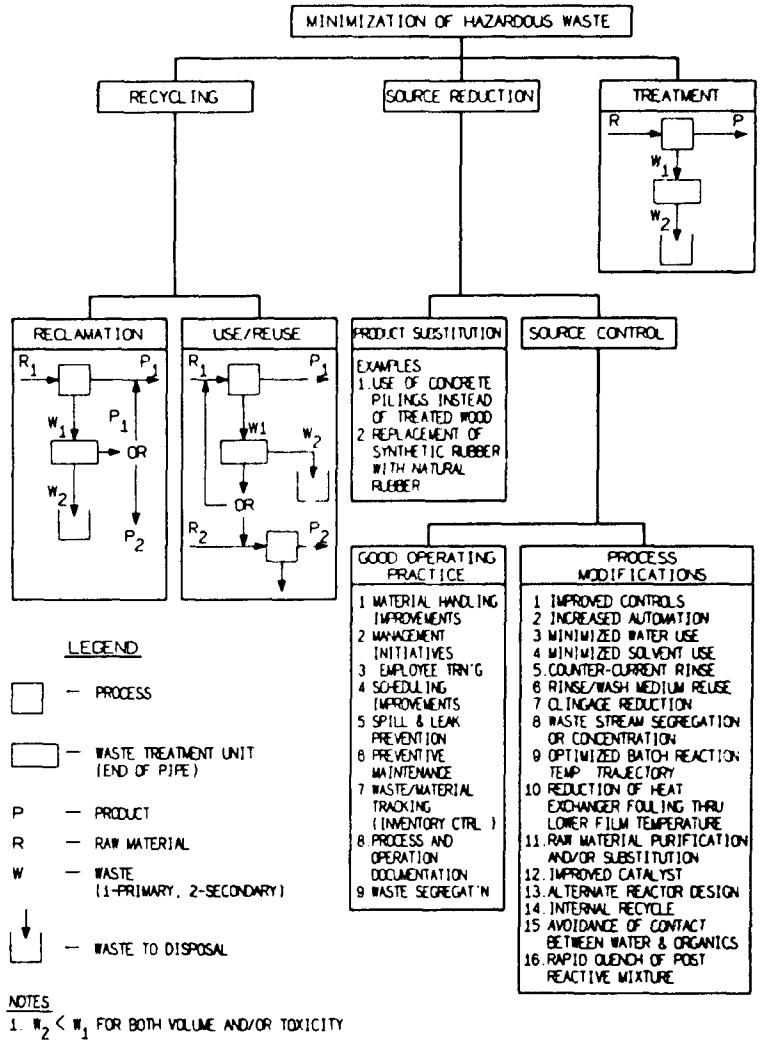

Figure 1
Graphical Depiction of Waste Minimization Components

with the original product's manufacture. Examples include replacement of treated wood pilings with concrete pilings in marine construction, replacement of synthetic rubber with natural rubber or replacement of paint coatings with longer lasting plastic coatings in certain applications. The definition can be broadened to also include research and development activity associated with seeking low-waste approaches to new products.

Source control means the reduction or elimination of hazardous waste generation within the process through application of good operating practices (or good housekeeping) or through process modifications. Individual components of good housekeeping and process modifications are presented in Figure 1.

WHY WASTE IS GENERATED

Industrial waste is generated because less than 100% of the raw materials entering a process end up as product. Historically, *maximizing* the product yield, or maximizing raw material utilization, always has been a primary goal of any process design or operation. Therefore, a key question at the outset of any waste minimization program is whether or not this goal has been successfully achieved in light of high waste disposal costs and the possibility of a ban on land disposal.

The attempt to characterize major causes of waste generation, along with the associated operational and design factors for typical sources of waste found in the chemical processing and metal finishing industries, resulted in the summary shown in Table 1. It is useful to distinguish between the operational and design factors affecting waste generation. While operational factors usually can be addressed and implemented within a very short time period, the design factors typically require more insight and, in many cases, extensive research (e.g., a search for a better, more selective catalyst).

Early recognition of waste generation aspects during the process or product development stage is extremely important, as evidenced by the experience at 3M Corporation. At 3M, the formulation process of new products involves an evaluation of the waste generation associated with the future manufacturing process. The company thus has been able to reduce the generation of waste before new products reach the production stage.[3]

BARRIERS TO WASTE MINIMIZATION

It is important to realize that a search for ways to minimize waste generation relies heavily on innovative, creative thinking and, in many cases, bold and decisive moves by company management. Some typical barriers to waste minimization are described below:

Table 1
Summary of Waste Generation Origins, Causes and Controlling Factors

Waste Origin	Typical Causes	Operational Factors	Design Factors
Chemical Reaction	• Incomplete reactant conversion • Byproduct formation • Spent catalyst - deactivation due to poisoning, sintering, etc.	• Inadequate temp. control • Inadequate mixing • Poor feed flow control • Poor feed purity control	• Inadequate reactor design. • Catalyst design or selection • Choice of process path • Choice of reaction conditions • Fast quench • Inadequate instrumentation or controls design • Poor heat transfer
Contact Between Aqueous and Organic Phases	• Vacuum production via steam jets • Presence of water as a reaction byproduct • Use of water for product rinse • Equipment cleaning • Cleaning of spills	• Indiscriminate use of water for cleaning or washing	• Choice of process route • Vacuum production via vacuum pumps • Use of reboilers instead of steam stripping • Clingage reduction
Disposal of Unusable Raw Materials and Offspec Products	• Offspec product generation caused by contamination, temperature/pressure excursions, improper reactants proportioning, inadequate pre-cleaning of equipment or workpiece • Obsolete raw material inventories	• Poor operator training and supervision • Inadequate quality control • Inadequate production planning and inventorizing of feedstocks	• Extensive use of automation • Maximizing dedication of equipment to a single process function
Process Equipment Cleaning	• presence of clingage (process side) and scale (cooling water side) • deposit formation • use of filter aids • use of chemical cleaning agents	• insufficient drainage prior to cleaning • inadequate cooling water treatment • excessive cooling water temperatures	• design for lower film temp in heat exchangers • design of reactors or mixing tanks with wall wiper blades • controls to prevent cleaning water from overheating
Metal Parts Cleaning	• disposal of spent solvent, cleaning sludge or spent cleaning solution	• indiscriminate use of solvents and water	• choice between cold dip tank or vapor degreasing • choice between solvent vs. aqueous cleaning solution
Metal Surface Treatment	• dragout • disposal of spent treatment solutions	• poor rack maintenance • indiscriminate rinsing with water • fast withdrawal of workpiece	• counter-current rinsing • fog rinsing • dragout collection tanks
Spills and Leaks Cleanup	• manual material transfer and handling operations • leaking pump seals • leaking flange gaskets	• inadequate maintenance • poor operator training • lack of operator attention • indiscriminate use of water in cleaning	• choice of gasketing material • choice of seals • use of welded or seal-welded construction.

- Lack of awareness of the benefits of waste minimization
- Lack of technical staff
- A "hands off the process" attitude caused by fear of upsetting a product's quality
- Organizational inertia (for example, an "if it isn't broke—don't fit it" attitude)
- Internal politics of the organization (for example, an innovator may feel inhibited by a fear of the lack of management's support)
- An "it can't be done" attitude; people may reject an innovative approach merely because it is outside their range of experience

In implementing a WRAP, the above inhibiting factors always must be recognized, since their identification and recognition allows formulation of constructive approaches to overcome them.

HOW TO IMPLEMENT A WASTE REDUCTION AUDIT PROCEDURE

The WRAP developed by the authors of this paper consists of eight sequential steps:

- Selection of the audit team
- Compilation by the audit team of a waste stream list for the facility with the associated flowrates
- Generation by the audit team of waste reduction options for each waste stream
- Ranking by the audit team of each compiled option in three categories: effectiveness, extent of current use and application potential
- Preparation by the audit team of documentation in support of selected options
- Presentation, discussion and joint review with plant personnel of options and their rankings
- Analysis by the audit team of revised rankings
- Final report preparation

The above procedure is applicable to all three categories of waste minimization (treatment, recycling and source reduction). However, it originally was developed and tested for source reduction options only. Source reduction measures should be considered even when recycling or treatment options are given priority. This is because reducing the quantities of waste that are recycled or treated often means an increase in revenues (e.g., due to an increase of product yield and lower cost of treatment).

Selection of the Audit Team

To effectively conduct a WRAP, it is necessary first to designate a leader for the audit. This person should have solid technical credentials and demonstrated problem-solving ability and can be either from within the company being audited or from the outside consulting firm conducting the audit. The leader and his team (audit team) preferably should not have any previous extensive association with the plant to be audited, primarily to avoid biases and to bring an independent perspective into analysis. Management must give the audit team enough authority to gain access to all required technical documentation (process flow diagrams, piping and instrumentation diagrams, inventory logs, operations logs, etc.) and technical personnel within the plant.

Waste Stream List

The second step consists of compiling a list of all waste streams leaving the plant. It may prove beneficial to include not only hazardous wastes destined for landfilling, but also other emissions such as wastewater, air emissions and non-hazardous wastes. Waste stream identification and quantification may require extensive site inspection, review of process documentation, interviews with plant operations personnel and, in some cases, material balance calculations.

Reviews of process flow diagrams, heat and material balances and piping and instrumentation diagrams are particularly useful. Each diagram should be analyzed for all points where waste generation can occur. When producing a chemical commodity, typical sources include reaction byproducts leaving the process as distillation column bottoms. Also, equipment cleaning wastes (e.g., wastes from storage tanks and heat exchangers) must be considered, although they are usually minor in a continuous process. In a batch process, large quantities of waste can be associated with cleaning operations, such as cleaning out a mix tank or reactor. Since these incidental wastes rarely appear on process flow diagrams or are mentioned in process descriptions, discussions with key operations personnel are important.

Waste streams must be quantified on a uniform basis. If a stream is intermittent, it should be represented as a pseudo-continuous stream. After all waste streams are quantified, it is useful to express each of them as a percentage of the total quantity of waste leaving the process.

Waste Reduction Options

The third step in WRAP involves the generation of waste reduction options for each stream previously identified. Good results can be obtained in the course of a brainstorming session preceded by independent preparation by each participant. This session must involve only the outside audit team—no plant personnel must be present. The reasons for exclusion of plant personnel at this point include:

- Working through the options generation process without plant personnel forces the audit team to work harder to gain a good understanding of the process and analyze it with a long-vision perspective—which is often absent among the plant operators.
- It is necessary, at this stage, to postulate a maximum number of options. The presence of plant personnel may inhibit people from submitting an option to the list.

Tables 1 to 4, developed by the authors of this paper, are provided to stimulate the discussion process to identify possible useful waste reduction measures. Tables 2 to 4 contain checklists of waste reduction measures compiled based on many process analyses and on experience with actual industrial WRAP applications.

Table 2
Waste Reduction Methodology Checklist: All Processes

All Waste Streams	1.	Use higher purity materials
	2.	Use less toxic raw materials
	3.	Use non-corrosive materials
	4.	Convert from batch to continuous process
	5.	Tighter equipment inspection and maintenance
	6.	Better operator training
	7.	Closer supervision
	8.	Practice good housekeeping
	9.	Eliminate or reduce water use for spill cleanup
	10.	Implement proper equipment cleaning techniques
	11.	Use improved monitoring systems
	12.	Use pumps with double mechanical seals
Commodities Produced Continuously		
Examples:		Acrylonitrile, Epichlorohydrin, Petroleum Refining, 1,1,1 Trichloroethane, Trichloroethylene/Perchloroethylene, Vinyl Chloride Monomer
Heavy and Light Ends	1.	Develop more selective catalyst
	2.	Optimize the reaction variables/reactor design
	3.	Use alternate process routes
	4.	Combust with heat (and HCl) recovery
Spent and Lost Catalyst	1.	Develop tougher catalyst support
	2.	Use filter inside reactor freeboard
	3.	Regenerate and recycle spent catalyst
Equipment Cleaning Wastes	1.	Increase equipment drainage time
	2.	Use corrosion resistant materials
	3.	Agitate and/or insulate storage tanks
	4.	Re-examine need for chemical cleaning
	5.	Use nitrogen blanket to reduce oxidation
	6.	Use in-process HX cleaning devices
Leaks and Spills	1.	Use bellow-sealed valves
	2.	Use canned (seal-less) pumps
	3.	Maximize use of welded vs. flanged pipe joints

Table 3
Waste Reduction Methodology Checklist: Commodities Produced in Batches

Examples: Dyes, Inorganic Pigments, Paint, Agricultural Chemicals Formulation, Phenolic Resins, Wood Preserving

Material Handling	1. Segregate containers by prior contents 2. Use rinseable/recyclable drums 3. Purchase materials in bulk or in larger containers 4. Purchase materials in preweighed packages 5. Use pipeline for intermediate transfer
Reaction/Processing Step	1. Optimize the reaction variables/reactor design 2. Optimize the reactant addition method 3. Eliminate the use of toxic catalysts
Filtration and Washing	1. Employ efficient washing/rinsing methods 2. Eliminate the use of filter aids 3. Use countercurrent washing 4. Recycle spent washwater 5. Maximize sludge dewatering
Baghouse Fines	1. Increase use of dust suppression methods 2. Use wet instead of dry grinding 3. Schedule baghouse emptying
Off-Spec Product	1. Tighter control of reaction temperature 2. Reformulation of off-spec product
Equipment Cleaning	1. Install high pressure spray wash system 2. Alter production schedule 3. Use mechanical wipers on mix tanks 4. Clean mix tanks immediately after use 5. Use a countercurrent rinse sequence 6. Recycle spent rinse water 7. Increase spent rinse settling time 8. Re-examine need for chemical cleaning 9. Dewater spent rinse sludge
Leaks and Spills	1. Use bellow-sealed valves 2. Install spill basins 3. Use canned (seal-less) pumps 4. Maximize use of welded vs. flanged pipe joints

Table 4
Waste Reduction Methodology Checklist: Manufacturing Operations

Examples: Electroplating, Lithographic Printing, Metal Parts Cleaning, Metal Surface Treatment, Paint Application Printed Circuit Boards

Material Handling	1. Segregate containers by prior contents 2. Use rinsable/recyclable drums 3. Purchase materials in bulk or in larger containers 4. Purchase materials in preweighed packages
Solvent Cleaners	1. Install/operate cleaning tanks properly 2. Avoid cross-contamination of solvent 3. Avoid water contamination of solvent 4. Remove sludge continuously 5. Monitor solvent composition 6. Consolidate cold cleaning operations 7. Recycle spent solvent 8. Use plastic bead blasting for paint stripping
Alkaline/Acid Cleaners	1. Install/operate cleaning tanks properly 2. Avoid cross-contamination of solvent 3. Remove sludge frequently
Plating/Etching/ Surface Finishing Solutions	1. Increase plating solution bath life 2. Use lower concentration plating bath 3. Use trivalent Cr in place of hexavalent Cr 4. Use non-cyanide plating solutions 5. Use in-line recovery techniques 6. Regenerate spent bath solutions 7. Segregate all waste streams 8. Inspect all parts for proper cleanliness
Rinse Water	1. Install/operate all rinse tanks properly 2. Use multiple rinse tanks 3. Install drain boards and drip tanks 4. Use fog nozzles and spray units 5. Agitate rinse bath 6. Use deionized water for rinsing 7. Recycle and reuse rinse water 8. Segregate all waste streams 9. Reclaim metal from rinse water
Paint Application	1. Use equipment with low overspray 2. Inspect all parts before painting
Leaks and Spills	1. Install splash guards and drip boards 2. Prevent tank overflow

Option Rating

The fourth step involves rating, by the audit team, of each option generated in term of three categories (effectiveness, extent of current use and future application potential). While the meaning of "effectiveness" is fairly obvious, "extent of current use" and "future application potential" need more discussion. The extent of current use can be based on either the number of waste streams that are controlled using a given method or the frequency of use of a given method on a particular waste stream. The future application potential is a measure of the probability that a given method will be implemented in the future. This variable is highly dependent on capital and operating cost, level of difficulty, implementation period, product yield credits, technological risk and the risk of detrimental effects on product quality.

In the course of developing and using this audit approach, it was convenient to ask people to rank each item on a scale of zero to four or zero to ten. Usually, the scale chosen will depend on the people conducting the WRAP and the extent of their knowledge. When people are asked to what extent a given method currently is implemented, it may be difficult for them to come up with an answer. However, when asked to rank these same methods on a scale of zero to four where the inference is from low to high, answers often are more forthcoming. Once each method is ranked, the amount of waste currently being minimized and the potential future reduction index can be calculated according to the equations presented in the Appendix of this paper. In addition, one or more waste reduction methods should be singled out for further study and implementation for each waste stream.

Audit Documentation

The fifth step involves preparation by the audit team of any documents outlining the concept, rationale and intended implementation of options which are not obvious and hence require explanation. This may involve a block flow diagram, a proposed revision of a piping and instrument diagram, an outline of proposed new equipment, a narrative description, etc.

Presentation to Plant Personnel

The sixth step is most crucial, as it involves presentation of the options evolved to the plant personnel. The chief objective of this session is to stimulate the innovative process within the entire group and not simply to have the plant people select from the menu prepared by the audit team. For that reason, the audit leader must be firmly in control of the meeting; after all, innovation is intended to occur through an interactive process that may include controlled conflict. An atmosphere of conflict, or at least polarization, is likely to exist between the members of the audit team and plant personnel as each proposed option is subjected to review. New rankings very often will be evolved, and alternative options to those previously compiled often will emerge. The function of the audit leader is to moderate the discussion, to provide positive resolution of conflicting opinions (e.g., subject the option to ranking by vote) and to keep the discussion focused on the subject. Prior to the meeting, plant personnel must re-

view and analyze the postulated options. However, the meeting is the culmination of the entire process. At the end of the meeting, the leader should undertake a review of the new rankings obtained for each option now appearing on the list. Any residual disagreements should be resolved at that time.

Analysis Re-Ranking

The seventh step involves the re-analysis of the rankings to evolve new waste reduction indices for each option as described in the Appendix.

Future Reduction Potential

The eighth and the final step involves review of "future reduction potential" indices, options screening and preparation of the final report in which the WRAP results are presented to company management. The report and any recommendations must be reviewed and concurred with by plant personnel.

A WRAP CASE STUDY

WRAP was applied to the batch process partially depicted in Figure 2 with the purpose of developing a process or equipment configuration minimizing emissions of toxic powders into the workspace environment. The release of these powders, apart from presenting an exposure problem to the operators, ultimately results in hazardous waste generation. The waste is generated when the work area is hosed down and the wastewater is sent to a clarifier in which a toxic sludge settles out.

The part of the process described involves weighing, mixing and dispersion of two toxic powders (Powders A and B) in the wet grinding unit. At the end of the wet grind operation, the slurry is poured into drying trays, which are placed into a drying oven. After the mixture has dried, the trays are manually removed and emptied into a dry grinding unit. As the powder is ground, it flows into a lined drum which then is sent to the existing equipment for additional processing. The waste producing operations identified were weighing operation, wet grind loading and unloading and dry grind loading and unloading.

For each operation, all of the control methods originally postulated by the consultant were listed (Table 5). The list was reviewed and modified during the meeting between the client's design and operating personnel and the consultant. It was during this time that each method was ranked for its effectiveness, extent of current use, future application potential and the fraction of waste generated by each process operation. In addition, the group was asked to add any methods that may have been overlooked. The paragraphs below describe each control method for every unit operation shown.

Starting with the weighing operation, the consultant suggested that the company return the empty containers to its supplier (some suppliers of toxic materials have facilities for recovering or disposing of material left in empty containers), purchase powder A (the more toxic of the two powders) in preweighed plastic bags and use drum covers when transferring the material. While few thought that the first method was practical, and the third method was currently being employed, the second method met with much enthusiasm. By using preweighed containers, the likelihood of spills or dusting of powder A would be greatly reduced. In addition, unloading of the preweighed powder at the wet grind station would allow rinsing out the bag so that the bag would no longer be considered hazardous.

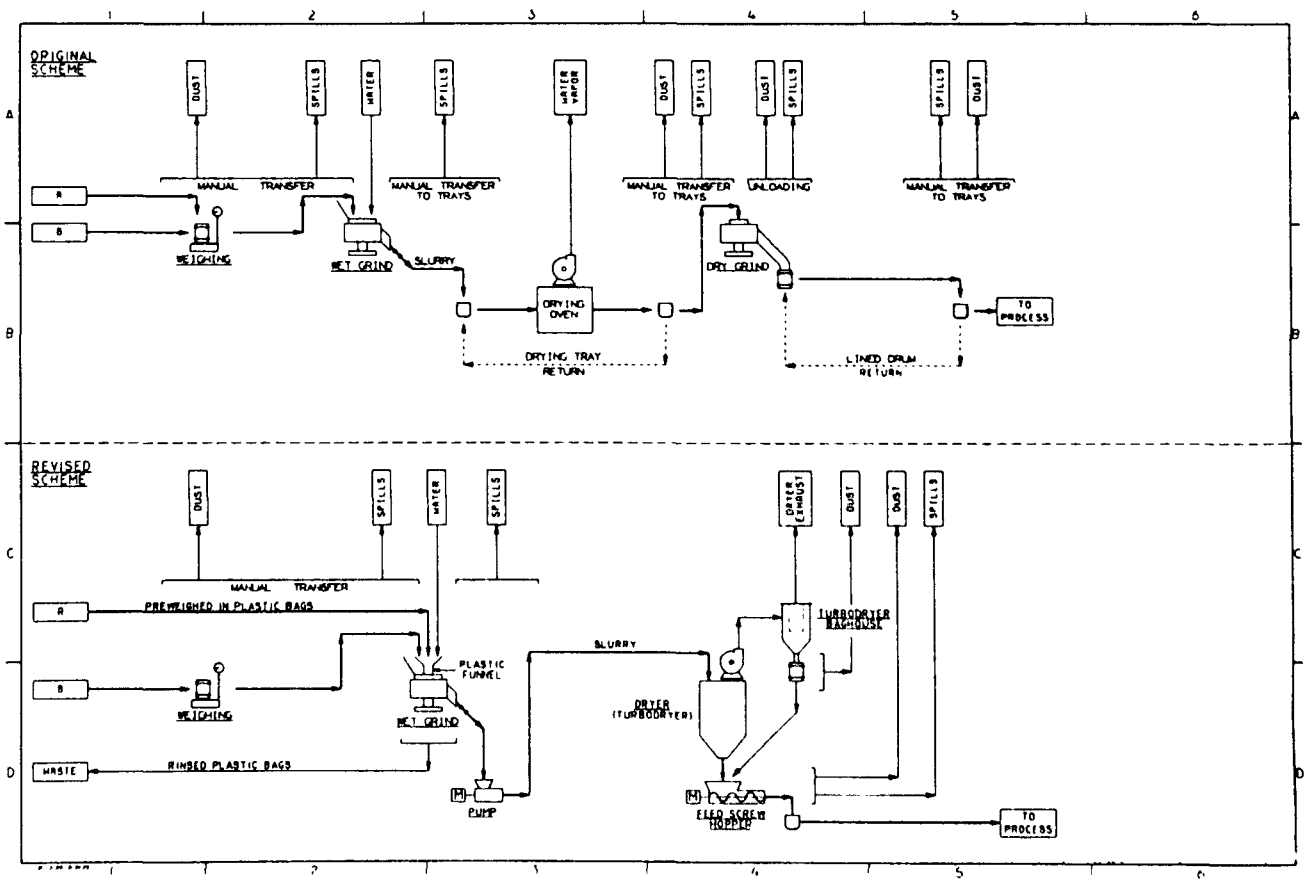

Figure 2
WRAP Case Study—Illustration of Process Modifications

Table 5
Summary of Source Control Methodology for the A/B Powder Formulation Process

Waste Source	Control Methodology	Waste Reduction Effectiveness	Extent of Current Use	Future Application Potential	Fraction of Total Waste	Current Reduction Index	Future Reduction Index
Weighing Operation	1. Return empty containers	2	0	2		0.00	0.25
	2. Use preweighed containers	2	0	4		0.00	0.50
	3. Use drum covers	2	2	1		0.25	0.06
	Overall	2.00	0.67	2.33	0.10	0.25	0.50
Wet Grind Loading and Unloading	1. Use plastic funnel/collar on unit	2	0	4		0.00	0.50
	2. Use smaller trays, manual operation	2	0	2		0.00	0.25
	3. Place trays on rack, walk-in oven	2	0	2		0.00	0.25
	4. Use elevator table to carry trays	1	0	1		0.00	0.06
	5. Install roller conveyor under valve	1	0	1		0.00	0.06
	6. Install fail-close valve on discharge	2	0	3		0.00	0.38
	7. Pump slurry into trays over at oven	2	0	1		0.00	0.13
	8. Reduce cleaning frequency	3	0	3		0.00	0.56
	9. Bypass dry grinding unit	2	0	4		0.00	0.50
	Overall	1.89	0.00	2.33	0.45	0.00	0.56
Dry Grind Loading and Unloading	1. Use plastic funnel/collar on unit	2	0	4		0.00	0.50
	2. Do not load while unit is operating	3	4	0		0.75	0.00
	3. Inspect all seals regularly	2	3	2		0.38	0.06
	4. Use drum covers	2	2	3		0.25	0.19
	5. Bypass dry grinding unit	4	0	4		0.00	0.90
	Overall	2.60	1.80	2.60	0.45	0.75	0.90
All Sources	All Methods				1.00	0.58	0.71

For the second operation, wet grind loading and unloading, eight waste reduction methods were suggested. For the loading operation, it was recommended that a plastic funnel or collar be used when pouring powder into the unit. The wet grinder had a small opening port and therefore the likelihood of a spill was great. For the discharge operation, the original procedure required the operator to manually slide-out a filled tray from underneath the discharge valve. Since the filled tray would be very heavy, movement of the trays on the floor would cause much spillage to occur. Once the trays were full, they were placed on a rack, taken to the oven and placed inside. Therefore, many of the methods focused on making the job easier for the operator. Suggested methods were to use smaller trays (easier to move), place the trays on a rack that could fit inside the walk-in oven, use an elevator table to carry the trays, install a roller conveyor under the valve and install a pump on the unit and pump the slurry to the oven area for tray filling. Of these methods, installing a roller conveyor and using a rack/walk-in oven were considered the most practical by both the consultant and plant operations group. Since drips from the valve onto the conveyor could occur, it was suggested that a fail-close valve also be installed so that the operator would be discouraged from the practice of opening the valve and sliding the trays underneath while the slurry continued to flow. Finally, it was agreed that the cleaning frequency of the unit would be reduced as compared to existing units since this unit would be dedicated to this operation.

For the third operation (which also involved a loading and unloading operation), the use of a plastic funnel or collar and the use of drum covers were again suggested. In addition, it was recommended that the unit not be loaded while operating and that the unit be inspected regularly. Finally, the client was asked why the dry grind operation was necessary—subsequent operations provided additional mixing and million. The discussions that followed proved to be the most productive of all.

At first, the facility process staff indicated that the design of the process had been taken from the procedure developed in the laboratory. Technical reasons for performing the dry grind operation were that segregation of the powders might occur during the long slurry drying operation and that powder dried in the oven had a tendency to form lumps or a crust. This then led the consultants' attention back to the drying oven. Could something be done to the oven to increase the drying rate (so that segregation would not occur) and yet produce a material with no lumps or crust? The use of a continuous drying, as opposed to batch drying, oven was suggested. The client had a Turbodryer (a continuous rotary tray dryer) that was seldom used. Since the material is dried rapidly and on a continuous basis, no segregation or lumping should occur. Also, since the material is not dried to the same degree as in the batch oven (the slight increase in moisture content would not affect the subsequent processing step), the degree of dusting should be reduced. Finally, the manual operation of loading the drying trays back at the wet grind operation is eliminated, since the slurry now will be pumped into the Turbodryer. A process flow diagram comparing the original and revised operations is shown in Figure 1.

Implementation of the modified process is currently underway. Emissions of materials to the workplace environment and the resulting generation of hazardous waste will be significantly reduced when compared to the original processing scheme.

CONCLUSIONS

It is believed that the systematic approach described in this paper for identifying and evaluating waste minimization options will prove valuable in conducting effective waste reduction audits.

As shown in the case study description, the systematic process has been applied and has led to the identification and implementation of measures to reduce hazardous waste generation. This will have the obvious effect of reducing the company's

waste disposal costs and of deriving higher profits realized through better utilization of raw materials. At the same time, in this particular case, there is the additional benefit to the company of reduced worker exposure to toxic emissions.

The reader is reminded, however, that the systematic Waste Reduction Audit Procedure by itself is no panacea. Successful use of this approach requires cooperation among the audit team and facility operations personnel; it requires a good understanding of the industrial process and its underlying principles, and finally it requires creativity and hard work.

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APPENDIX: COMPUTATIONAL PROCEDURES

The text below explains how individual rankings of each option in three separate categories (effectiveness, extent of current use and future applications potential) are combined to obtain qualitative measures of how much waste has already been reduced and how much waste can be reduced in the future for each option, for each waste stream and for the entire process.

Current Waste Reduction Index

The current waste reduction index C is the fractional reduction of waste resulting from the employment of current waste reduction measures. In other words, it represents the reduction in waste that occurred because of measures currently being implemented. The derivation of equations allowing computation of C from the ratings given to each waste reduction method is presented below.

Consider a process which, in the past, generated waste at a specific rate, W_p. Assume that, due to implementation of certain source control techniques, the same process now generates waste at a specific rate, W_o. Hence, the currect overall fractional reduction of waste generated is:

$$C = (W_p - W_o)/W_p \tag{1}$$

where:

C -current fractional reduction of waste produced by the process
W_p -past specific waste generation rate (lb waste/lb product)
W_o -current specific waste generation rate (lb waste/lb product)

Now consider that the process has N different waste streams and that for each j-th stream (j = 1,2,..N) there are different source control methods available. Each method can be characterized by its effectiveness, eij, its extent of current use, uij, and its extent of further application or application potential, pij. The first parameter, effectiveness, eij, is defined as the measure of volume or toxicity reduction for the j-th waste stream due to full implementation of the i-th (i = 1,2,..Mj) source control method. The second parameter, extent of current use, ij, is defined as the measure of current level of use of the particular method to control the j-th waste stream. Finally, the future application potential, pj, is a stochastic variable defined as the measure of probability that a given source control method will be implemented to control the j-th waste stream. Such a variable depends on capital and operating cost, level of difficulty, implementation period, product yield credit technological risk and the risk of detrimental effect on product quality.

In mathematical terms, the current fractional reduction of the j-th waste stream by the implementation of the i-th source control method is given by:

$$c_{ij} = e_{ij} \times u_{ij}/S^2 \tag{2}$$

The normalizing factor, S, a maximum score, equals 4 if u and e were ranked on a scale of zero to four or equals ten if u and e were ranked on a scale of zero to ten. If the cumulative effect and the mutual exclusivity of all methods can be ignored, the current reduction index for the entire j-th waste stream can be expressed as:

$$C_j = \max (c_{ij},\ i=1,2,\ldots M_j) \tag{3}$$

By ignoring the mutual exclusivity of the methods, the determination of Cj is vastly simplified. While the mathematical equation was formulated to account for any cumulative effects, it is doubtful if the accuracy of the estimation would actually have improved. After all, the current reduction index is based on a theoretical waste generation rate from the past, and its intent is to provide a qualitative estimate of what already has been done to reduce waste.

Now that Cj is determined, it is useful to express it in terms of W_{0j} and Cj. Rearranging equation (1) and writing it in terms of a single waste stream gives:

$$W_{pj} \qquad W_{oj}/(1 - C_j) \tag{4}$$

$$W_p = \sum_{j=1}^{N} W_{pj} = \sum_{j=1}^{N} W_{oj}/(1-C_j) \tag{5}$$

To obtain the current reduction index C for the whole process (all waste streams), equations (5) and (1) are combined to yield:

$$C - 1 - \qquad W_o/\sum_{j=1}^{N} W_{oj}/(1 - C_j) \tag{6}$$

Since it is usually easier to estimate the fraction of waste, Zj, that a waste stream represents as part of the total waste generated (as opposed to estimating the actual waste generation rate), the following equations are used to calculate C:

$$W_{oj} - \qquad W_o Z_j \tag{7}$$

$$C = 1 - 1/\sum_{j=1}^{N} Z_j/(1 - C_j) \tag{8}$$

The above equation relates the current fractional extent of waste reduction for the entire process to the current fraction Zj of each process waste stream and to the current extent of waste reduction Cj for each waste stream.

Future Waste Reduction Index

In addition to the current reduction index, C for the entire process, an estimation of the potential future reduction index F is required. Future reduction indices for each control method can be calculated by using the equation:

$$F_{ij} \quad e_{ij}\,(S-u_{ij})\;p_{ij}/S^3 \tag{10}$$

Again, ignoring the effect of mutual exclusivity or assuming that a given facility will implement the most effective control method for each waste stream:

$$F_j \quad \max\,(F_{ij},\ i - 1,2,\ldots M_j) \tag{11}$$

$$F \quad \sum_{j=1}^{N} F_j Z_j \tag{12}$$

Future reduction index F, expressed by equation (12) is a semi-qualitative measure of expected fractional waste reduction from the process due to implementation of the single most effective control option for each waste stream.

In summary, the method described above is based on an heuristic approach where the estimates of waste reduction were derived from the ratings given to the variables eij, uij and pij. In actual applications, it usually is not possible to obtain precise fractional values of e, u and p. Instead variables should be ranked on some integer scale such as zero to four or zero to ten with the degree of resolution based on the expertise of the individuals involved and availability of information. Since the use of an integer scale can result in Cj or Fj equal to 1.0 (100% reduction of waste), it is recommended that the maximum fractional values allowed be set equal to 0.9 to avoid division by zero.

Minnesota Technical Assistance Program: Waste Reduction Assistance for Small Quantity Generators

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ABSTRACT

Waste minimization is a feasible approach to hazardous waste management, reducing the volume of waste generated at the source and reducing industry's reliance on landfilling.

Unlike the federal hazardous waste regulations governing compliance of small quantity generators between 100 and 1000 kg/month, Minnesota regulations allow no exemptions for small quantity generators. This means that more small quantity generators in Minnesota (0 to 1000 kg/month) must abide by the hazardous waste rules. In addition, because Minnesota has no waste disposal facility, the costs of disposal can be high.

In response to the high costs of disposal and the additional number of small quantity generators, Minnesota has adopted a stringent policy of waste minimization or waste reduction. The Minnesota Waste Management Board has created the Minnesota Technical Assistance Program (MnTAP) to foster and implement waste reduction in Minnesota.

Many states across the country are initiating technical assistance programs to assist industry with the changing regulations. Technical assistance programs have the benefits of being non-regulatory and confidential and thus are a good vehicle for encouraging compliance and waste reduction. Compliance with hazardous waste regulations, too often viewed by industry as difficult and expensive, can instead present methods such as product substitution, waste segregation, more efficient equipment and quality improvement in addition to recycling and treatment opportunities.

MnTAP offers several services to foster and implement waste reduction in industry including on-site consultation, research grants, the engineer intern program, educational seminars, information gathering and dissemination and a telephone hotline. Waste reduction successes achieved through research, the engineer intern program and on-site consultation are documented and provided to other industries through reports and presentations. Significant cost saving can be realized by seemingly insignificant changes in a manufacturing process, including savings in raw materials, savings in disposal costs and savings in ultimate liability.

INTRODUCTION

The trend toward hazardous waste reduction is largely in response to changing public policy at the Federal and State levels. One of the goals of the RCRA Amendments of 1984 is the minimization or reduction of hazardous waste generation and its disposal on land. The obvious consequences of land disposal as historically acceptable waste management have been poor management of hazardous waste, groundwater contamination and other significant hazards to human health and the environment.

The U.S. EPA has set forth its "waste minimization" policy by requiring generator certification on the manifest that the generator has reduced waste generation to the maximum extent which is economically feasible. The U.S. EPA's definition of waste minimization may include both source reduction and recycling/reuse. Those reduction methods which are economically feasible for a particular generator are left to the generator's discretion, rather than being specified by the U.S. EPA. Waste reduction measures taken must be documented and reported every 2 years.

A programmatic trend toward hazardous waste reduction already is taking place among the states. Currently, approximately 20 states have programs in some stage of development to respond to the U.S. EPA waste minimization policy and generator needs. Both the U.S. EPA and the states believe such programs are best handled at the state level to better respond to generator needs and specific state regulatory requirements. These state programs typically take the form of technical assistance, regulatory assistance or both.

The Minnesota Technical Assistance Program (MnTAP), for example, was established by the Waste Management Board for several reasons, largely driven by state needs: (1) the adoption of waste reduction as the most favored state policy for waste management by the Waste Management Board and the State of Minnesota due to the absence of hazardous waste treatment/disposal facilities in Minnesota; and (2) the regulation of all small quantity generators in Minnesota with no exemption for any volume of waste generated.

Two main areas of emphasis exist for MnTAP: waste reduction and small quantity generator assistance. A five-step approach is taken in educating generators on the options available for waste reduction and implementing waste reduction measures.

THE APPROACH TO WASTE REDUCTION

In the past, the availability of cheap landfill sites has acted as a disincentive to capital expenditures or changes in operation needed to implement waste reduction and waste recovery.[1] Land disposal now is recognized by most as the waste handling method of last resort. Long-term liability costs of disposal have become a major incentive to some generators to reduce their waste generation and not rely upon landfilling. When these long-term costs are factored in, landfilling no longer appears attractive.

In place of land disposal, the hierarchy shown in Fig. 1 is gaining greater acceptance as the optimal management strategy for hazardous wastes. The goal of a waste management system is to utilize the most cost-effective combination of management options to handle wastestreams within the confines of the regulations.[2] Utilizing one or more of the elements in the hierarchy may

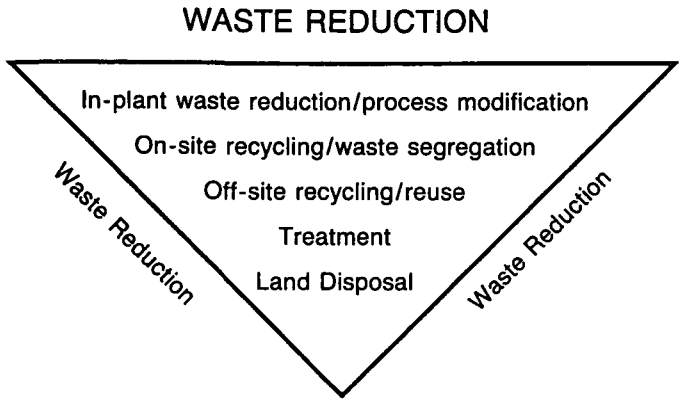

Figure 1
Optimal Management Strategy for Hazardous Wastes

result in a three-fold benefit: (1) savings on raw materials; (2) avoiding disposal costs; and (3) minimizing future liability.

In-Plant Changes

Source reduction, or in-plant reduction, is the preferred method and first step in working toward the overall scheme of waste reduction. Source reduction not only has the greatest potential to reduce waste generation over other options, but also reduces occupational exposure to toxic substances in the workplace. Source reduction is also most likely to result in the greatest savings on raw materials and avoided disposal costs.

A step in the right direction toward source reduction is to conduct an in-plant survey, or waste audit. A survey involves collecting information on the volume and characteristics of waste streams generated in a plant. With this information in hand, opportunities for source reduction can be identified. Some of these opportunities are reviewed below.

Improved Housekeeping

Low cost measures such as good housekeeping practices, routine checks for faulty and leaking valves or pipes, balancing material inputs and outputs to identify losses, better inventory control and shipping and minor process changes all help to minimize pollution in a cost-effective manner. Cutting back water usage in electroplating rinsewaters or eliminating vented solvent emissions in a dry cleaner's plant are examples.

Product Substitution

Product substitution involves replacing a hazardous product used in a production process with a less hazardous or a non-hazardous product. Examples of product substitution may include eliminating the use of metal-containing paints or solvent-based paints and substituting water-based paints containing no metals. Many companies have eliminated the use of chlorinated solvents in degreasing operations and have replaced them with non-chlorinated solvents or caustic washes, as appropriate.

Product Reformulation

Product reformulation is substituting an end-product which requires a less waste-intensive manufacturing process.[3] As an example, during the manufacture of polyester resins, toxic styrene monomer was released into the air. This process was changed when chemical producers began manufacturing a line of styrene-suppressed resins that reduced styrene loss into the air by 70% compared with nonsuppressed systems.

Production Process Modernization

Replacing existing equipment with more efficient equipment based on the same production methods can significantly reduce waste generation. A classic example is replacement of conventional air-atomized spray equipment having a transfer efficiency of 30 to 60% with electrostatic equipment (transfer efficiency of 65 to 80%) or with powder coating equipment at 90 to 99% transfer efficiency.[1]

Production Process Redesign

Developing and using production processes of a fundamentally different design than those currently used, such as waste stream segregation, can greatly enhance opportunities for waste recycling or reuse. Wastewater from one part of the plant may be clean enough for reuse in another part of the plant. Segregation of metals streams may allow metals recovery with installation of a metals recovery system.

On-Site Reuse/Recycling

Reuse or recycling a waste stream refers to returning the waste stream as a raw material to the original process that produced it, with or without treatment. A large selection of equipment is available for solvent distillation on-site. It makes economic sense to reclaim waste paint or overspray (through reformulation if necessary) for its original purpose.

Off-Site Reuse/Recycling

The low volumes of waste produced by some small companies may not justify the purchase of needed equipment for on-site recycling. In this case, wastes may be shipped for off-site recycling at a centralized recycling facility. "Milk runs" by solvent transporters have been established to help reduce transportation costs and facilitate recycling.

Treatment

Treatment of the waste to render it less-hazardous or non-hazardous can be done by applying physical, chemical, biological or other methods. These methods may include concentration, neutralization, detoxification, stabilization or incineration of the waste.

Disposal

Once all reduction, reuse, recycling and treatment options have been exhausted, remaining wastes or residuals must be disposed of in some environmentally acceptable manner.

Table 1
Hazardous Waste Generation in Minnesota in 1984[4]

Waste Category	Amount (tons)	Percent
Oily wastes	466	1%
Waste oil	8720	7
Paint	1606	1
Pesticides/Herbicides	30	<1
PCBs	1753	1
Organic chemical production	26	<1
Halogenated solvents	2260	2
Non-halogenated solvents	13461	11
Other organics	19025	15
Heavy metal solutions and sludges	15386	12
Corrosive	42063	34
Reactive	982	1
Other organic	4483	4
Misc chemicals	13202	11
TOTAL	123,463	100%

MINNESOTA HAZARDOUS WASTE GENERATION AND MANAGEMENT

Approximately 123,000 tons of hazardous waste were reported to be generated in Minnesota in 1984 in 14 waste categories (Table 1). Some waste streams were not reported by disclosure but should be included in the overall description of Minnesota waste generation. All waste streams including disclosed wastes, SQG wastes, spill and site cleanup waste and waste oil result in an overall waste generation amount of 221,000 tons (Table 2).

Table 2
Overall Estimate of Waste Generation in Minnesota in 1984[4]

Source	Amount (tons)	Percent
Disclosed	123,000	55%
Additional SQG waste	6,000	3
Spill and site clean up	41,000	19
Additional waste oil	51,000	23
TOTAL	221,000	100%

Disclosure data for 1984 suggest 57% of Minnesota waste is being sewered with or without pretreatment, 13% is being recycled, 10% is being incinerated, 6% is being land disposed and 14% is unknown or being treated/disposed in other ways. Manifest data for 1984 indicated that 58,000 tons (including site cleanup) of waste (47% of total reported waste) were shipped out-of-state for treatment, recycling or disposal. Approximately 31,000 tons of waste were managed through on-site recycling, fuel blending, stabilization, waste oil rerefining, land treatment or other methods in-state.[4] The remainder is being sewered.

This information suggests Minnesota's hazardous waste generation and management concerns may not be as severe as in some other states. However, the absence of permitted hazardous waste treatment facilities in Minnesota causes concern when one considers that roughly one-half of reported Minnesota waste must be sent out-of-state.

In order to reduce reliance on out-of-state facilities and take responsibility for its own waste generation, Minnesota has adopted a policy of waste reduction. MnTAP was created to educate generators on waste reduction opportunities and to offer direct technical advice and assistance to small quantity generators.

SERVICES OF THE MINNESOTA TECHNICAL ASSISTANCE PROGRAM

MnTAP was established by the Minnesota Waste Management Board (WMB) in November 1984 as one of the recommendations to the Minnesota legislature in the Waste Management Board's Hazardous Waste Management Plan. The WMB is a solid and hazardous waste planning and siting agency and provided the MnTAP grant to the University of Minnesota in order to call upon the available technical resources and faculty. In response to generator needs in Minnesota, several services are available free-of-charge through MnTAP.

Information Dissemination

Three types of information are available to generators through MnTAP: (1) technical literature on waste reduction; (2) professional assistance contacts; and (3) equipment information. All of this information is stored on the computer and can be accessed by industry or waste stream type.

Telephone Hotline

Approximately 40-50 calls per month are received from a broad base of industries (service and manufacturing) covering a wide range of topics. The majority of calls have been received from painters/coaters and metal finishers.

On-Site Consultation

Assistance by telephone may not be adequate to meet generator needs. An on-site visit may be made to provide the generator with more detailed information, clarify regulations and look for waste reduction opportunities. As of November 1985 30 site visits had been made by MnTAP staff.

Engineer Intern Program

A site visit may reveal the need for longer-term waste reduction assistance. In this case, a student intern (paid by MnTAP) can be provided to the company to work on a dedicated waste reduction project for one school term. The project typically involves conducting an in-plant survey, evaluating equipment, talking to vendors and assisting with design and selection of equipment. An intern is a valuable resource for a small company which may otherwise be unable to hire a consultant. Seven interns were employed by MnTAP during the summer of 1985.

Education

Education of generators is conducted primarily by presentations and seminars for trade associations or generators. MnTAP has just completed a series of industry-specific seminars for dry cleaners, metal finishers and others. Fact sheets prepared by MnTAP staff provide information on waste management disposal and reduction options for specific waste streams.

SUCCESS IN WASTE REDUCTION

MnTAP assistance to Minnesota generators covers a broad base of industries from service related firms, such as dry cleaners and service stations, to manufacturing including metal finishing and plastics manufacturing. Informational needs of generators may be as straightforward as providing a transporter list or may involve a long project such as evaluating and installing equipment for metals recovery from plating operations. Two examples of actual waste reduction practices implemented as a result of MnTAP assistance follow.

Metal Plater Assisted

Company A is a precious metal plater of gold and silver. The spent gold and silver rinsewaters are sent off-site for recovery, but copper and other metal rinsewaters historically have been pretreated on-site, prior to discharge to the sewer system. The company uses an existing system for neutralization, precipitation of metals and sludge dewatering as wastewater pretreatment prior to sewer discharge.

In order to expand operation and meet sewer discharge requirements, this company needed to install a metals recovery system to remove metals from its wastewaters prior to the current pretreatment stage. An in-plant survey was conducted to characterize the various waste streams. This information enabled the company to select and size the needed equipment.

After reviewing technical literature and talking with vendors, Company A selected a scheme proposed by an equipment vendor using electrolytic metal recovery operating in conjunction with the existing pretreatment system. It is estimated that installation of the new system will result in a reduction of as much as 90% of the hazardous metal components of the sludge.

Electronics Firm Assisted

Company B, a large electronics and computer manufacturing firm, generates two drums per day of dewatered metals sludge from its copper plating operations. The total cost of disposal including transportation and cost of the drum is approximately $200 per drum of waste for an annual total disposal cost of $100,000. This cost is in addition to chemicals for the wastewater treatment process, operating personnel and utilities.

MnTAP provided the firm with an engineer intern to aid in the evaluation and installation of a metals recovery unit. It is estimated that metals recovery will reduce sludge generation from two drums per day to two drums per month. This waste reduction will result in an annual cost savings of approximately $100,000 in avoided disposal costs and transportation costs.

CONCLUSIONS

Waste reduction, or waste minimization, as the new approach toward waste management is clearly an improvement over historical end-of-pipe treatment for pollution control. The U.S. EPA is encouraging waste reduction through its waste minimization program. Many states have adopted waste reduction as a way to effectively manage large and small quantity waste generation. A number of state technical assistance programs are in place to educate generators on waste reduction opportunities and help them implement process changes.

In Minnesota, the Minnesota Technical Assistance Program plans to maximize waste reduction efforts. Much of the emphasis on waste reduction is due to the absence of hazardous waste treatment/disposal facilities in Minnesota. MnTAP believes this approach is working and that assistance at the state level responding directly to generator needs is the best way to reduce the nation's dependence on landfilling.

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Waste Minimization at Air Force GOCO Facilities

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ABSTRACT

Continuing waste minimization efforts at eight aerospace manufacturing facilities owned by the U.S. Air Force have identified significant opportunities for reducing the quantities of hazardous wastes requiring off-site treatment or land disposal. In most instances, these alternatives would allow operating cost reductions from current practices, provide payback of capital investments within 3 years and result in significant liability exposure reductions.

Hazardous waste streams which exhibit the greatest potential for reduction include machine coolants, hydraulic oils, solvents, cyanide wastes, paint stripping wastes, chemical milling wastes and wastewater treatment sludges. The Air Force is now implementing waste minimization measures at its facilities to achieve these benefits and to comply with RCRA requirements. As a part of this program, the Aeronautical Systems Division/PMDA is funding a program to demonstrate zero waste generation at Air Force Plant 44 in Tucson, Arizona.

INTRODUCTION

Interest in waste minization has long been promoted by Federal legislation, including the Federal Water Pollution Control Act Amendments of 1972, the Energy Policy and Conservation Act of 1975, the Used Oil Recycling Act and Department of Defense (DOD) directives such as AFR 78-22 and DODD 19-14. More recently, the impetus for waste minimization has become even stronger. The 1984 reauthorization of RCRA includes bans on landfilling and underground injection of certain waste types and a requirement for certification that waste minimization is being conducted by hazardous waste generators. Similarly, DOD has issued directives requiring zero land disposal of solvents by 1986.

The Aeronautical Systems Division/Facilities Management Division (ASD/PMDA) of the U.S. Air Force anticipated these developments and initiated programs in 1983 to address these issues. Studies at government-owned contractor-operated (GOCO) facilities under ASD/PMDA's cognizance were conducted in 1983 and 1984 to identify resource conservation and recovery activities and opportunities.

The 1984 study demonstrated that, in many cases, plant operators were implementing methods that could substantially reduce waste generation volumes and raw material requirements. However, significant opportunities for waste minimization which appeared both technically and economically feasible but were not being pursued were also identified. In light of these findings and the new certification requirements of RCRA, ASD/PMDA adopted a Waste Minimization Program which includes the study reported in this paper.

STUDY APPROACH

The Earth Technology Corporation was given a contract by ASD/PMDA to assist in implementing the Waste Minimization Program through detailed studies at each GOCO facility where significant opportunities had been identified in the preliminary studies. Each of the eight selected facilities was visited by a two-person study team for periods ranging from 2 to 5 days to review in-plant records, observe current operations and identify waste minimization opportunities. Based on these data, extensive vendor contacts and engineering analyses of planned and potential waste minimization measures, detailed reports were prepared for each plant describing the opportunities for minimization of every hazardous waste stream generated, associated costs and benefits.

The following sections describe the most common waste minimization opportunities identified during the study. These sections, arranged by waste type, include descriptions of the technologies available to minimize each waste type and case studies illustrating the benefits available from implementation.

MACHINE COOLANTS

Machining operations (e.g., milling, turning, grinding) typically utilize a water-soluble coolant diluted to a 2 to 5% concentration with water. The coolant mixture is sprayed directly on the tool-part interface to provide lubrication and dissipate heat, thereby preventing part damage and excessive tool wear. After prolonged use (usually 1 to 8 weeks) the coolant is degraded, as evidenced by ineffective lubrication, rancidity and free-floating tramp oils. Common disposal methods for waste coolants include underground injection and treatment through oil-water separation in industrial waste plants. Waste coolant treatment and disposal costs range from $0.10/gal to $1.00/gal and average $0.30/gal at the eight plants studied, while coolant replacement costs are approximately $0.35/gal (diluted).

Advances in coolant recovery technology have allowed industrial facilities to greatly extend the life of machine coolants. Several systems are commercially available which effectively remove tramp oil and other impurities from waste coolants. Fresh fluids are added as needed to replace lost oils and biocides, and the recycled coolant is returned to the machine sumps for reuse.

Centrifugation is the most common method now used for coolant recycling. Such systems provide high efficiency separation of swarf and tramp oils from coolant. Biocide often is added to the recovered coolant to curtail bacterial growth before it is returned to the machines for reuse. Alternately, systems may be purchased with "flash pasturization" capabilities which negate the need for biocide addition.

The second type of coolant recovery now finding wide application is coalescing plate filtration. These systems utilize series of corrugated plates to enhance gravity separation of swarf and tramp oil from the coolant. Although centrifuges can achieve greater efficiencies than coalescing plate filtration systems, their cost is typically five to ten times that of a plate system.

Three approaches to coolant recycling are commonly employed: (1) connection of all machines to central sump systems with continuous recycling of sump coolants; (2) manual collection of coolants with batch processing in a central location; and (3) use of mobile recycling systems to treat coolants at each machine separately. Although all three approaches will achieve approximately equivalent recovery efficiencies, their economics vary significantly. Mobile systems have the lowest implementation cost but have the highest labor requirements. However, even the comparatively high labor costs of mobile systems are still generally less than conventional coolant replacement labor costs.

The advantages offered by coolant recycling can be seen by examining operations at Air Force Plant (AFP) 4 in Forth Worth, Texas. Coolant use at AFP 4, operated by General Dynamics, is approximately 20,600 gal/yr (undiluted) with replacement costs of $158,500/yr. Waste coolants are disposed off-site by contracted underground injection at a cost of $0.53/gal or $121,200/yr.

Coolant use and waste generation already have been reduced significantly at AFP 4 by using a centrifuge. Six of the plant's largest machines are connected to a centralized drainage system, a high speed centrifuge and a 12,000-gal coolant holding tank. Approximately 500 gal/yr of biocide are added to the recycled coolant to control bacterial growth at a cost of $25,900/yr. This system extends coolant life to over 6 months, or approximately four times that of untreated coolant. A net reduction in plant-wide waste coolant generation rates of approximately 25% is attributable to this system.

Additional measures now under consideration at AFP 4 could result in a reduction in current coolant waste generation rates of 90%. These include:

- Installation of a second high speed centrifuge to reduce downtime and improve recovery efficiency of the existing system (cost $126,000; payback 3.1 years)
- Connection of six additional large machines to the central recovery system (cost $100,000; payback 1.8 years)
- Installation of a chip wringer on the central system to recover excess coolant now carried out on aluminum chips (cost $233,500; payback 0.9 years)
- Installation of a coolant recovery system and collection vehicle for machines not on the central sump (cost $104,000; payback 1.9 years)
- Purchase of a coolant analyzer to allow better control of coolant quality (cost $5,000; payback 0.7 years)

The total estimated cost of these improvements, $570,000, is expected to result in savings of $410,000/yr with projected payback in 1.4 years.

HYDRAULIC OILS

Hydraulic oils are used as internal lubricants in mills, grinders, lathes, stretchers and other metal- and wood-working machines. After extended use, hydraulic oils may become contaminated with water, acids and particulates, leading to a loss of antioxidants and critical lubricating properties. To avoid internal damage to machines, hydraulic oils typically are replaced every 6 to 12 months.

Used oils generally are sold to off-site recyclers for eventual reuse. However, the geographical location of the generator or the presence of toxic constituents in the oil occasionally result in a disposal fee being levied for its removal. During the study, management costs were found to range from a $0.50/gal fee for disposal to revenues of $0.40/gal for recyclable oil. The average waste oil revenues at the eight facilities studied is $0.15/gal. Oil replacement costs average $2.00/gal.

On-site purification of hydraulic oils to prolong their useful life is a viable option for implementation at many facilities. Commercial "off-the-shelf" systems are available which effectively remove contaminants and allow continued oil use. Most of these systems employ cartridge filters to remove particulate matter. Filter sizes ranging from 2 to 10 microns generally are sufficient for removal of all particulate matter of concern. Advanced oil purification systems are equipped with systems for removal of water, acids formed during use and other volatile liquids. Such systems usually function by exposing a thin layer of heated oil to a vacuum, effectively stripping these contaminants from the oil.

Analyses of oils recycled with such systems have consistently demonstrated higher purity levels than those found in new oils. Through the routine purification of hydraulic oils (purification intervals of approximately 1 to 2 months are recommended), useful life can often be extended to 10 years or more.

Labor requirements for on-site purification generally are equivalent to or less than those for routine oil replacement. Mobile purification systems can be attached directly to the machine's oil return line and left unattended. This compares quite favorably with the labor required to periodically drain, flush and refill oil reservoirs and has the added advantage of keeping the machine in use during servicing.

Rockwell International's operations at AFP 3 in Tulsa, Oklahoma, illustrate the potential benefits of an on-site oil purification program. Approximately 12,300 gal/yr of waste hydraulic oil are drained from metal-working machines and sold to a local oil recycler for $0.15/gal. It has been estimated that two advanced, portable purification systems could reduce Rockwell's hydraulic oil use by 90%. Based on manufacturer's estimated operating costs of $0.20/gal, avoided new oil purchase costs of $2.00/gal and lost resale revenues of $0.15/gal, net annual savings of approximately $17,800 are projected. Based on system acquisition costs of $28,000, payback could be expected in under 2 years. Additional unquantified savings would result from reduced maintenance labor requirements.

SOLVENTS

A wide variety of waste solvents were encountered during the course of the study. Table 1 lists these wastes and their cumulative generation rates and disposal costs at the eight facilities studied. The bulk of the solvent wastes result from cleaning/degreasing operations. Solvent wastes typically are disposed off-site by underground injection, landfilling, combustion in industrial furnaces or boilers and high temperature incineration. Solvents with wide commercial applicability such as 1,1,1-trichloroethane and Freon usually are sold to off-site recyclers for reclamation and reuse. The eight facilities studied generate 302,650 gal/yr of solvent wastes. Management costs for these wastes total $254,740/yr and average $0.84/gal.

Several viable approaches exist for reducing solvent waste generation, including on-site distillative recovery and reuse as fuels. In most situations, improved segregation of solvents at the point of generation and/or accumulation is required to achieve the maximum possible benefits from these methods. In addition, many facilities could markedly increase the quantities of solvents resaleable to off-site recyclers through improved segregation.

Waste Solvent Segregation

As shown in Table 1, over 75% of the waste solvents generated at the GOCO facilities were mixed with other solvents, water, paints and other wastes, usually during their accumulation. These mixed solvents generally are not suitable for recovery or use as fuels because of this contamination. It is estimated that 50 to 75% of these solvents could be recycled or used as fuel supplements if properly segregated. In every situation encountered during the study, proper segregation appeared to be achievable by increasing the number of containers used for accumulation and training workers in the importance of waste segregation.

On-Site Solvent Recycling

Many solvents used at the GOCO facilities studied are excellent candidates for on-site distillative recovery and reuse. Although distillation has been used widely for many years in commercial facilities to extend solvent life, concern exists over the use of recovered solvents in military applications. Solvents purchased for use in cleaning, degreasing and painting operations usually must meet rigid military specifications (mil specs). Two approaches have been suggested for resolving this problem: (1) recovered solvents can be tested to assure that they meet mil specs and are suitable for reuse without restriction and (2) recovered solvents can be assumed not to meet mil specs and their use restricted to noncritical operations. The former approach is being used successfully at one of the facilities studied.

AFP 59 in Binghamton, New York, operated by General Electric (GE), has been using a simple batch distillation system for 7 years to extend the useful life of 1,1,1-trichloroethane (TCA) degreaser solvents. Simple pH and specific gravity analyses are used to determine when TCA in the degreasers must be replaced and to verify that the distilled TCA is suitable for reuse. This approach has resulted in a reduction of approximately 70% in waste TCA generation at AFP 59.

In addition, GE now is evaluating the use of additives to further extend solvent life. Acid acceptors and white metal stabilizers present in commercial blends of TCA will become depleted through continued use and eventually will render the solvent unsuitable for reuse. Replacement additives, available from several solvent manufacturers and suppliers, can be used to replenish lost additives, thus allowing continued reuse of the solvent.

The second alternative, restricting the use of recovered solvents, is particularly well suited to painting cleanup operations. The largest single type of waste solvent at the facilities studied, painting cleanup waste, typically contains approximately 50% methyl ethyl ketone (MEK) from the cleanup of spray guns and other equipment. (Some facilities recently have switched from MEK to nonregulated cleanup solvents to comply with VOC emission requirements.) As these cleanup solvents need not meet mil specs, they are excellent candidates for on-site distillative recovery and reuse. Segregation of concentrated paint gun residues from the washing solvents can further increase the efficiency of recovery measures.

The efficiency of distillative recovery operations is highly dependent on the type of equipment utilized. The continuous type side stills used on many vapors degreasers do extend solvent life considerably, but they also produce a solvent-rich waste stream. Analyses have shown that many side stills produce residues containing 95% or more solvent. Several manufacturers now offer batch systems which generate a waste stream that is virtually solvent-free. Recovery efficiencies of 95% and recovered solvent purity levels in excess of 99% are commonly reported with such systems.

The economics of on-site solvent recovery usually are very attractive. As an example, the system used by GE at AFP 59 reduces waste generation and solvent purchases by approximately 7,500 gal/yr, resulting in an estimated net savings of $50,400/yr. The distillation system was purchased in 1978 at a cost of $3,500.

Table 1
Solvent Waste Generation at Air Force GOCO Facilities

	WASTE STREAM	RATE (GAL/YEAR)	DISPOSAL COST
1.	Methyl Ethyl Ketone Paints, Thinners	133,800	$144,300
2.	Mixed Solvents	102,500	$113,400
3.	1,1,1-Trichloroethane	40,450	$ 20,600 (revenue)
4.	Trichloroethylene	18,500	$ 13,000
5.	Freons	1,100	$ 500 (revenue)
6.	Naptha	2,500	$ 1,320
7.	Isopropyl Alcohol	600	$ 320
8.	Other Segregated Solvents	3,200	$ 3,500
	TOTALS	302,650	$254,740

Waste Solvents as Fuels

Many waste solvents contain considerable energy and are excellent candidates for use as supplemental fuels in boilers and furnaces. Six of the eight facilities surveyed currently sell a portion of their waste streams to off-site fuel blenders. However, none of the facilities studied reuse waste materials on-site as fuels, even though most do operate industrial boilers to meet plant steam needs. Although nonhalogenated waste solvents such as MEK, Stoddard solvent and acetone could be used to provide a small portion of these energy needs, uncertainties regarding the eventual regulatory requirements which will apply to hazardous waste fuel use have deferred such undertakings at the facilities studied.

In its Nov. 29, 1985 promulgation of waste oil burning regulations (*Federal Register,* 49164), the U.S. EPA has indicated that regulations addressing the use of hazardous wastes as fuels will be promulgated in 1986. Current regulations, contained in 40 CFR Part 266, do not address issues critical to the decision process for facility operators: equipment permitting and waste testing requirements. It appears that the planned regulations will have significant impacts on the economics of waste fuel use, particularly for facilities which generate small quantities of hazardous waste suitable for use as fuels.

The average GOCO facility surveyed generates approximately 23,000 gal/yr of nonhalogenated waste solvents suitable for use as a supplemental fuel. Assuming an average disposal cost of $0.85/gal, an average waste heat content of 110,000 Btu/gal and fuel costs of $6.00/mmBtu, it is projected that the average GOCO facility could save $34,000/yr in fuel and disposal costs through the use of waste solvents as fuels. However, as the costs of regulatory compliance and boiler system engineering modifications could overshadow these potential savings, it now appears prudent to delay implementation decisions until the U.S. EPA's final regulations are promulgated.

CYANIDE WASTES

Cyanide is used widely at Air Force GOCO facilities in electroplating processes. Cyanide, present in cadmium, silver, zinc and other electroplating solutions, typically renders the spent solutions, tank sludges and rinsewater treatment sludges hazardous. These wastes typically are treated on-site through cyanide destruction but also may be sent off-site for treatment or disposal. In addition to conventional cyanide destruction, two alternative cyanide-free plating technologies are being considered for application at GOCO facilities; Ion Vapor Deposition (IVD) and acid plating.

Ion Vapor Deposition

IVD technology is now being considered at AFP 4 in Fort Worth, Texas, as an alternative to cyanide-cadmium plating of aluminum aircraft components. The system, which relies on the deposition of ionized aluminum in a vapor form, would virtually eliminate waste generation from the cadmium plating line and would reduce plant-wide cyanide waste generation by 80%. Cadmium consumption would decrease significantly, owing to the high efficiency of IVD, and the need for continuous rinsing would be eliminated, thus reducing wastewater generation.

Acid Cadmium Plating

A promising alternative available for cadmium cyanide plating replacement appears to be acid cadmium plating. One such plating solution is manufactured by LeaRonel, Inc. of Freeport, New York, under the trade name "Kadizid" plating solution. This proprietary batch solution consists of cadmium oxide, sulfuric acid, brightener, starter and stabilizer compounds. Lockheed-Georgia Company at AFP 6 incorporated this acid cadmium plating system in August 1983. Lockheed has found no reduction in product quality following changeover, but has realized a slight reduction in operating costs and total elimination of cyanide operations.

PAINT STRIPPING WASTES

Two of the eight GOCO facilities studied conduct large-scale paint stripping operations. Paint stripper, typically a methylene chloride/phenolic compound, is rinsed with water from the part being stripped and collected in floor drains for bulk off-site disposal or on-site treatment in wastewater systems. Waste generation at these two facilities totaled approximately 500,000 gal/yr in 1984 with off-site disposal costs of $117,000/yr. Three approaches for reducing the generation of paint stripping wastes are being considered by the GOCO facilities: (1) segregation, (2) on-site treatment and (3) alternative stripping techniques.

Segregation

In both facilities involved in large-scale stripping, significant quantities of other nonhazardous wastes also could enter the stripping waste collection systems by virtue of their designs. Improved segregation of paint stripping wastes from floor washings, noncontact rinsewater and surface runoff could significantly reduce waste generation at these facilities. For example, segregation measures recommended at Lockheed's AFP 42 operations in Palmdale, California, are projected to cost $2,000 and would result in a 70% reduction in waste generation with disposal cost savings of $46,000/yr.

On-Site Treatment

In conjunction with waste generation reduction techniques or alone, waste treatment represents a viable approach to reducing off-site waste disposal. AFP 3 in Tulsa, Oklahoma, is now proceeding with the design of an on-site paint stripper waste treatment system as part of a long range wastewater treatment plan. The planned system involves batch treatment of liquid stripper wastes with hydrogen peroxide in the presence of an iron catalyst to oxidize organics. Treated paint stripping waste then would be discharged to the plant's general industrial waste treatment system for further treatment.

Through this treatment scheme, all stripper waste, except sludges currently generated in collection sumps, would be eliminated from off-site disposal. Some increase in sludge volumes from waste treatment would occur, but this would be insignificant. Although the economics of the planned system are not available, significant savings are expected to result as AFP 3 stripper waste generation approaches an anticipated rate of 1.2×10^6 gal/yr.

Dry Media Stripping

Several alternative paint stripping techniques currently are being studied by DoD. One of the most promising methods is dry media stripping with plastic beads. Hill Air Force Base in Ogden, Utah, has successfully demonstrated plastic media stripping for aircraft renovation. In the Hill AFB process, conventional sand blasting equipment is being employed with recoverable plastic beads for paint removal. A dry waste of paint and plastic beads is generated which can be separated to produce a relatively small volume of paint waste. Waste volumes and labor requirements have been shown to be significantly lower than conventional wet stripping methods. A full size dry media stripping demonstration operation currently is being implemented at Hill AFB.

In addition to Hill AFB, several other DoD facilities are interested in plastic media stripping methods including Alameda NARF and Pensacola NARF. At Pensacola, dry stripping currently is being tested for fiberglass helicopter components. Problems with dry media stripping appear to be control of the stripping operation to prevent aircraft damage and dust generation and collection. However, current development efforts are directed at alleviating these problems through careful design and operation of stripping systems.

WASTEWATER TREATMENT SLUDGE

Five of the GOCO facilities studied operate on-site industrial wastewater treatment plants. Approximately 2.9×10^6 lb/yr of sludge from three of these plants are disposed off-site at a cost of $112,000/yr. The other two facilities produce 16.3×10^6 lb/yr of sludge for on-site disposal. Three of the GOCO facilities studied are implementing renovations expected to reduce sludge generation by 30 to 90% at each facility. Additional reduction measures are under consideration at all facilities.

The most significant sludge reductions planned will result from the installation of more efficient sludge dewatering systems. Two of the GOCO facilities studied are planning to replace older vacuum filtration systems, now producing sludge with approximately 20% solids, with presses expected to increase solids levels to 35% or greater. At AFP 3 in Tulsa, Oklahoma, a sludge dewatering system will be utilized to dewater a 2% solids slurry now being disposed on-site in lagoons. The planned AFP 3 renovations also will include improved treatment measures which should allow delisting of the dewatered sludge.

Increasing chemical waste storage capacity often can allow significant decreases in sludge production. During the study, several waste treatment plant operators noted that a lack of adequate holding capacity for waste acids and bases often required the use of purchased chemicals to achieve neutralization. If additional storage capacity were available, acidic and caustic wastes could be mixed to achieve neutralization, thus reducing chemical usage and sludge production.

Another waste minimization option being considered is the use of high-performance neutralizing and coagulating agents. Several

chemical manufacturers now are offering substitutes for conventional treatment compounds such as lime, caustic soda, ferric chloride, ferric sulfate and aluminum chloride. These high performance substitutes reportedly decrease sludge bulk and improve dewatering characteristics. In many situations, plant throughput can be increased significantly through the use of these compounds, thus reducing or eliminating expansion needs.

FUTURE DIRECTIONS

It is ASD's intent, as demonstrated by this program, to vigorously pursue all viable approaches for waste minimization at the GOCO facilities for which it has responsibility. As appropriate, funding for implementing waste minimization measures is being incorporated into current and future plant budgets.

AFP 44 in Tucson, Arizona, is being used to demonstrate the feasibility and benefits of waste minimization. In conjunction with the plant operator, Hughes Aircraft, ASD already has implemented measures which have reduced waste generation by 99% from 1983 levels. These measures include a state-of-the-art wastewater treatment system which provides plant makeup water that is cleaner than available city water, a coolant recycling system and computerized plating lines. Future plans at AFP 44 call for installation of a high-temperature hazardous waste incineration system for organic wastes, replacement of cyanide plating lines with IVD systems, and on-site solvent recycling and reuse. It is ASD's goal to demonstrate the complete elimination of hazardous waste generation at AFP 44 and eventually transfer these minimization technologies and management approaches to the other facilities for which it is responsible.

Defense Environmental Leadership Project Study of Industrial Processes to Reduce Hazardous Waste

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ABSTRACT

The U.S. Department of Defense (DOD) operates industrial facilities that repair and recondition planes, helicopters, ships, tanks and other vehicles and equipment. At these facilities, paint stripping, solvent cleaning and metal plating are the industrial processes that produce most of DOD's hazardous wastes. In policy directives issued in 1980, DOD directed the armed services to significantly reduce the generation of hazardous wastes.

CH2M HILL was contracted by the Defense Environmental Leadership Project and the U.S. Army Corps of Engineers to evaluate 42 cases of industrial process modifications attempted by the three armed services to reduce their generation of hazardous wastes. Process modifications evaluated included resource recovery and recycling, source separation, raw material conservation, material substitution, improved housekeeping practices and the development of innovative manufacturing techniques.

INTRODUCTION

Traditionally, waste producers have not paid the true costs of disposal. Prior to the twentieth century, these costs were borne by water consumers and paid for in disease and premature death. At the turn of the century, an understanding of the link between polluted water and disease and the adoption of water treatment led to a dramatic decline in the incidence of water-borne epidemics. Still, the costs of waste disposal were borne by water consumers, this time in the cost of water treatment.

Gradually, pressure was exerted to shift the burden from water consumers to waste dischargers. Industries and communities were required to treat their wastes sufficiently to protect downstream users.

As our understanding of the long-term effects of trace quantities of contaminants improved and our analytical capabilities for detecting minute concentrations developed, increasingly stringent treatment requirements were placed on water and wastewater treatment plants. The logical result has been to shift the burden of compliance closer to the individual producers of hazardous wastes, since segregated concentrated wastes can be treated more efficiently before they are mixed or diluted.

Now that producers are faced with the true costs of disposing of their hazardous wastes, it has become increasingly evident that waste minimization is rapidly becoming an economic necessity. Waste minimization can be accomplished by the recovery and recycling of waste materials or, preferably, by modifying industrial processes to reduce or eliminate the production of the offending waste products.

Since 1980 it has been DOD policy to limit the generation of hazardous waste through alternative procurement policies and operational procedures that are both environmentally attractive and fiscally competitive. The DOD directed the Army, Navy and Air Force to reduce quantities of hazardous waste, when feasible, through resource recovery and reclamation, recycling, source separation and raw material conservation.

In carrying out the intent of these policies, many studies have been performed that recommended industrial process modifications which, if successfully implemented, have the potential to significantly reduce the generation of hazardous wastes at the source, rather than treating these wastes at end-of-pipe facilities. Several modifications have been successfully implemented; however, many other suggested changes either have not been implemented or have failed to meet their goals.

While there are specific circumstances and reasons behind the success, or lack of success, of each modification attempted, two factors have been an integral part of each of the successful process modifications; one or both of these elements has been missing from those modifications that have been less than successful. Very simply stated, in process modifications that were successfully implemented, the production people were sufficiently motivated to make the change, and the technologies were "elegant in their simplicity." Factors that motivated personnel included an improvement in production rate and quality, a reduction in overall costs, a decrease in manpower requirements and a decrease in the quantity of hazardous wastes to be disposed of. Technologies that were elegant in their simplicity were easy to operate and maintain, reliable and cost-effective. Successfully implemented process modifications combined effective technology and motivated personnel to significantly reduce hazardous waste production by substantially changing the process, substituting raw materials, or recovering and reutilizing waste by-products.

This paper reviews a few of the more useful examples of industrial modifications attempted by the armed services. These examples include paint stripping modification, solvent recovery, metal plating modification and the elimination of solvent cleaning. These modifications affect the major sources of hazardous waste generated by the DOD. The paper also summarizes the conclusions of the project on factors contributing to the successful implementation of process changes. Detailed analyses can be found in project reports[1,2] and in a previous paper.[3]

PAINT STRIPPING

Paint stripping, in preparation for reconditioning and recoating, is performed at virtually every DOD industrial facility. In a typical paint stripping operation, sprays or baths containing

acidic methylene chloride, phenolic compounds or hot alkaline sodium hydroxide solutions are employed to loosen and dissolve old paint. After the paint softens, the resulting solvent-paint mixture is scraped off. In addition, hard to remove paint is machine sanded, often resulting in damage to the metal.

The solvent-paint mixture falls to the floor, where it attacks the concrete and makes the floor slippery. The floor is frequently washed with water to reduce the slipping hazard. For a typical stripping operation on a fighter aircraft, thousands of gallons of solvent-laden wastewater are generated. Wet paint stripping is labor intensive, dirty and imposes a significant burden on waste treatment facilities.

Several alternative paint stripping processes have been studied by private industry and the military. Among these are dry media blasting, laser stripping, flash lamp stripping, water jet stripping, CO_2 pellet blasting and cryogenics. The most promising of these techniques is dry media blasting using recoverable plastic media.

In plastic media stripping, small, angular plastic particles are air blasted at the painted surface, causing the coating to dislodge. The key parameter for the successful use of plastic media blasting is hardness. The paint must be softer than the plastic media, which, in turn, must be softer than the underlying substrate. Through careful control of the size of the particles and the conditions of the process, the used plastic media can be separated from the loosened paint particles and recycled. Generation of wet hazardous waste (solvents and paint sludge in water) is completely eliminated. A small volume of dry hazardous waste is produced.

While there are significant advantages to the plastic media stripping process, care must be taken in adapting it to specific applications. Stripping of thin-skinned aluminum, magnesium, fiberglas and other composite surfaces requires skilled operators. These operators must carefully select and control several variables (e.g., media hardness, roughness and size; blast pressure; stand-off distance; application angle; nozzle size; and feed rate) so that surfaces are not damaged during stripping.

Following extensive testing on aircraft components to demonstrate the effectiveness and safety of the process, personnel at Hill AFB stripped a complete F-4 fighter plane in July 1984. The aircraft was completely stripped with one-tenth of the manpower required for conventional wet paint stripping. This test demonstrated that the process is much less labor-intensive than solvent stripping. In addition, greater control in stripping was achieved compared to that achieved with wet paint stripping and sanding. This degree of control resulted in reduced damage to underlying surfaces.

A full-sized plastic media blasting booth has been constructed at Hill AFB based on the prospects of reduced manpower requirements and favorable environmental impact. The booth incorporates five blast machines, a live floor vacuum system to provide ventilation and particle and dust removal, and a separation system for media recovery and reuse. This booth was used to blast strip an F-4 aircraft in an elapsed time of 5.4 hours.

The new booth cost $650,000 to purchase and install. Yearly savings are anticipated to be $5,600,000, resulting in a 6-week payback period. A significant portion of this savings is attributable to a reduction in hazardous waste from the currently estimated 10,000 lb of wet hazardous sludge per aircraft to 320 lb of dry paint chips and decomposed plastic media per aircraft.

The Naval Air Rework Facility (NARF) in Pensacola, Florida, has successfully stripped paint from aircraft and helicopter parts using plastic media. Paint stripping of parts is currently being done in enclosed glove boxes and walk-in blast rooms. Pensacola's long-range plans involve converting two helicopter hangars to accommodate dry media stripping. These plans have been postponed pending resolution of OSHA regulations that prohibit people from working in rooms in which blasting is carried out with "organic" media. Concern was expressed that generation of dust might post a possible explosion hazard.

The Army is utilizing plastic media blasting to strip paint from composite helicopter components at Corpus Christi Army Depot in Texas. Following a demonstration of the technology at Hill AFB, Republic Airlines installed a plastic media paint stripping system in its repair facilities in Atlanta, Georgia. Using this system, they have successfully stripped the paint from more than 30 DC-9s. Plastic media paint stripping is rapidly becoming the state-of-the-art for paint stripping.

The development of the plastic media blasting technology at Hill AFB in Ogden, Utah, is a clear example of the key elements that contribute to the successful implementation of a modification. The process is simple. Conventional sand blasting equipment was adapted to include media recovery and separation of the media from the waste paint chips and dust. The modification was championed by R. Roberts, a staff member at Hill AFB, who recognized the environmental disadvantages of the existing methods used for stripping planes. He tried many processes before discovering, developing, implementing and promoting dry plastic media stripping.

The DOD has estimated that millions of dollars could be saved annually and that the generation of millions of gallons of hazardous wastewaters could be avoided by switching to plastic media paint stripping at all facilities.

RECYCLE OF SOLVENTS

Organic solvents are used at virtually every military facility. Trichloroethylene (TCE), 1,1,1-trichloroethane and perchloroethylene are used in vapor degreasers, and mineral spirits, such as Stoddard solvent and Varsol, are used in cold cleaning baths. Alcohols and Freon commonly are used for metal preparation and precision cleaning of electronic equipment. Solvents also are used in painting operations. Methylene chloride commonly is used to strip paint and carbon from metal surfaces, and toluene commonly is used to thin solvent-based paints. Volatile solvents, such as methyl ethyl ketone (MEK) and xylene are used to clean painting equipment.

The safe disposal of waste solvents can cost more than $100 per drum. This cost is expected to increase substantially as a result of RCRA regulations banning the disposal of liquid hazardous wastes on land. In addition, when waste solvents are disposed of, fresh solvents must be purchased. A recent study estimated that DOD purchases and disposes of approximately 50,000 drums of cleaning solvents per year.[4] The recycling of waste solvents can result in a savings of hundreds of dollars per drum due to the elimination of the costs of waste disposal and initial purchase of virgin material.

Solvents most frequently are reclaimed by batch distillation which typically consists of a still pot, a heat source and a condenser. The waste organic mixture is loaded into the still pot, and heat is applied to the contents, causing the mixture to boil. Organic vapors separate from the waste mixture and pass overhead to the condenser. Cleaned organic fluid then is collected for reuse, and the still bottoms are disposed of as hazardous waste.

An atmospheric still can reclaim organic solvents that have boiling points of less than 325 °F. By adding vacuum, a distillation unit can be used to recover organic fluids that have atmospheric boiling points of up to 500 °F while maintaining a 300 °F limit in the still's pot to limit degradation. A still is usually heated directly by electricity or indirectly by steam generated by an electrically heated boiler.

Waste solvents can be collected and transported to a centralized distillation facility for recovery, or they can be recycled at the point of use. DOD facilities have successfully used both ap-

proaches. Regardless of where the distillation occurs, it is critical that waste solvents be properly segregated and stored so that various solvents and impurities do not mix.

The main advantage of operating a large centralized facility is that capital costs can be recovered quickly due to economies of scale. A centralized facility can redistill large quantities of various types of solvents. The disadvantages of a centralized facility are that, since many different types of solvents are recycled, great care must be taken with waste segregation and sample analysis, and solvents must be transported to and from the point of use.

Decentralized facilities are sometimes preferable because the waste generator has total control over the recycling operation. Since only a few types of solvents are redistilled at small facilities, laboratory analysis of waste solvents often is not required. Labor-intensive transportation and segregation activities also are eliminated.

A centralized facility is dependent on a dedicated individual to initiate and supervise the operation of the system and on an enthusiastic staff dedicated solely to solvent collection, analysis, recycling and distribution. In a decentralized facility, more personnel (foreman and operators) must be persuaded to adopt solvent recovery as part of their routine. Both centralized and decentralized solvent recycle facilities have been successfully implemented by DOD.

Warner Robins AFB, Macon, Georgia, has had a centrally operated atmospheric still since August 1982. Their organic fluid recovery system consists of a single-stage batch still, a water separator and an electricallly powered steam generator. The still can operate with a pot temperature up to 300 °F and can reclaim organic fluids at a rate of 55 gal/hr. The still has been used to reclaim trichloroethane, Freon-113 and isopropanol at recovery rates of 70 to 99%. From the initial startup in August 1982 to Dec. 31, 1984, it was estimated that more than $230,000 was saved due to a reduction in the need for virgin material and in hazardous waste disposal costs. Reclamation of the used chemicals cost only $13 per drum, whereas disposal of the chemicals and repurchase of new materials would have cost from $250 to $500 per drum.

Robins AFB has been able to successfully recycle solvents in a large-scale operation because of careful waste segregation, storage and transportation. Site managers are responsible for segregating and labeling waste drums at 30 different collection areas, Before solvents are reclaimed, samples are analyzed to confirm the labeling. Samples are also analyzed after distillation to ensure that they meet appropriate military specifications.

Solvent recycling has been successful at Robins AFB because of a strong commitment from management to reduce the quantities of waste solvents that must be disposed of. More importantly, production personnel have cooperated with the recycling team so that waste solvents can be segregated, labeled, analyzed, transported and redistilled in an orderly and systematic fashion.

One major factor in the success of the Robins solvent recovery program was the commitment of O.H. Carstarphen, the solvent reclamation manager. Through his perseverance, colleagues and management were convinced to supply equipment and manpower to set up and run the program. In addition, Mr. Carstarphen had extensive experience in distillation technology, and he selected proven equipment that was reliable, simple to operate and easily maintained.

An example of a decentralized facility is Norfolk Naval Shipyard in Norfolk, Virginia, which installed a $10,000 nonfractionating, batch still to recover waste solvents generated in the paint shop during cleaning operations. This small still, which has a capacity of 2 gal/hr, is used to recover methyl isobutyl ketone, MEK, epoxy thinners and mineral spirits. Operators can operate the still with or without a vacuum system depending upon the distillation temperature required. After a 15-minute startup period, the still runs without operator attention. More than 80% of the waste solvent is recovered at a cost of about $0.15/gal.

The recovery process was successful at Norfolk because of the personal dedication of J. Coulter, the paint shop foreman, and the straightforward, uncomplicated operation of a technically innovative system.

METAL PLATING

Plating is defined as the deposition of a layer of metal on the surface of a base metal for the purpose of changing the properties of the base metal. Plating may be used to improve the appearance of the metal (decorative plating), to increase its resistance to corrosion or to improve its engineering properties (hardness, durability, solderability or frictional characteristics). The principal metals used for plating at military facilities are cadmium and chromium.

The major discharges of hazardous waste from typical metal plating facilities are rinsewater contaminated by drag-out from various cleaning and plating baths, cleanup of spills, disposal or acid and alkaline cleaners and occasional plating bath dumps.

Sacrificial cadmium coatings normally are applied to protect the base metal, which is typically iron or steel. A thin surface coating normally is applied for decorative purposes or to provide corrosion protection, improve wear or erosion resistance, or reduce friction. Many parts can be efficiently plated in a few tanks, but a significant amount of waste rinsewater is produced due to the drag-out of plating solutions on the parts.

Cadmium almost universally has been plated from alkaline cyanide baths, due to the improved plate resulting from the stable cadmium cyanide complexes. Unfortunately, cadmium cyanide baths are costly, dangerous to operate and expensive to treat.

Lockheed's plating shop located in Air Force Plant No. 6, Marietta, Georgia, switched from an alkaline cyanide cadmium bath to a proprietary acidic noncyanide cadmium bath. Lockheed found that the product quality improved as a result. However, more careful process control was required. Although the new plating solution, which costs approximately $3/gal, is more expensive than the old cyanide formulation, reduced waste treatment costs have resulted in a net cost savings for this modification. As a result of this modification, alkaline chlorination for the treatment of cyanide no longer is needed.

The new process was implemented primarily to reduce the hazards associated with the operation and disposal of cyanide baths. An improvement in quality and a reduction in total costs led to the permanent adoption of the modification. In addition, the process required a minimal amount of change from the old method, and existing personnel had no trouble adapting to it.

Getting rid of both cadmium and cyanide was the goal of a modification attempted at North Island NARF in San Diego, California. Wet cadmium plating was replaced by a method of coating parts with aluminum using ion vapor deposition (IVD) for corrosion resistance. This substitution eliminated the environmental problems associated with cadmium and cyanide. For the past 7 years, metal parts such as landing gears, bolts and tail hooks have been plated with the dry IVD process.

Advantages of the process include safer working conditions, an end product that can withstand higher operating temperatures, improved throwing power and better adhesion of the aluminum coating compared to that achieved with cadmium. Despite these advantages, this process has not realized its potential.

The process is considerably more complex and requires more labor and skill than cadmium plating. For this reason, the process has been used for only a few parts, and new parts are evaluated on an individual basis to determine the preferable plating technique. The process change has not significantly reduced the amount of

cadmium plating performed at the facility. In addition, there was no champion who assumed responsibility for implementing the modification and ensuring its success.

Chromium is used principally in the remanufacturing of worn parts whose replacement with new parts would not be feasible or economic because of their unique design. Remanufacturing consists of machining the worn part or stripping a portion of the old plate, overplating it with a thick layer of chromium (hard chromium plating) and machining it back to original specifications. To achieve the required thickness of chromium, parts typically are plated for more than 24 hours as opposed to minutes required for cadmium plating. In contrast to cadmium plating, many tanks are needed for a few parts, and drag-out losses are slight. Lack of drag-out creates a buildup of contaminants in the plating bath, and the resulting bath dumps are the major source of waste from hard chromium plating.

Pensacola NARF and Charleston NSY tested a vapor recompression evaporator system for the recovery of chromium from hard chromium plating rinsewater. The system consisted of a cation exchange unit used for the removal of contaminating cations and a vapor recompression evaporator used to concentrate the cleaned rinsewater to plating bath strength.

There were several reasons for the lack of success of this modification. The initial feasibility evaluation was based on the amount of drag-out experienced from decorative chromium baths rather than the significantly lower quantity of chromium available from hard chromium plating. The equipment was complicated and required excessive operation and maintenance attention. The system was plagued by the failure of seals and by severe corrosion of the carbon steel compressor.

Despite the fact that the testing programs were championed by Ms. D. Preble (Pensacola) and B. Mordecai (Charleston), the complexity of the chosen equipment and the faulty assumptions used for the initial feasibility evaluation doomed this project to failure.

As a result of the lessons learned from the failure of the vapor recompression evaporator system, the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California, chose other methods to modify the hard chromium plating process at Pensacola NARF to reduce rinsewater flows and recover the chromium. They retrofitted an existing countercurrent rinse tank with a recirculating spray rinse system. This new rinse system reduces rinsewater usage sufficiently enough to allow all the rinsewater to be used for plating bath makeup. A pump recirculates rinsewater through eight high-velocity spray nozzles located around the perimeter of the rinse tank. The pump is activated by a foot pedal as parts are lowered into the empty tank. Clean rinsewater is available via a hand-held sprayer. After repeated use, a portion of the rinsewater is pumped through a cloth filter into the plating tank and added to the plating bath to replace water lost through evaporation. Plating baths are operated at elevated temperatures to increase the rates of both evaporation and plating.

These modifications reduced the use of fresh water from 350,000 gal/mon for countercurrent rinsing to about 1,200 gal/mon for spray rinsing. Since this amount was less than the evaporation rate, all of the spray rinse was returned to the plating bath, resulting in a zero discharge condition. A total savings of approximately $25,000 per year per bath was projected, principally due to reduced industrial wastewater treatment costs.

Without drag-out to aid in removal of contaminants from the bath, a cleanup process was required to reduce the need for plating bath dumps. An electrolytic bath purification system was installed to continuously remove cations from the chromium plating solution. The system uses cathodes contained within membrane modules to selectively precipitate cation impurities from the plating solution and anodes to oxidize trivalent chromium to hexavalent chromium. Hexavalent chromium ions remain on the anode side of the membrane and are returned to the plating bath.

The purification system did not effectively remove contamination from the chromium plating bath during a trial run. The system experienced a failure of the membrane modules caused by a supplier's change of material. Replacement of the membrane modules is expected to rectify the problem, but further testing is required before this technology can be recommended at other DOD facilities.

NCEL implemented these process modifications at Pensacola as a prototype system. Although NCEL has proven that the spray rinse system is effective in removing drag-out, plating personnel remain skeptical about the effectiveness of the system. Despite resistance from platers, there are plans to construct a permanent spray rinse and bath purification system because of the prospects of reduced wastewater flows and treatment costs.

At other military installations where the spray system was implemented, the rinsewater modifications were received more favorably because an extensive training program was provided prior to startup. In addition, engineering and management personnel have been very supportive of the process modifications. That these plating modifications have succeeded is due in large part to the dedication of C. Carpenter of NCEL, who originated the new system, diligently supervised its implementation and remained available for ongoing consultation.

ELIMINATION OF SOLVENT CLEANING

Prior to servicing, tactical vehicles and equipment used at Army bases typically are washed and cleaned at a common washrack located at individual motor pools. Each base as 2 to 45 washing locations with a total of 30 to 80 washracks. Exterior washing involves removing road dirt and sediment from tracked and wheeled vehicles. Detergents and solvents sometimes are used to assist in exterior cleaning.

Scheduled maintenance of tracked vehicles usually is preceded by removing the engine from the vehicle and cleaning both the engine and its compartment. Cleaning prior to servicing often removes large quantities of petroleum, dirt and vegetation. Solvents regularly are used to assist in the cleaning operation.

Vehicle washing produces a large volume of wastewater, which is principally contaminated with soils and minimal concentrations of oils and organic material. Maintenance produces low flows of wastewater that are contaminated heavily with oils, greases, solvents and other organic contaminants. Conventional Army practice has been to perform both washing and maintenance on open wash stands, with the resulting large flow of contaminated wastewater discharging to the base stormwater system. Many facilities were having difficulty meeting wastewater discharge permit requirements. In addition to a lack of wastewater treatment, other deficiencies of the combined washing facilities include inadequate water pressure, ineffective solvent and oil collection facilities and undependable steam cleaners.

Planning for process modifications to reduce water and solvent use began in 1974 at the Corps of Engineers Construction Engineering Research Laboratory (CERL), Champaign, Illinois. J. Matherly of CERL developed the concept of segregating external vehicle cleaning from maintenance servicing so that the resulting two waste streams can be treated separately. It was Mr. Matherly's influence that promoted the planning and installation of the segregated cleaning and maintenance facilities at Fort Polk and Fort Lewis.

Fort Polk, Louisiana, has two central vehicle wash facilities, each consisting of a large washing basin or "bird bath." Two staggered rows of 24-in. steel pipes were installed at the bottom of each lane. This configuration causes a teetering action when a

tank or other tracked vehicle drives through. The tracks extend through their entire range of motion as they move over the corrugations on the bottom of the bird bath. This movement dislodges caked-on soil. Water monitors (spray cannons) provide secondary cleaning. Facilities are provided with hoses to clean the insides of vehicles after they exit the bird bath. Waste washwater is treated in a sedimentation lagoon and reused.

J. Kelley of Fort Polk developed this simple concept for cleaning heavily soiled vehicles and implemented its use at his facility. Aiding in the adoption of the process was a significant reduction in manpower. At the old washracks, it took an estimated 7 manhours to wash a tracked vehicle. At the central wash facilities, only 0.5 manhours were needed to wash a tracked vehicle.

At Fort Lewis in Washington, D. Hanke, Chief of the Sanitation Branch, implemented the program to segregate cleaning and maintenance facilities in response to notices of violations caused by the discharge of polluted stormwater from the facility.

In contrast to Fort Polk, which uses predominantly tracked vehicles and has heavy soils, Fort Lewis has light soils and uses mainly wheeled vehicles. For these local conditions, central vehicle wash facilities were developed that consisted of individual wash stations with high-pressure, high-volume (30 gal/min of 90 lb/in.^{2} water) hoses. These facilities met local needs better than the bird bath installation used at Fort Polk.

Waste washwater is reused after treatment in a simple gravity (API) oil/water separator and intermittent sand filters. At one of the vehicle wash facilities, water is not recycled but is discharged to the sanitary sewer instead.

With the lower water pressure in the old system, cleaning a vehicle required approximately 2 hrs. With the new high-pressure system, a tracked vehicle can be washed in approximately 20 to 30 min, and a wheeled vehicle can be washed in 15 to 20 min.

At Fort Lewis, facilities were designed to provide a covered location for scheduled maintenance to exclude rainwater and thereby limit the amount of solvent- and oil-laden wastewater. High-pressure, hot water cleaners successfully remove oil and grease from engine compartments, eliminating the need for solvents and detergents which promote oil emulsification and complicate treatment. The resulting low volume of oil-laden wastewater then is treated in gravity oil/water separators and discharged to the sanitary sewer system.

The combination of reduced solvent use, separation of exterior cleaning from vehicle maintenance, installation of oil/water separators and recirculation of washwater has led to a 90 to 95% reduction in the amount of contaminants being discharged through the storm sewers to surface water at Fort Lewis.

CONCLUSIONS

As demonstrated in the discussions of plastic media paint stripping at Hill AFB, hard chromium plating at the Pensacola NARF, solvent recovery at Robins AFB and at Norfolk Naval Shipyard and solvent cleaning elimination at Forts Polk and Lewis, a number of features were common to the industrial process modifications that were successfully implemented.

Production people were enthusiastically and actively involved. Attaining positive involvement usually required that the modification result in some production benefit, such as reduced manpower requirements or simplification of the process; the change did not have an adverse effect on product quality; and the change preferably had a beneficial effect on the end product. Care was taken to tailor the modification to the individual facility. During design and installation, operations and production personnel were asked to provide input in order to inspire them to adopt the process change.

A "champion" guided the project, overcoming developmental problems and the inertia that protects existing processes, especially those that function, even though they may product undesirable wastes.

Support was provided at a sufficiently high level in the chain of command to influence production and environmental policy decisions.

The technologies tended to require evolutionary rather than revolutionary changes. That is, off-the-shelf equipment was adapted to a new application, and special or complex equipment was avoided. Successful modifications were straightforward and simple to operate, requiring minimal training for personnel unfamiliar with the technology involved. Process reliability was high, and maintenance requirements were minimal.

ACKNOWLEDGEMENTS

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1210 Citizens Pkwy.
Morrow, GA 30260 404/968-3255

Drainage Nets: Landfill Leachate Collection • Landfill or Surface Impoundment Leakage Detection • Landfill Cover Drainage • Landfill or Surface Impoundment Gas Drainage • Waste Pile Liquid Drainage • Landfill or Surface Impoundment Groundwater Underdrain. Slope Reinforcement Geogrids. Roadway and Base Reinforcement Geogrids.

Trofe Incineration, Inc. **332**
Trofe Industrial Park
Mt. Laurel, NJ 08054 609/235-3030

Trofe Incineration, Inc. is an engineering and construction firm that manufactures, markets and installs high-temperature incineration and energy recovery systems. Three types of modular combustion systems are offered: a solids system, a liquids system or a single all-purpose system. The systems are designed with flexibility for expansion upon need.

U.S. Pollution Control, Inc. **425-427**
2000 Classen Ctr.
Oklahoma City, OK 73106 405/528-8371

Waste disposal and transportation of RCRA and PCB waste. Remedial resonse and cleanup. Commercial analytical laboratory and state-of-the-art recycling facilities.

WAPORA, Inc. **204**
1555 Wilson Blvd., Suite 700
Rosslyn, VA 22209 703/524-1171

WAPORA is a leading engineering and environmental consulting firm that has served industry and government for over 15 years. The firm offers a wide range of experience in hazardous waste site investigation and remediation, including groundwater cleanup. Our corporate headquarters are located in Washington, DC, and we maintain regional offices in New York, Philadelphia, Cincinnati, Chicago, Atlanta and Dallas.

Waste-Tech Services, Inc. **421**
445 Union Blvd., #223
Lakewood, CO 80228 303/987-1790

Waste-Tech Services, Inc. provides a total service program designed to destroy organic hazardous waste at a client's site by using our proven and patented fluidized bed incineration technology. Our patented system handles gases, liquids, slurries, sludges and solids. WTS, Inc. secures and holds all permits, provides all compliance reports and interfaces with all regulatory agencies.

Watersaver Company, Inc. **334**
P.O. Box 16465
Denver, CO 80216 303/238-1818

Watersaver Company provides the world's most reliable membrane lining systems. Our products meet all regulatory requirements for zero seepage. With over 30 years' experience and 300 million square feet of successful installation, Watersaver leads the way with proven products and systems that work correctly and continuously. Linings and floating covers of Hypalon, CPE and PVC up to 60 mils.

Wilson Laboratories **217**
525 N. 8th St.
Salina, KS 67401 913/825-7186

Full service analytical laboratory specializing in environmental monitoring and the analyses of hazardous waste samples. Expertise includes GC, GC/MS, HPLC and Industrial Hygiene.

Woodward-Clyde Consultants **305**
P.O. Box 66317, 2822 O'Neal Ln.
Baton Rouge, LA 70815 504/291-1873

Woodward-Clyde Consultants is a nationwide professional services firm serving clients for over 30 years. Our practice includes the application of knowledge in engineering, the earth sciences and the environmental and social sciences. Services offered include: waste management; environmental assessments; geology and hydrogeology; hydrology; site selection studies; oil spill contingency planning; air and water quality studies; geotechnical engineering, and risk and decision analysis.

YWC, Inc. **431**
200 Monroe Tpke.
Monroe, CT 06468 203/261-4458

A multidisciplinary environmental laboratory/engineering consulting firm, YWC, Inc. provides air, soil, water and waste characterization for full-profile site assessments. The York Laboratories Division is a participant in EPA's Contract Laboratory Program. Additional services available include contract operation of wastewater treatment facilities, interim sludge dewatering services, hazardous waste management and remedial investigation/feasibility studies. Growth has been achieved through dedicated personal service with an emphasis on quality at most competitive prices.