STAFF MEMORANDUM

GROUNDWATER PROTECTION STANDARDS FOR HAZARDOUS WASTE LAND DISPOSAL FACILITIES: WILL THEY PREVENT MORE SUPERFUND SITES?

Industry, Technology, and Employment Program

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*This staff memorandum is part of an ongoing assessment, Cleanup of Uncontrolled Hazardous Waste Sites Under Superfund, that is being conducted by OTA's Industry, Technology and Employment Program. The full assessment, which will focus on technical problems and issues of the Superfund program to clean up uncontrolled hazardous waste sites will be delivered to the Congress later this year. Another assessment, Technologies to Measure, Monitor and Mitigate Groundwater Contamination, is being conducted by OTA's Ocean and Environment Program. That assessment, to be released shortly, will provide a comprehensive technical framework to assist Congress in understanding the major groundwater contamination issues facing the Nation.

GROUNDWATER PROTECTION STANDARDS FOR HAZARDOUS WASTE LAND DISPOSAL FACILITIES: WILL THEY PREVENT MORE SUPERFUND SITES?

One of the principal reasons for the passage of the Resource Conservation and Recovery Act (RCRA) in 1976 was for the regulation of future disposal of hazardous waste. It then became evident that additional legislation was needed to deal with the burgeoning number of uncontrolled sites which resulted from past practices. In 1980, therefore, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also known as Superfund. There has been a general impression and hope that these two laws would eventually provide effective protection of public health and the environment from hazardous wastes: CERCLA by cleaning up past problems and RCRA by preventing future ones.

This analysis concludes that, where groundwater is at risk, RCRA groundwater protection standards are not likely to prevent land disposal sites from becoming uncontrolled sites that will require cleanup under Superfund. The problems with the RCRA groundwater protection standards are so numerous and serious that the standards cannot compensate for what has been found to be ineffective and unproven land disposal technology. Although OTA has not focused on the details of the RCRA statute in this analysis, there does not appear to be a major statutory problem.

The limitations of the RCRA groundwater protection standards, coupled with those of land disposal technology are likely to cause serious problems for future generations. Concern for the future indicates that land disposal be limited to inert low hazard wastes, such as the stabilized residues from waste treatment operations, and to facilities where groundwater is not threatened. Otherwise, Superfund is likely to face a continuing stream of substantial burdens in the decades ahead from land disposal facilities sanctioned by the regulatory structure, but whose operators may not bear cleanup costs. There remains, moreover, a threat from the billions of tons of hazardous waste which have been disposed for many decades at what are now the interim status facilities under RCRA.

SUMMARY

General conclusions

- RCRA groundwater monitoring and protection standards issued by EPA were not designed to prevent RCRA regulated sites from becoming CERCLA sites and they are not capable of doing so.
- Many of the RCRA regulations may seem reasonable on their surface; however, detailed technical analysis reveals serious inadequacies, especially associated with providing for effective, long-term management of hazardous wastes.
- Many important decisions in the RCRA regulations were apparently made without consideration of alternative approaches and without cost/benefit analysis or risk analysis of alternative approaches. Had such analysis been performed, alternative approaches for groundwater protection which cost less over the long term and present fewer risks to public health and the environment probably would have been identified.
- There appears to be almost no consideration given, in the RCRA regulations, to the huge cost of cleaning up groundwater contamination. Regulatory decisions have had the effect of keeping down the short range costs of the regulated community.
- The regulations take an optimistic view of the availability of

technologies to detect and clean up contamination but a pessimistic view of technologies which can prevent contamination, even when they are the same technology.

Summary of Specific Conclusions

o Interim Status Facilities: Groundwater protection standards for these facilities are less stringent than for new facilities, and most of them already are, or are likely to become leaking sites; however, there are no corrective action requirements.

o Fixing Leaks: With confirmed groundwater contamination there are no requirements that a facility be closed until the leak is found and corrected, nor to even find or stop the leak.

o RCRA Coverage Stops at the Fenceline: Although contamination may spread beyond the legal boundary of a facility and have to be cleaned up under CERCLA, under RCRA the operator only has to clean up within the facility limits.

o RCRA Coverage Limited to 30 Years: New facilities must be designed not to leak for 30 years after closure during which time the operator must maintain the facility, but later when leaks are more likely CERCLA becomes responsible.

o Financial Responsibility: There are no RCRA requirements for financial assurance for corrective action on a leaking site.

o Contaminants Which Are Regulated: Because CERCLA regulates more substances than RCRA, and detection levels for other substances are set lower by CERCLA than by RCRA standards, a permitted but leaking RCRA facility can become an uncontrolled site under CERCLA.

- o <u>Tolerance Levels of Contaminants</u>: Acceptable levels of groundwater contaminants are not based on health effects, and using detection limits of analytical techniques may not be protective of human health.

- o <u>Geological Standards</u>: There are difficulties in predicting groundwater movement or the rapid movement of contamination in some geological environments which makes early detection and correction uncertain at some sites. However, RCRA has no facility siting standards to restrict hazardous waste sites to geologically suitable locations.

- o <u>Groundwater Monitoring</u>: Technical complexity and site specificity make it difficult for government rules to set the conditions for effective groundwater monitoring.

- o <u>Monitoring in the Vadose Zone</u>: Although the technology exists, RCRA standards do not require monitoring in the land between the facility and underground water; hence, an opportunity to gain an early warning of leaks is lost.

- o <u>Test for Statistical Significance</u>: Tests required by RCRA keep the probability of falsely detecting contamination low at the expense of high probability that contamination might go undetected.

- o <u>Corrective Action Delays</u> Complex RCRA procedures can lead to delays of several years, increase cleanup costs, and increase the chances of CERCLA financing of cleanup.

- o <u>Compliance Monitoring and Corrective Action</u>: Technology does not necessarily exist to meet the RCRA standards for taking corrective action, nor in all cases for compliance monitoring, required after contamination is found.

RCRA in Relation to CERCLA

There have already been cases of hazardous waste from clean-up at CERCLA sites going to RCRA regulated sites which were later found to be leaking. Moreover, although RCRA and CERCLA are managed by the same agency, research for this analysis has found that the two program offices do not coordinate closely and that one office appears to be unaware, at times, of what the other is doing.

Many people view RCRA as the program which will prevent present and future hazardous waste sites from becoming CERCLA sites. However, in the 80,000 word preamble to the final RCRA land disposal regulations standards, written two years after the passage of CERCLA, there is no reference to the concept that the standards are to serve the purpose of preventing regulated sites from becoming uncontrolled sites. Indeed, the only two references to CERCLA in the preamble are in the context of what CERCLA can do for RCRA, not what RCRA can do for CERCLA. Consequently, it appears that RCRA groundwater monitoring and protection standards were not designed to prevent RCRA regulated sites from becoming CERCLA sites and they are not capable of doing so.

Interim Status Facilities

Although they are "grandfathered" by the RCRA legislation, interim status facilities do not have EPA-issued permits for operation. In contrast to the regulations for new facilities, existing interim status facilities are not designed or operated to EPA's specifications for adequate groundwater protection. However, these facilities are the ones most likely to have received wastes which are most inappropriate for land disposal (e.g., uncontainerized, highly toxic liquids). No matter what may be done to limit land disposal in the future, the interim status facilities have already received billions of tons of hazardous wastes over several decades; they continue to receive wastes. Moreover, available data and historical experience indicates that many of them already are, or are likely to become, leaking sites which will require corrective or remedial action. It will be many years before EPA can closely examine interim status sites - even ones given priority - to determine whether or not, and how, they should be permitted. But every day that goes by without detecting existing contamination or correcting contamination once it is found, adds to the cost of correction and makes it more likely that CERCLA will be involved. Nevertheless, the groundwater monitoring requirements for interim status sites are far less stringent than for new facilities designed to EPA specifications and there are no corrective action requirements. Alternatives to current regulations which could reduce high future cleanup costs include: requiring financial assurance for corrective action; improved monitoring and sampling; requiring prompt corrective action upon discovery of contamination; and promptly closing down obviously badly designed and badly located facilities.

No requirement to fix leaking land disposal facilities

Although EPA regulations require new hazardous waste disposal facilities to be designed so that they do not leak for at least 30 years after closure, if the facility does leak there is no requirement in the RCRA regulations that the facility be closed until the leak is found and corrected, indeed there is not even a requirement to find or stop the leak. Cleaning up the consequence of a leak, such as a plume of pollution, but not the leak itself is only a temporary expedient. Since the cost of cleaning ground water is generally proportional to the amount of time a site is allowed to leak, inattention to leaks raises the cost of remedial action to the point where facility owners may not be able to afford facility modification and cleanup and the result is an abandoned site. This research found no cost/benefit analysis or risk assessment to justify this policy, which runs a considerable risk of creating more sites and high cleanup costs for CERCLA. The result may be that short-term benefits will accrue to facility operators and users, and the longer-term costs likely to be borne by the site operator, the government, and the public will mount.

RCRA coverage stops at the fenceline

RCRA regulations do not require corrective action for groundwater contamination which goes beyond the fenceline of the regulated facility which created the problem. The reason given by EPA is that it may not be possible for the owner to gain access to the neighboring property in order to conduct corrective action. EPA assumes that the problem of plumes migrating off the property boundary would be addressed under CERCLA. However the same agency administers CERCLA and the same problem of gaining access to the neighboring property would have to be faced under CERCLA. It is unclear why this problem can be addressed under CERCLA, but not earlier and less expensively under RCRA which does not legislatively limit actions to within facility boundaries.

RCRA coverage limited to 30 years

Even though many toxic wastes will remain dangerous for many decades, if not forever, RCRA regulations require that a new hazardous waste disposal site be designed so that it will not leak for 30 years after closure. The regulations also require the site owner to be responsible for routine maintainance of the site for 30 years after closure. However after 30 years, when the site may be more likely to leak, or for a leak to be detected through adverse effects, the maintenance cost is turned over to CERCLA.

Financial responsibility

A major cause for the abandonment of hazardous waste disposal facilities, and subsequently their becoming CERCLA sites, is the inability of site owners to finance the high cost of corrective action. This was recognized by Congress in its explicit requirement that the RCRA regulations provide assurances of financial responsibility consistent with the risk. Nevertheless the regulations have no financial assurance requirement for corrective action. A prudent, precautionary approach in establishing the level of financial responsibility, considering the historically proven limits of the technology, would be to assume that a leak will occur, will not be detected very early, and that groundwater contamination will be significant.

Contaminants regulated under RCRA and CERCLA

The universe of toxic groundwater contaminants of concern to CERCLA is greater than those of concern to RCRA. CERCLA regulates all contaminants defined by RCRA but not vice versa. Therefore, a RCRA regulated facility in compliance, with all RCRA standards can still become a CERCLA site. Additionally for many contaminants of concern to both RCRA and CERCLA, the levels of detection are set higher under RCRA procedures than under CERCLA procedures.

Tolerance levels of contaminants

Under RCRA, EPA does not appear to have set tolerance levels of groundwater contaminants based on their danger to human health, yet under CERCLA EPA is concerned with <u>any</u> contamination which threatens human health. Under RCRA, tolerance levels appear to be whatever detection limits result from the chemical analysis techniques used, and the choice of technique appears to be based on cost and ease of analysis rather than health factors. This is borne out by the fact that for many chemicals the tolerance level (allowable concentration) appears too high to adequately protect human health, and for many more chemicals, including EDB, dioxin, and DBCP, test protocols were established without knowledge of their detection levels. There is no cost/benefit analysis to evaluate whether costlier analytical techniques should be used to lower the detection limits, and no risk analysis to evaluate whether land disposal of some chemicals should be banned until the detection limits that are determined to be adequate are set by EPA.

Geological standards

There are some geological formations in which groundwater movement cannot be predicted; hence, groundwater cannot be monitored effectively at these sites. There are others in which groundwater contamination moves so rapidly that it cannot be detected and corrected before it has spread dangerously. Many states (e.g. California and Illinois) and other government agencies (e.g. Nuclear Regulatory Commission), therefore, have set standards which preclude locating land disposal facilities in certain geological formations. The RCRA standards, however, do not recognize this problem in permitting hazardous waste land disposal facilities. EPA has indicated that corrective action technology to effectively deal with groundwater pollution will become available in the future.

Groundwater monitoring

Groundwater monitoring must be "custom tailored" for each site. There are numerous complex hurdles to be overcome in order to do the job right, the failure of any one of which can lead to incorrect results. If the geology of the site is suitable (which it frequently is not) and if enough time, money and expertise are spent in designing and operating a groundwater detection system, then there is a reasonable chance of detecting pollution. However, groundwater monitoring has not yet proven its effectiveness as a regulatory tool. Technical complexity and site specificity make it difficult for government rules to set the conditions for effective groundwater monitoring. As a result, many facilities are inadequately monitored and significant improvement in the future is unlikely. A possible alternative would be to have the government (but not necessarily a regulatory agency) conduct monitoring.

Monitoring in the Vadose Zone

Detecting contamination before it reaches groundwater (i.e. in the vadose zone underneath the facility) might save millions of dollars in corrective action costs and might make the difference in keeping a site from becoming a CERCLA responsibility. Vadose zone monitoring has been used for some years at hazardous waste facilities in several states. The techniques have been studied by EPA's research laboratories and many of them are available today.

Nevertheless, both EPA's RCRA interim status standards and the 1982 standards for permitted facilities dismiss the use of this technology without analyzing its effectiveness in reducing groundwater cleanup costs.

- Test for statistical significance

Before a facility is required to report the presence of contamination in a detection monitoring well, a test for "statistical significance" is performed. EPA has chosen a test procedure which keeps the probability of falsely detecting contamination low, but this has happened at the expense of increasing the probability that groundwater contamination might go undetected until it becomes obvious through environmental impacts, when cleanup costs may soar. Indeed, EPA apparently has not calculated the probability of detecting contamination with their procedures. Under some circumstances (e.g. interim status facilities following minimum RCRA requirements) the probability of detecting contamination may be such that the plume of contamination goes by the detection system for many years.

Delays in onset of corrective action

The RCRA regulations contain many complex procedural steps which can cause delays of several years in implementing corrective action, increase the costs of cleanup, and increase the chances of the need for CERCLA.

Compliance monitoring and corrective action

For most cases, the technology does not exist to meet the standards for taking corrective action required by the RCRA regulations, nor in all cases for compliance monitoring, required after contamination is found. The regulations rely on the availability of the technology some time in the future. The option of banning land disposal for untreated hazardous wastes until the technology to clean up groundwater (to background levels as required by the regulations) is available does not appear to have been evaluated. How such sites will be treated is unclear. If EPA insists on their meeting an unachievable monitoring or cleanup standard then the sites may be forced into bankruptcy and into the CERCLA program. If such sites are allowed to operate, then groundwater pollution would likely worsen.

INTRODUCTION AND BACKGROUND

This analysis examines how EPA has implemented the RCRA statute, and how this implementation affects the use of CERCLA. Although OTA has not focused on the details of the RCRA statute in this analysis, there does not appear to be a major statutory problem. On the other hand, it is possible to conceive of statutory changes which could remedy the problems found in this analysis. Indeed, in the current RCRA reauthorization process some changes have been proposed which would direct EPA to remedy some of the problems discussed in this Memorandum.

The Scope of Superfund. CERCLA provides authority to EPA to arrange for removal and provide remedial actions whenever any "hazardous substance" is released or there is substantial threat of such a release. In addition, whenever there is a release or substantial threat of a release of a "pollutant or contaminant" which may present an imminent and substantial danger to the public health or welfare, EPA may also initiate removal and remedial action (CERCLA §104(a)). The term "hazardous substance" means not just "hazardous waste" as defined under RCRA, but includes any material designated as hazardous or toxic under the Clean Water Act or the Clean Air Act (CERCLA §101(14)). "Pollutant or contaminant" is defined even more broadly to cover any substance that can cause death or serious health effects (CERCLA §104(a)(2)).

Thus, CERCLA goes far beyond the original interest in the adverse health and environmental impact of hazardous waste disposal. It includes the impacts from such sources as mining operations, leaking pipelines, runoff from raw materials, piles and spills from loading operations.

At the time CERCLA was passed, there was no systematic attempt to ascertain whether any kind of prevention programs were in place. While in many areas, such as air, surface water, ground water, hazardous waste, and surface mining, there are Federal laws in effect, for many others there are none. This places the Federal government in the position of assuming the responsibility for the failure of operations over which it has no original regulatory control.

The extent of government control over the several causes of environmental problems covered by CERCLA merits considerable study. This paper, however, is limited to the study of land disposal of hazardous waste as regulated by RCRA. While all modes of pollution are covered by CERCLA, this paper will only look at groundwater contamination. This is the most significant mode of contamination accounting for the majority of the sites on the National Priorities List (1). Moreover, cleanup of groundwater contamination poses substantial technical complexity as well as very high costs.

RCRA and Land Disposal. Several aspects of the RCRA regulations have already received considerable analysis. For example, OTA completed a major study of hazardous waste control in March, 1983 (2). Another major study was done by the National Academy of Sciences (7). A large part of these and many other studies dealt with the technology of hazardous waste land disposal and its alternatives. Therefore this paper will not focus on EPA's regulations under RCRA for the design and construction of hazardous waste treatment and disposal facilities. This analysis concentrates on EPA's groundwater protection standards for land disposal facilities.

There are, however, several conclusions from these earlier works which will help to better understand the context of this paper. The first is that even with the best available land disposal technology, hazardous wastes placed in land disposal facilities will likely migrate into the broader environment sooner or later. The second is that there are commercially available waste reduction and waste treatment alternatives to the land disposal of many hazardous wastes. And the third is that RCRA regulations present technical and economic disincentives to industry to utilize more fully these alternative technologies.

Many more resources continue to be allocated to the regulation of fundamentally flawed land disposal technology than to the development and demonstration of alternatives to land disposal. EPA has frequently been criticized for not encouraging alternative technological approaches to the land disposal of hazardous waste. EPA's response has been (a) that the technology for recycling and alternative treatment to land disposal may not exist for all or most wastes, (b) that the technologies are not "off-the-shelf" but are in some stage of development, and (c) that to the extent to which technology does exist, the necessary plant capacity may not be in place. However, it will be seen from this study that EPA did not apply these same conditions to the writing of the land disposal groundwater protection standards, as they suffer from all of the same defects.

To sum up, RCRA regulations cannot overcome the fundamental inadequacies of land disposal technology, and experience has shown that regulatory enforcement efforts do not assure compliance with regulations. Just as troubling, the following analysis reveals that even if there was compliance with RCRA groundwater protection standards, land disposal would still pose serious risks to health and environment. Moreover, attempts to limit the future use of land disposal do not address the problem of billions of tons of hazardous waste already land disposed.

Data to Illustrate the Scope of the Problem. About 2000 hazardous waste land disposal facilities required to conduct groundwater monitoring filed for interim status. EPA has released data for 1981 which provide some indication of the number of hazardous waste management facilities which operated that year and which might threaten groundwater. (Note that injection wells are regulated under another statute and not by the RCRA groundwater protection standards even though they are used for hazardous waste disposal.)

surface impoundments	770
landfills	200
injection wells	90
land treatment	70
waste piles	170
storage and treatment tanks	2040
	3,340

OTA has analyzed the data from EPA's study of waste management in 1981 to examine the extent to which land disposal facilities receive hazardous wastes which are toxic. Such information has not been available previously. Toxic wastes present long-term chronic health risks and are to be contrasted with waste which are hazardous only on the basis of characteristics such as reactivity, ignitability, and corrosivity. These results are given in Table 1, but it should be recognized that the data have poor statistical reliability and there likely have been changes in hazardous wastes and waste management practices since 1981. Nevertheless, the data indicate that a significant fraction--perhaps a majority--of the wastes being placed in land disposal facilities nationwide are toxic chemicals which pose long-term health problems if released into the environment. For surface impoundments and landfills almost all the wastes may be toxic, while for injection wells about one-third

Table 1

NATIONAL ESTIMATES OF HAZARDOUS WASTE TYPE BY PROCESS OF DISPOSAL
FROM EPA 1981 SURVEY
(in millions of metric tons)

	Reported as Toxic[1]	Reported as Non-Toxic[2]	Reported as Waste Only[3]	Totals[4]
Well Injected	8	14	4[5]	26.1
Surface Impounded	14	0.7	--	15.1
Landfilled	3	0.3	0.1	3.3
Land Treated	0.2	0.1	--	0.3
Other[6]	2	0.1	--	2.4
Total Land Disposed	28	14	4	47.2[7]

(Columns and row totals may not check because of rounding.)

[1]As defined in 40 CFR 261.24, 261.30 -261.33.

[2]As defined in note 1; wastes that are <u>only</u> ignitable, corrosive, and/or reactive.

[3]Respondants did not specify wastes by appropriate RCRA hazardous waste numbers.

[4]Private communication from EPA to OTA.

[5]OTA analysis of data in "The CMA Hazardous Waste Survey for 1981 and 1982" indicates about 60 million metric tons of hazardous wastewaters were injected into wells for the entire chemical industry. These wastes do not appear to be included in the EPA data. Nor is it clear what type wastes these are.

[6]May include above categories, ocean dumping, etc.

[7]The CMA report also indicates that, excluding wastewaters, hazardous wastes regulated by the states but not Federally can be as much as the amount which EPA regulates.

Source: OTA

of the wastes may be toxic.

A recent report by EPA's Superfund Task Force discusses the future of the Superfund program. (Memo to Alvin L. Alm and Lee M. Thomas, December 8, 1983) EPA projects a total inventory of 22,000 uncontrolled sites. As of December, 1983, nearly 900 sites had been evaluated; and 546 of those sites have been placed on the National Priority List (NPL). Contamination of groundwater is the number one problem with currently assessed uncontrolled sites. For example, for the 881 sites scored for the NPL, 526 sites had observed releases of hazardous substances into groundwater. Over eight million Americans are potentially exposed to the groundwater from these sites, and in about 350 of these sites the contaminated groundwater is the only source of drinking water for the affected population. Another 6.5 million people are potentially exposed to contaminated surface water at 450 sites. Most of the commonly encountered of the 444 toxic pollutants found at these 881 sites are acknowledged by EPA to exhibit chronic toxicity and pose health threats at extremely low levels of human exposure.

Furthermore, most of the cleanups being conducted under Superfund involve either leaving the wastes in the ground and attempting to contain them, or removing wastes and contaminated materials and placing them in land disposal sites. Of the 546 sites on the NPL, 40 percent were landfills originally and 30 percent were surface impoundments. We are beginning to see cases of land disposal sites leaking after they have received wastes from Superfund cleanups (e.g., the BKK facility in California). This is to be expected, as EPA research, as early as 1975, indicated that more than 90 percent of operating land disposal facilities were leaking. Therefore, not only is the RCRA regulatory program contributing to future Superfund burdens, but the Superfund program is adding to the uncontrolled site problem through its own cleanup efforts. While attempts to spread limited Superfund resources among many sites may seem necessary and reasonable, the longer term risks (often to different communities) and costs support a different approach.

EPA's Dependence on Current Groundwater Protection Standards. Current Federal regulatory control of hazardous waste land disposal facilities is critically dependent on EPA's groundwater protection standards. Because of the admitted deficiencies and uncertainties of land disposal technology, such as the inability of synthetic liners to fully contain liquids and the unproven long-term effectiveness of leachate collection systems, protection of human health and the environment rests ultimately on the protection afforded by the groundwater monitoring requirements.

For example, EPA's director of its Office of Solid Waste has said:

> While no method of hazardous waste management is failproof, our rules should protect human health and the environment. Even if a containment system fails, groundwater monitoring will identify leakage and the pollutant plume will have to be cleaned up. (Letter from John H. Skinner to Keith H. Gordon, August 12, 1983.)

However, no mention is made of dealing with the leak itself, nor of stopping the disposal of hazardous materials in the leaking site. Cleaning up the pollutant plume is of limited effectiveness when the leaking is allowed to continue.

And the director for air and waste management in EPA's Region VIII has said:

> In the Agency's view, the cornerstone of our land disposal program rests on the groundwater protection standards. They were devised to provide essential environmental and health controls. (Letter from Robert L. Duprey to Leo Younger, August 10, 1983.)

More recently, EPA has been formulating a national groundwater protection strategy in response to a growing awareness that this national resource needs more effective protection. EPA recognizes that "In most circumstances it is prudent to protect the resource from contamination in the first place, rather than rely on cleanup after the fact." However, because of OTA's conclusions concerning the inadequaces of the RCRA groundwater protection standards, it is imperative to note that EPA's new national groundwater protection strategy guidelines "...will not alter the existing technology and monitoring requirements for hazardous waste facilities incorporated in existing regulations." ("Draft A Ground-Water Protection Strategy for the Environmental Protection Agency," January, 1984.) Thus, OTA concludes that the goal of protecting the resource rather than cleaning it up after the fact is in serious jeopardy.

The Economics of Prevention. The national problem of uncontrolled hazardous waste sites has received much attention not merely as a result of the threats to human health and the environment, but also because of the high costs of cleanup. What was once perceived to be a problem that might be handled with a five year $1.6 billion program, is now generally recognized to require a long-term commitment - perhaps many decades - with costs which are still difficult to forecast.

EPA has estimated that 1400 to 2200 uncontrolled sites will require Federal action as National Priority List (NPL) sites for a cleanup cost of $8.4 billion to $16 billion (in 1983 dollars). The EPA estimate does not include costs for decontaminating polluted aquifers. In March, 1983, OTA estimated future cleanup costs at $10 billion to $40 billion. However, an unreleased survey of the States conducted for EPA indicated that State officials believe that well over 7,000 sites will require cleanup under Superfund; if true this would bring cleanup costs to the high end of the OTA estimate. Moreover, such estimates have not included studies to indicate the extent to which present RCRA facilities, both for hazardous and nonhazardous solid wastes (municipal and sanitary landfills), may become future uncontrolled sites. These may total in the thousands. Nor do these estimates include the costs for cleaning up Federal uncontrolled sites, which now number about 500 in EPA's inventory and are expected to increase.

A major economic issue is the extent to which it pays to prevent more uncontrolled sites from being created. The primary consideration is the widespread use of land disposal rather than alternatives to it. Even if such alternatives were substantially costlier than land disposal in the short-term, they would still be cheaper than the ultimate cleanup costs for uncontrolled sites resulting from land disposal. When such cleanup costs are related to the amount of hazardous waste originally disposed they are generally 10 to 100 times greater than the costs of currently expensive waste treatment options.

Cleanup costs for uncontrolled sites vary greatly and depend not only on the nature of the site's problem(s), but also on the extent of cleanup chosen. If permanent rather than "band-aid" cleanups are used, then costs escalate sharply. For example, cleanups which leave wastes in the land or move them to another land disposal facility are far cheaper than the use of onsite or offsite destruction or detoxification of wastes. But such lower short-term costs for containment and land disposal ignore probable future costs of cleanup actions at such sites in just the same way that land disposal of newly generated wastes does.

Moreover, although there is much groundwater contamination at uncontrolled sites, there have been very few attempts to actually decontaminate the water rather than to simply contain the plume of pollution by, for example, a slurry wall, or to take no action. Decontamination of groundwater is a very costly and time-consuming process which can take tens of millions of dollars and many years for an aquifer. However, such cleanup costs can be minimized by minimizing the extent of groundwater contamination. Simply put, the greater the volume of contaminated groundwater, the greater the cleanup costs and time. In addition to preventing leaking land disposal facilities and correcting leaks themselves, future groundwater cleanup costs, therefore, can be reduced by early detection of groundwater contamination and prompt cleanup. There is now some evidence (albeit of a statistical nature) that suggests that EPA's strategy may be not to spend CERCLA funds to decontaminate groundwater. A recent analysis of EPA's use of the Hazard Ranking System (HRS) and its allocation of CERCLA funds found the following:

> ...the HRS ground water scores bear a statistically significant negative relationship to obligations. This means that when the HRS total score increases due to a higher ground water score, the increase in obligations is smaller than if the increase in the total score is attributable to another component measure of hazard. ...Given the relatively high cost of cleanup when ground water contamination is present, EPA may have concluded that the damage associated with other cleanups foregone is too great to justify cleanup of a particular site's ground water. ...If EPA places greater weight on short-term dangers, they would be less likely to fund remedial action in relationship to ground water contamination. ...this aspect of EPA's Superfund allocation decision making shifts the social cost of hazardous waste forward to future users of contaminated ground water or to future tax payers. (Harold C. Barnett, "The Allocation of Superfund, 1980-1983," Dept. of Economics, Univ. of Rhode Island.)

Finally, there is the issue of whether or not it makes a difference if cleanup of groundwater at RCRA sites is accomplished under the CERCLA program (which this analysis concludes is likely to be the case) rather than through the RCRA program. Aside from the equity of the situation, there is a difference , if it is advantageous to have the operators and users of RCRA land disposal facilities bear the actual or anticipated cleanup costs so that the market price of land disposal reflects its true long-term costs. Cleanup

may require CERCLA funding without collection of moneys from responsible parties. Enforcement action under CERCLA may not be effective for the same reasons that RCRA enforcement actions may not be effective (e.g., due to bankruptcy of the facility operator). Consequently, through the financing mechanisms of CERCLA, cleanup costs are borne by industry broadly and the general public rather than directly by the most responsible parties.*
Moreover, by shifting cleanup to CERCLA there is likely to be more procedural delays which contribute to additional cleanup costs as leakage continues and groundwater pollution spreads.

* After closure, responsible parties may not bear full costs. This is true for a facility which is closed and, after five years, when there is no detection of leaking, it becomes covered by CERCLA's Post-Closure Liability Fund. Although the fund is supported by a tax on land disposed wastes, there is no distinction among facilities on the basis of their design, location, or operation; hence, there is no incentive for active facilities to reduce taxes by achieving maximum protection. Nor is there is any assurance that the fund will be able to fund extensive actions to fix leaks and cleanup groundwater contamination.

INDUSTRIAL SOURCES OF CERCLA SITES

Although RCRA regulates many industrial sites, it does not have jurisdiction over non-waste related activities which may cause a site to be addressed under CERCLA.

A review of the National Priorities List shows many manufacturing sites where non-waste materials have been spilled or discharged resulting in polluted groundwater. Some of the mechanisms are:

- o spills in loading areas
- o leaking tanks
- o runoff from storage piles
- o spills from floods, hurricanes and fires
- o leaking underground pipelines, and
- o leaking manufacturing equipment.

Few measures* at the Federal level have been taken to prevent such non-waste sources of CERCLA sites. There are industrial sites regulated and inspected by EPA under RCRA which have considerable groundwater pollution from non-waste sources, but these are largely ignored by EPA. For example, a manufacturing plant might have a waste pile and a storage pile of raw materials on the same site. Both may be capable of polluting groundwater from runoff. The legal position of EPA is that there is an advantage in having a groundwater monitoring network which does not detect pollution from the material pile, because doing so would confuse any enforcement action the Agency could take against the site owner under RCRA. However, pollution from

*One of the few measures which has improved industrial operations is the CERCLA reporting and liability requirements for leaks and spills.

the material pile would trigger action under CERCLA. Therefore, in the absence of Federal measures to control pollution from such non-waste sources, it is reasonable to expect increasing pollution problems to come under the purview of CERCLA.

There are also several waste-related sources of groundwater pollution that have been addressed by acts of Congress but for one reason or another are not required to comply with the most stringent groundwater protection regulations. Often there is a presumption of effective waste containment technology (Type A), that wastes do not contain toxic materials (Type B), or that toxic wastes will not enter the ground (Type C). These are not necessarily correct. These facilities could, therefore, become uncontrolled CERCLA sites. Examples of these, which are not the subject of the following analysis, include:

Type A

- o double lined waste disposal sites with leachate collection and leak detection systems
- o injection wells
- o closed hazardous waste disposal sites not yet leaking

Type B

- o facilities for RCRA exempt wastes, including state regulated hazardous wastes
- o impoundments and sanitary landfills (RCRA - Subtitle D) for solid wastes
- o disposal sites for petroleum drilling wastes

Type C

- o waste recycling and recovery sites

INTERIM STATUS

When Congress passed RCRA in 1976, it provided a "grandfather" clause for existing facilities so that they could continue to operate as if they had a permit until EPA issued them a permit (RCRA §3005(a)). This "interim status" was to allow for a smooth transition to a condition of federally permitted hazardous waste treatment, storage and disposal facilities. It was not envisioned, at that time, that this process would take almost two decades. As of December 1983, there were about eight thousand interim status sites. Two thousand of these are required to monitor groundwater because they conduct waste management activities capable of polluting groundwater, such as landfilling and placement in surface impoundments (3). Although seven years have elapsed since the passage of RCRA, none of these two thousand facilities has yet been issued a permit by EPA (3);* thus all continue to operate under interim status. While the permitting process has begun, EPA estimates (6) that it will not complete the permitting of the 2,000 facilities for ten more years. In the following discussions the use of the terms "new" or "permitted" facilities refers to either newly built facilities or interim status ones which have become permitted.

EPA's Implementation. Although Congress allowed interim status facilities to operate without a permit, it did not excuse them from complying with all the standards necessary for the protection of human health and the environment. However, in May of 1980, EPA issued "interim status standards" (40 CFR 265) as the "minimum requirements" for interim status facilities. These were, by EPA's admission, considerably less than what would be necessary

*To date EPA has permitted only three disposal facilities under RCRA; all of these are new facilities (3).

to meet the legislative requirement for standards adequate to protect human health and the environment. These interim status standards (or Part 265 standards) are "in lieu of" (40 CFR 264.3) the more stringent part 264 standards which only go into effect after the facility is permitted by EPA. This action cut off any means of bringing an interim status facility into compliance with standards "adequate to protect human health and the environment" short of issuing (or denying) a permit.*

EPA's estimate of the time to permit all interim status facilities is now ten years, after having been revised upward several times. Many facilities could be in interim status for ten years and some for even longer. EPA states that these facilities will be permitted on a priority basis with the highest priority going to facilities which show the greatest environmental problems. Even where problems are identified, it takes over a year to process a permit and there is a backlog of over 1500 disposal facilities waiting for their permits to begin to be processed.

As previously mentioned, the interim status (Part 265) regulations do not require interim status facilities to comply with the more stringent Part 264 groundwater protection and facility design standards. The technical details of the groundwater protection standards will be discussed later, but the importance of stringent groundwater protection can be seen by the fact that there are already over fifty RCRA interim status facilities regulated by EPA on the CERCLA National Priorities List (9). And several interim status sites

*There are provisions in both RCRA and CERCLA for EPA to seek an injunction to require action if it can be demonstrated that there may be an imminent and substantial endangerment to health or the environment. These provisions may have been used in a few cases to require corrective action for groundwater pollution at an active interim status site. Their use at an active RCRA regulated site would indicate that there are no pertinent regulations with which the agency can require compliance.

in which wastes from CERCLA remedial action clean up activities have been disposed have been found to be leaking and could themselves become CERCLA sites.

Although the interim status groundwater monitoring requirements have only recently gone into effect, about 145 facilities are currently "in assessment" because their groundwater monitoring systems indicate that they are polluting groundwater (10). This figure takes on more significance when considered with a 1983 study by the General Accounting Office (6) of several states with above average regulatory programs. The study found that only 22% of the regulated facilities were complying with the interim status groundwater monitoring requirements.

EPA is reported in the press to have estimated that 50% to 60% of the interim status land disposal facilities are leaking and will require corrective action (60). There is evidence that the figure is closer to 90% to 100%. A study conducted by EPA in 1975 (12) investigated 50 facilities randomly selected from these 2,000 hazardous waste disposal facilities and found that over 90% of them were leaking into groundwater. Therefore, even before the passage of RCRA, the poor state of these interim status facilities was well known.

EPA could have written regulations for financial assurance for corrective action; regulations to monitor and gather necessary environmental data as well as regulations to bring them promptly in compliance or close them down. However, the interim status standards abrogate most of EPA's authority to regulate interim status sites until they are issued a permit by EPA. These facilities may continue to operate for a decade or more, perhaps leaking all the while, increasing the ultimate cleanup cost and increasing the chances of their ultimately becoming uncontrolled sites.

Indicator Parameters. To illustrate just one aspect of the interim status standards, consider the parameters required to be monitored in groundwater at interim status sites. EPA has identified four indicator parameters to determine whether an interim status hazardous waste facility is leaking enough to cause "gross contamination." The four indicator parameters are: specific conductance, pH, total organic carbon, and total organic halogen. In its interim status permitting standards, EPA limited the groundwater monitoring requirements for purposes of leak detection to these four parameters (40 CFR 265.92(b)). EPA gave the following reason for choosing these four parameters (45 FR 33194):

> Increases in specific conductance indicate the presence of inorganic substances in the groundwater. Likewise, increases or decreases in pH suggest the presence of inorganic contamination. Total organic carbon (TOC) and total organic halogen (TOX) concentrations in groundwater tend to increase as a result of organic contributions from a hazardous waste facility. The methodology to sample and analyze for these indicators is presently available. EPA believes that monitoring these indicators will be sufficient to make the threshold assessment of whether a facility is leaking.

However, the more stringent Part 264 standards for EPA permitted sites (40 CFR 264.98) give the EPA permit writer the option of requiring monitoring of the actual waste constituents or their reaction product rather than the four indicator parameters. EPA's guidance to the permit writers (13) says this about the four indicator parameters:

> In some cases, these parameters may not be the most appropriate, and this use should be carefully reviewed before they are included as indicator parameters in a detection monitoring program. For example, TOC and TOX will be of little value at a facility where no organic wastes are present, and even at facilities handling organic wastes, background levels may reduce the utility of these

parameters. The use of pH and specific conductance may also not always be appropriate. There are so many geochemical controls on pH, such as natural buffering capacity, that it is difficult to predict what changes in pH might occur in a leachate migrating through the unsaturated and saturated zones. In addition, unless extremely acidic or basic, the addition of large amounts of leachate will likely be required to significantly alter pH. Consequently, pH may be suitable only as an indicator of gross contamination. Detectable changes in specific conductance will similarly require a relatively large increase in ion concentrations. Consequently, it may also be useful as an indicator of gross pollution, and then only at facilities where constituents migrating to groundwater are primarily inorganic ions.

Further criticism of the ability of the indicator parameters to detect toxic contaminants at critical concentrations was made at a recent groundwater symposium (14):

> ....there can be highly selective migration of contaminants that are hazardous to human health in drinking waters at concentrations far less than those that would be detected using the "indicator" parameters. For example, the analytical detection limit for TOX is 5 ug Cl/l. The toxic concentrations of many organohalogens are less than 1 ug/l....for some organohalogens the critical concentrations are on the order of picograms/l. For TOC, the analytical detection limit is 1 mg/l. There is a large number of chemical contaminants that occur in aquatic systems that have critical concentrations for human health at orders of magnitude below this detection limit.

Number of Monitoring Wells. Another feature of the interim status standards is that they require only three wells for detecting groundwater contamination. This is true regardless of the size of the facility, the size of the aquifer, the extent of pollution, or the potential for damage to human health and the environment. In many cases, three wells are far too few to give a reasonable probability of early detection of pollution. In the processing of RCRA permits the number of required detection wells is generally in the range of four to twenty for interim status sites currently operating with three wells. On the state level, one interim status site in Illinois was required by the state to install 40 wells and another over 50 (66), and three sites in New Jersey are required to have over one hundred wells (62) while Federal standards require only three wells for the same sites.

In summary, the facilities which are most likely to leak, the two thousand existing interim status facilities, have a much less stringent groundwater monitoring standard then the three presumably far better designed new facilities. EPA's own characterization of these standards is that they are "minimal and are specifically designed not to be burdensome" (11). There are no corrective action requirements or requirements to stop dumping should groundwater contamination be detected. Sites found to be polluting will be put on a "fast track" for issuing a permit so that corrective action may be required, but as of this date no Federal permits have been issued to interim status facilities requiring groundwater monitoring.

LIMITATIONS ON COVERAGE

The viewpoint of EPA, as evidenced in the groundwater protection provisions of Part 264 of RCRA, is to determine when groundwater is getting polluted enough to cause concern for public health and then to require the groundwater to be cleaned up. There tool for this is groundwater monitoring. Groundwater monitoring is not a feasible substitute for techniques such as leak detection systems used as a tool to analyze the engineering soundness of the waste management facility, e.g., to locate a ruptured liner in a landfill or a leaking storage tank. Permitted facilities are required to be designed and built to exacting EPA engineering standards whose goal is to "minimize the formation and migration of leachate to the adjacent subsurface soil or groundwater" (47 FR 32312). However, when leachate does appear in groundwater there is no requirement to find out what went wrong, "a landfill liner which has been designed not to leak does not violate the design standards if the liner fails at some future time" (47 FR 32330). There is no requirement under RCRA regulations for fully permitted facilities that the leak be fixed or that the waste disposal activities be halted. When pollution may be coming from one of several sources, there is no requirement to determine which of them it is. In short, it is not a violation of any RCRA standard to pollute. There is only the requirement that the pollution which has reached groundwater be cleaned up and this, as will be discussed later, is a very limited requirement.

If the RCRA standards were designed less for the detection of pollution and more for assurance of the engineering integrity of the facility, they would have been more protective of human health. If EPA had the viewpoint that the detection of any pollutant at any level was indictive of the failure of the facility to meet the design specifications, then EPA might require that waste disposal be halted while the failure is found and corrected, or the waste removed. Rather than doing this, however, lengthy evaluations of the extent of groundwater contamination are conducted. However, there is no evaluation of the implications of a leak for the continued operation of a facility.

A further measure which tends to suggest that many RCRA sites will become CERCLA sites is the fact that RCRA groundwater clean up requirements end at the boundary line of the facility (40 CFR 264.91(a)(3)). Any pollutant that runs off the property of a RCRA regulated site becomes a CERCLA problem. The regulations explain that a site owner cannot be expected to get permission for cleanup outside of the property under his control. The regulations go on to state that "plumes migrating beyond the property boundary could, however, be addressed under other authorities such as CERCLA" (47 FR 32311). The regulations do not explain why EPA could handle this problem under CERCLA--perhaps years later--when EPA cannot handle it under RCRA.

A similar EPA limitation on its RCRA jurisdiction is to limit the site owner's responsibility for site maintenance to thirty years after site closure (40 CFR 264.117 and 265.117). Since EPA (as well as many others) has concluded that it is "inevitable" that landfills and disposal lagoons will leak (46 FR 11126-28), it is therefore inevitable that many of these facilities will eventually fall under CERCLA. Moreover, for a number of reasons (e.g. firms going out of business) clean-up costs would then shift from facility owners and users to the government.

GROUNDWATER MONITORING WELLS

The hydrogeology of the site is important in the design of a groundwater detection monitoring system for interim status and permitted facilities. A good knowledge of the hydrology and geology in the immediate area of a waste disposal site is necessary in order to know where, how many, and how deep to locate detection monitoring wells. In addition, for compliance monitoring, it may also be necessary to be able to create a mathematical model of the groundwater flow in order to be able to predict the speed and direction of contamination movement.

OTA will shortly be coming out with a study of groundwater pollution which will go into some detail on the science of hydrogeology so it is not necessary to repeat that here. This discussion will therefore be limited to this issue: how realistic and reliable are the RCRA (Part 264 and Part 265) standards for establishing groundwater monitoring networks?

Hydrogeological structures are very complex. In determining the location, depth, number, and type of monitoring wells a great many assumptions have to be made about the underground geological structure at the site, the adjacent area, and the location, depth, quantity, direction and speed of underground water. Furthermore, the proper location of monitoring wells depends on a knowledge of how all the above parameters may vary with season, rainfall, tidal water, and groundwater usage. These latter factors can cause groundwater flow to greatly increase, decrease, or even change direction over time.

The physically hidden characteristics of hydrogeological structures mean that they cannot be viewed but must be inferred from limited data. Such data are obtained from sources such as core samples, well drilling logs, and historical rainfall data. The difficulty of doing this was summarized picturesquely in a recent review by the Princeton University Water Resources Program (27).

> Effective monitoring of a hazardous waste disposal site is an extremely difficult data collection problem. To understand its complexity, consider air pollution. Often we can see whether the pollution controls on a chimney are working: the smoke may be darkened and the odor (downwind) noxious. As the wind carries the pollution smoke, we can see and follow in direction.
>
> Now imagine there are thousands of little chimneys around a factor site. By looking at the smoke, we may be able to tell which air pollution control devices are working and which are not. Again, we can see the trail of polluted smoke as it is carried away.
>
> Imagine that we cannot see the sky, we cannot tell the direction or velocity of the wind, and we ask: Is the factory (with its thousands of little chimneys) polluting the air? That is our groundwater monitoring problem--at its easiest. It is made more difficult because the geological properties of the soil vary with depth and direction, and this variation is unknown or uncertain. When we look up in the sky, we observe the spatial variation of the pollutants. If we could look up only through a small tube or telescope, then the information we gathered from the one sighting might not be representative of what we would see if we looked everywhere. The small tube into the sky is like our groundwater monitoring well: the data we gather may not tell us too much about what is occurring in other nearby locations.

One of the few studies of operational land disposal sites was an investigation of 50 typical hazardous waste disposal sites conducted in 1976-77 for EPA by the firm of Geraghty & Miller (12). One of the major conclusions of this study was:

> At sites presently monitored the use of wells as an aid in evaluating groundwater conditions is generally poor, due to inadequacies with respect to one or more of the following parameters:
>
> --number of wells
> --distance of wells from potential contamination source
> --positioning of wells in relation to groundwater flow
> --selection of screened intervals

--use of proper well construction materials
--sealing against surface water contamination, or inter-aquifer water exchange
--completion methods, such as development, maintenance, and protection against vandalism

Of the 50 sites evaluated by Geraghty & Miller, 32 of them had existing groundwater monitoring systems which were usually installed to meet the requirements of state law. Of the 32, Geraghty & Miller found 7 monitoring systems (or 22%) so inadequate that they had to install new wells in order to conduct the relatively basic monitoring required by the contract.

RCRA was passed in 1976 during the Geraghty & Miller study. Six years later, in 1982-83 EPA conducted another study of 148 interim status facilities which had implemented groundwater detection monitoring programs in response to RCRA interim status regulations (31). They found that 64 facilities (or 43%) had "deficiencies related to the number, depths, and/or locations of monitoring wells." Among the problems encountered were:

- o background wells not in the uppermost aquifer,
- o background wells affected by the facility,
- o downgradient wells not located in the direction of expected contamination movement, and
- o downgradient wells not located at depths which would intercept contaminants.

These studies show that the percentage of unsatisfactory monitoring systems was 22% in the 1977 study and 43% in the 1983 study. Since these two studies are not comparable, it is perhaps too simplistic to conclude that the practice of groundwater monitoring had deteriorated in those six years, but there is no basis for believing, in spite of improvements in technology, that the practice had gotten any better. There are several possible explanations (not mutually exclusive) for this state of affairs. There was a workshop of experts on groundwater resources and contamination in the United States sponsored by the National Science Foundation in March of 1983 (30). One expert, Keros Cartwright, head of the Hydrogeology and Geophysics Section of the Illinois State Geological Survey, offered the failure of our institutions as a major problem. He stated that: "From my experience, very few monitoring systems today on existing disposal sites are adequately monitoring the site."(33) And that "the most common reason we have (for monitoring) is simply a cosmetic procedure to reassure the public. . . . too many of our monitoring systems are cosmetic, not real." (34)

Another expert, Professor John Cherry, pointed to limitations in the state of the art as a second explanation. He observed, for example, that "contamination migration in *fractured rock is complex and generally* unpredictable" and that "prediction of contaminant travel paths through fracture networks is generally beyond the state of the art" (35). Not only fractured rock but fractured clay and fractured silt make for very difficult monitoring conditions. The best media for predicting pollutant movement and the one for which there is the most knowledge is sand and gravel. Ironically, this media is the worst media for land disposal because of the rapidity of pollutant movement in these very porous soils. The only soils which have good containment properties and are hydrogeologically predictable are unfractured silt and clay. However, these soils are found in only about 10 to 20% of the United States (36).

There are many other hydrogeological conditions which make the design of groundwater monitoring systems very difficult if not impossible:

- o There can be connections between different aquifers which are difficult to detect. (39)
- o Groundwater flow can change direction due to: intrusion of tidal water, seasonal recharge patterns, nearby production wells, etc. (38)
- o Leachate does not always flow straight down to an aquifer, but under some geological conditions would flow at an angle and enter an aquifer downstream of the monitoring wells. (24)
- o Liquid contaminants in an aquifer do not always flow in the same direction as the groundwater. (37)

A third possible explanation for the poor state of groundwater detection monitoring involves a combination of institutional problems and current technology limitations. Frequently, the establishment of a proper groundwater monitoring system takes a great deal of money, time and expertise, all of which are normally in short supply. In order to meet governmental regulatory requirements without costing too much, reliance is placed on "engineering judgment" rather than hard data. This warning appears in the EPA RCRA permit writers guide (5):

> Experience with the installation of monitoring systems for compliance with the Interim Status Regulations has indicated that most owners/operators who have hired a ground-water consultant to install the groundwater monitoring system have not envisioned spending the time or money to conduct as thorough an investigation as is suggested in this chapter. To retrieve all of the information necessary to design the system in accordance with considerations in this document, test-boring and piezometer installation programs will be necessary. Though some local geologic reports usually exist in the region of most facilities, site specific considerations almost invariably require extensive test borings. Because of the lack of time and funds, in most cases parameters such as the direction of ground-water flow and the nature of subsurface materials have been determined through evaluation of local topography and, to the extent possible, evaluation of existing building foundation borings. Monitor wells are usually located on the basis of this information and completed to just below the water table. Variations in ground-water flow direction and geologic variability have usually not been considered because of lack of information. The primary factors for

minimizing the pre-monitor well installation field investigation have been time and cost.

A similar point about cost was made by David Miller at a Congressional hearing in 1982 on EPA's Part 264 groundwater protection standards (41):

> There are, of course, certain geologic environments in which monitoring becomes extremely expensive and may not be cost-effectively employed. In order to obtain credible information, dozens of wells and hundreds of groundwater samples may be required to develop an adequate analysis of the hydrogeologic system. Although there are probably a large number of existing land diposal sites located in such areas, it is my recommendation that no new land disposal facilities be allowed under these conditions regardless of engineering design.

What is required for a facility operator to detect groundwater pollution? The hazardous waste disposal facility operator must want to detect groundwater pollution, and must determine if the geology of the site is suitable for groundwater monitoring. The operator must be willing to hire the experts, spend the time, and spend the money (probably far in excess of EPA's minimum requirements). Finally, sampling and analysis procedures must be designed which optimize the ability to detect contamination, even if they are more stringent than EPA's procedures (see e.g. section on statistical procedures). There are many facilities operating this way, although they are not required to do so. However, they are not required to report to EPA the results of anything over the minimum requirements.

At the other extreme is the facility operator who monitors his groundwater because he is required to, fulfilling only the minimum requirements of the law. He may hire experts more as the representative of the interests of the facility operator in dealing with the regulatory agency than in optimizing the efficiency of the groundwater detection system. Past experience has shown that groundwater detection systems designed and operated under these circumstances have a low probability of detecting groundwater contamination. Many of the sites on the National Priorities List (1) had such groundwater monitoring systems.

The latest EPA Part 264 regulations of July 26, 1982, while an improvement over the Part 265 standards, do not take account of past experience on the failure of regulatory groundwater monitoring systems, nor of expert advice on the unsuitability of many geological formations. It continues to rely on regulatory groundwater monitoring in any terrain to detect leaks. But the minimum requirements of the regulations are inadequate to assure a high probability of detection. As a result, many more sites, <u>including sites permitted under RCRA</u>, will probably be added to the National Priorities List.

One additional point should be made. Several experts have pointed out that a knowledgeable but unscrupulous person could set up a groundwater monitoring system which met all the legal requirements of Part 264 but which would <u>not</u> be likely to detect a contaminant plume. This is mentioned to illustrate the vulnerability of the current regulations.

CONTAMINANT TOLERANCE LEVELS

The RCRA regulations for EPA permitted land disposal facilities (40 CFR 264), unlike those for interim status facilities (40 CFR 265), provide for detection monitoring of the specific contaminants being disposed as an alternative to the use of the four indicator parameters (at the discretion of the EPA permit writer). This would appear to overcome one of the problems mentioned in the section on Interim Status. Upon close examination, however, this process raises many other equally troublesome issues having to do with the tolerance levels of these contaminants.

In regulatory parlance the "tolerance level" of a chemical is the concentration which is acceptable to the regulatory agency. The Part 264 RCRA regulations do not have an explicit tolerance level for groundwater contaminants except for the sixteen chemicals in the EPA primary drinking water standard. However for the hundreds of toxic constituents listed in the RCRA regulations (40 CFR 261 appendices VII and VIII) there is an implicit tolerance level. The regulations specify that the EPA publication "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods" (17) shall be used to determine whether a sample contains a given toxic constituent (40 CFR 261 appendix III).

For most substances, reference 17 lists more than one analytical method. Some methods are more sensitive than others. In issuing permits, EPA plans to use relatively low cost scanning techniques, which are the least sensitive methods, explaining (59):

> The Agency feels that a special hiearchical approach is appropriate for this purpose. These approaches will first use scanning techniques designed to detect broad classes of compounds. If the presence of a particular class of compound is detected, more specific analysis to determine which constituents are actually present can then be initiated.

Although some sensitivity may be sacrificed by such an approach, the range of detection of certain scanning methods are clearly adequate....

Therefore, <u>the detection limit of the scanning methods which are least sensitive of the required test methods, constitutes a de facto tolerance level</u>, since no action will be taken for contaminants which appear below that level. Furthermore, there are more sensitive test methods than those chosen, and EPA has demonstrated in the case of dioxin that more sensitive methods can be developed when required. The RCRA regulations give no explanation of why certain test procedures were chosen and why others were not. Finally, tolerance levels are only implicit in these procedures for most cases, and have not actually been determined, and this is discussed below.

Table 2 illustrates the fact that these implicit tolerance levels have been set without adequate consideration of health effects. The first column shows the minimum concentrations at which twelve selected chemicals can be detected using the RCRA procedures (17). For each of these chemicals, the second column shows EPA's estimate of the concentration which EPA projects will cause one cancer per one hundred thousand people drinking two liters a day of the water over a lifetime (45 FR 79325-41). The concentrations associated with cancer are based on animal studies, and projections from high doses to low doses, and projections from carcinogenic activity in animals to estimated effects in humans. There are substantial disagreements about the accuracy of such projections, and the values listed in table 2 are not universally accepted. They are, however, EPA's own published projections and they continue to be used by EPA. Since it is EPA's criteria which determine whether a site should be included in CERCLA, these projections are relevant to this study despite uncertainties about their derivation.

Table 2

EPA DETECTION LIMITS FOR SOME CARCINOGENS

Chemical	Highest permitted EPA detection limit (nanograms/liter)(17)*	Concentration projected** to cause one cancer per 100,000 people † (nanograms/liter)	Projected** cancers per 100,000 people
aldrin	1,900	0.74	2,600
dieldrin	2,500	0.71	3,500
1,1,2,2-tetrachloroethane	6,900	1700	4
3,3'-dichlorobenzidine	16,500	103	160
heptachlor	1,900	2.78	680
PCBs	36,000	0.79	46,000
benzo(a)pyrene	2,500	28	90
benzidine	44,000	1.2	37,000
chlordane	14	4.6	3
DDT	4,700	0.24	20,000

* A nanogram is a billionth of a gram. One nanogram per liter is approximately one part per trillion.

* Projections based on the consumption of two liters (a little over two quarts) a day of the contaminated drinking water over a lifetime. Projections are also based on animal studies that include assumptions on the transfer of results from animals to humans, and extrapolation from high doses to low doses. Despite the uncertainties introduced by these assumptions, these are the projections EPA uses. Column 3 has been calculated by OTA by dividing Column 1 by Column 2. This calculation converts back towards high doses. Uncertainties introduced into Column 2 by high-to-low dose extrapolation are thus partially corrected for in deriving Column 3. Column 3 contains no correction for uncertainties introduced by applying animal results to humans.

†Reference: 45 FR 79325-79341

By dividing the entry in the first column by the entry in the second column, the projected number of cancers per one hundred thousand is estimated in column three. Thus, for example, table 2 shows that a hazardous waste disposal site operator, permitted by EPA, may, without violating his permit, pollute groundwater with up to 2,500 nanograms per liter of dieldrin. This is a concentration which EPA data projects may cause 3,500 cancers per hundred thousand people who drink such water over their lifetime.

To put this in its proper context, EPA is currently seeking to ban the use of pesticides on the basis that the cancer risk is as low as one in one hundred thousand (8). Therefore, it is likely that a facility which is polluting groundwater at a level which is projected to cause 3,500 cancers per hundred thousand would come to the attention of CERCLA.

The next point to be made concerns the explicit tolerance level associated with the sixteen contaminants for which there is an EPA drinking water standard. EPA allows (20) that for pollutants for which there is an existing EPA primary drinking water standard, RCRA permitted facilities may contaminate up to the standard. The primary groundwater pollution standards are shown in table 3. Just as in table 2 (and with the same caveats), this table also projects the cancers per hundred thousand for those substances for which data are available from the EPA published source. In addition, the fourth column indicates the substances known or believed to be carcinogens.

For some of these pollutants, there may be no "zero effects" level and any amount of the substance is considered a risk to human health. For example, cadmium is carcinogenic (23) and is not considered without risk at any level (15). Arsenic, lindane and toxaphene are alleged carcinogens and,

Table 3

DATA ON RCRA POLLUTANTS WITH PRIMARY DRINKING WATER STANDARDS

Pollutants	EPA Primary Drinking Water Standard (ug/l)*	Concentration projected** to cause one cancer per 100,000 people† (ug/l)	Projected** cancers per 100,000 people	Comments
arsenic	50	0.022	2300	a
barium	1000			b
cadmium	10			a
chromium	50			
lead	50			
mercury	2			
nitrate (as N)	10000			
selenium	10			
silver	50			
fluoride	1400-2400			
endrin	0.2			
lindane	4	0.186	22	b
methoxychlor	100			
toxaphene	5	0.0071	700	b
2,4-D	100			
2,4,5-T, Silvex	10			

a - known human carcinogen (23)
b - probable human carcinogen based on animal studies (23)

* ug/l: microgram per liter, or millionth of a gram per liter. 1 ug/l is approximately one part per billion.

** Projections based on the consumption of two liters (a little over two quarts) a day of the contaminated drinking water over a lifetime. Except for arsenic, projections are also based on animal studies that include assumptions on the transfer of results from animals to humans, and extrapolations from high doses to low doses. For arsenic, projections are extrapolated from the effects of high doses in humans. Despite the uncertainties introduced by these assumptions, these are the projections EPA uses. Column 3 has been calculated by OTA by dividing Column 1 by Column 2. This calculation converts back to high doses. Uncertainties introduced into Column 2 by high-to-low dose extrapolations are thus partially corrected for in deriving Column 2. Except for the arsenic number, which is based on human data, Column 3 retains the uncertainties introduced by applying animal results to humans.

†Reference: 45 FR 79325-79341

as shown in table 3, are associated with significant cancer risks at the EPA tolerance level.

The next point in regard to tolerance levels is that not all toxic pollutants which can cause a site to be regulated under CERCLA are monitored under RCRA. A most conspicuous example is dioxin contaminated soils which are being sent to RCRA regulated landfills although under regulations EPA cannot currently require the monitoring of some dioxins, although they are proposing to do so (48 FR 14514). Table 4 is a list of some other hazardous substances regulated under CERCLA which are not regulated or monitored under RCRA.

Table 4 was drawn up by reviewing the rules proposed under CERCLA on May 25, 1983 (48 FR 23552). These rules propose "reportable quantities" for a long list of hazardous substances. A reportable quantity (RQ) is that quantity of a hazardous substance which if spilled must be reported to the National Response Center (CERCLA §103) so that, among other things, a determination can be made if any response under CERCLA is necessary. RQ's are based on six criteria, i.e., aquatic toxicity, mammalian toxicity, ignitability, reactivity, acute toxicity, and carcinogenicity. They are in five reporting levels: [illegible], 10, 100, 1000, and 5000 pounds. The lower the RQ the more hazardous the substance is supposed to be.

Table 4 lists those hazardous substances which have proposed RQ's in the two most hazardous categories of 1 and 10 pounds and which are <u>not regulated under RCRA</u>. The proposed rules do not indicate the basis of the rating for each substance; therefore, it is possible that it is inappropriate to regulate some of these hazardous substances under RCRA, but no discussion of this issue has been found. Table 4 also shows the oral mammalian toxicity (in LD50) where this information is available in the NIOSH registry (3).

Table 4

SOME POLLUTANTS REGULATED UNDER CERCLA (REPORTABLE QUANTITIES) BUT NOT UNDER RCRA

Pollutant	Proposed Reportable Quantity (pounds) †	Oral (mammal) LD^{50}* (mg/kg) (23)
carbofuran	10	11
chlorpyrifos	1	97
diazinon	10	76
dichlone	1	
alpha - endosulfan	1	
beta - endosulfan	1	
endosulfan sulfate	1	
endrin aldehyde	1	
guthion	1	13
mercaptodimethur	10	34
mevinphos	10	3.7
naled	10	250

† 48 FR 23552-23595

* LD_{50} - Lethal Dose Fifty - a calculated dose of a substance which is expected to cause the death of 50% of an entire defined experimental animal population. It is measured in milligrams of substance ingested per kilogram of animal body weight. For comparison purposes note that the oral toxicity of iodine is 14,000 mg/kg, arsenic acid is 48 mg/kg, and potassium cyanide is 10 mg/kg.

The significance of table 4 is that these substances could be leaking into groundwater from a RCRA permitted facility without violating the permit, yet would be candidates for regulations under CERCLA. Even more to the point is the fact that if these substances are spilled in transportation or manufacturing operations in excess of their RQ, they must, under CERCLA, be cleaned up and disposed in a RCRA regulated facility where RCRA regulations would not require their monitoring.

Table 5 addresses those contaminants of concern to CERCLA that are also regulated under RCRA. In many cases, the groundwater detection levels are higher under RCRA, as much as 1000 times higher. This is another example of the puzzle that often occurs in comparing RCRA regulations with CERCLA. The cure is more protective of public health than the prevention. Thus an EPA RCRA regulated site may legally pollute groundwater to a level tolerated by RCRA but come to the attention of CERCLA for the same pollution.

The last, and perhaps most important point in regard to tolerance levels is that for many, perhaps even for most of the several hundred hazardous constituents for which EPA has published test procedures for groundwater monitoring samples (17), the level at which these contaminants can be detected has not been published in reference 17 and has not yet been determined by EPA. Although research is underway to determine detection levels, this further confirms that considerations of human health did not play a major role in determining the test protocols to use. Some of the hazardous constituents for which EPA does not yet know the detection limits are listed in table 6. The substances shown on this table were selected because they are alleged carcinogens to which preliminary EPA research has given high hazard ratings. Nevertheless, RCRA rules permit groundwater contamination by these substances to an undetermined level.

Table 5

SOME EXAMPLES OF GROUNDWATER DETECTION LEVELS OF HAZARDOUS CHEMICALS WHICH ARE HIGHER UNDER RCRA THAN UNDER CERCLA

Pollutant	CERCLA Detection Levels (ng/l)(21,22)	RCRA Detection Levels (ng/l)
dieldrin	5	2,500 (17)
DDT	10	4,700 (17)
DDE	5	5,600 (17)
DDD	10	2,800 (17)
heptachlor	5	1,900 (17)
heptachlor epoxide	5	2,200 (17)
aldrin	5	1,900 (17)
antimony	20,000	32,000 (63)
arsenic	10,000	53,000 (63)
cadmium	1,000	4,000 (63)
lead	5,000	42,000 (63)
selenium	2,000	75,000 (63)
thallium	10,000	40,000 (63)

Table 6

SOME CARCINOGENIC CHEMICALS FOR WHICH EPA HAS NOT YET DETERMINED THE LEVELS AT WHICH THEY CAN BE DETECTED IN GROUNDWATER BY THE METHODS OF REFERENCE 17

aflotoxin
4-aminobiphenyl
aziridine (ethyleneimine)
bis-(chloromethyl)ether
chloromethyl methyl ether
1,2-dibromo-3-chloropropane (DBCP)
diethylnitrosamine (n-nitrosodiethylamine)
diethylstilbesterol*
dimethylaminoazobenzine
7,12-dimethylbenz(a)anthracene
dimethylcarbamoyl chloride
1,2-dimethylhydrazine
ethyl methanesulfonate
hydrazine
methylnitrosourea
nitrosomethylurethane (n-nitroso-n-methylurea)
n-nitosopiperidine
n-nitrosopyrrolidine
streptozotocin*
2,3,7,8-tetrachlrodibenzo-p-dioxin (TCDD)
ethylene dibromide (EDB)

*Test methods not yet published by EPA as of January 19, 1984.

In addition, the RCRA test procedures manual indicates that when several chemicals are mixed together, as is usually the case in groundwater monitoring, the ability to detect a specific chemical by a given test procedure is reduced. These so called analytical interferences raise the detection limits by an undetermined amount (17). It is clear that not being able to detect carcinogens, which can be of concern at very low levels of contamination, as well as other hazardous materials, is not only dangerous to human health, but increases the likelihood of CERCLA involvement.

The effects of this can be best illustrated with the example of ethylene dibromide (EDB). EPA has recently cancelled the use of EDB as a fungicide because of its carcinogenicity. In recent Congressional testimony, EPA's pesticide program director, Edwin Johnson said (58):

> . . . .we believe that the risks posed by EDB in drinking water at levels in the low parts per billion are roughly comparable to the risks posed by grain fumigation. In both cases we consider these estimated risk levels to be unacceptable for a lifetime of exposure. . . .According to our information, the State of Florida has acted to provide alternative drinking water for approximately 500 wells found to contain EDB at or above 0.1 p.p.b. This appears to be a responsible and effective way of dealing with these potential risks. In short, the risks of EDB being reported in Florida ground water (typically 1 to 20 p.p.b.) are probably similar to risks posed by grain products. . . .

EPA's Office of Solid Waste has indicated that the appropriate test method for EDB in groundwater is the "GC/MS method for volatile organics" which is test method number 8240 in reference 17. While this reference does not list a detection level for EDB, it does list detection levels for 21 other volatile organics. These range from 1.6 parts per billion to 7.2 parts per billion. Furthermore, the text states that the table "lists detection limits that can be obtained in waste waters in the absence of interferences. Detection limits for a typical waste sample would be significantly higher."

Therefore, the RCRA tolerance level for EDB could be from one to possibly three orders of magnitude higher than the 0.1 parts per billion indicated as "responsible" in the EPA testimony quoted above.

In summary, CERCLA is required to address releases of any "hazardous substance" which is defined as any substance designated under CERCLA and four other acts administered by EPA. EPA has chosen to have RCRA regulate a much narrower universe of substances and many of those are not regulated with the same stringency as in other EPA programs. Therefore, compliance with a RCRA permit will not necessarily be sufficient to prevent a site from becoming a CERCLA site.

MONITORING IN THE VADOSE ZONE

EPA regulations for permitted facilities require that groundwater detection monitoring wells be placed in the uppermost aquifer at the edge of the waste disposal area (40 CFR 264.98(b)). Any contaminant detected by the well may have first traveled anywhere from a few feet to several hundred feet under the waste disposal area before it reaches the aquifer. Then the contamination may have traveled anywhere from a few feet to several thousand feet in the aquifer before it reached the well. Furthermore, if the leading point of the plume of contamination is between two monitoring wells, it could travel some distance past the wells before it is detected. Therefore, even if a detection monitoring system works exactly as planned, there could still be considerable environmental damage before the contamination may be detected in a monitoring well.

The vadose zone is the ground above the uppermost aquifer. In humid areas of the United States it is rarely over one hundred feet deep and is usually much less. In arid western areas, however, the vadose zone can be several hundred feet deep. Water and associated contaminants from a land disposal facility will travel through the vadose zone to an aquifer at a rate determined by the soil characteristics, the depth of the vadose zone, the amount of fluids in the waste, and the amount of water. This can take anywhere from a few months to many decades. P.F. Pratt, Chairman of the Soil and Environmental Sciences Department at the University of California at Riverside points out (44):

> In irrigated agriculture we have estimates of water movement and time required for water to move through the vadose zone. For sandy soils having low water retention properties and fairly large drainage volumes the time required to move through 100 feet of the unsaturated zone is 10 to 20 years. For clayey soils of higher water retention and lower drainage

> volumes the time is 40 to 60 years for 100 ft of the unsaturated zone. The transit time is proportional to the water retention properties of the soil material in the vadose zone and inversely proportional to the amount of water that leaves the surface zone (root zone in cropland or the storage facility in case of a waste disposal facility). In irrigated agriculture the drainage volume usually ranges from about 6 to 20 surface inches per year. If the leakage from a waste disposal facility is of the same order of magnitude as in irrigated agriculture the transit times will be of the same order of magnitude. If the leakage is smaller the transit time will be longer.

The significance of this fact is that by the time contamination is discovered in a groundwater monitoring well, the vadose zone could have stored significant amounts of contamination. Such toxic materials could continue to pollute the groundwater for many decades even if disposal is halted and the groundwater is initially cleaned up. Furthermore, the trend in regulatory actions is to require land disposal facilities to be located in areas with low porosity clay soils preferably at great depth to groundwater. Such locations postpone the time it will take the contamination to reach groundwater, but also increase the amount of contamination stored in the vadose zone.

Not all contamination which reaches the aquifer is carried away by the groundwater. Some contaminants may be adsorbed on solid surfaces or otherwise contained in the aquifer and only gradually released or desorbed in small amounts to pollute the groundwater. Professor John Cherry cites one example for such materials as paint thinners, pesticides and PCB's (45):

> These dense halogenated immiscible hydrocarbons currently pose many intractable problems pertaining to subsurface contaminant evaluation and prediction. They are so dense that in some situations, irrespective of the directions of groundwater flow or water table configuration, they can move downward or laterally along paths of least resistance offered by granular beds or fractures. While this movement occurs and after it occurs, the immiscible liquid yields toxic dissolved contaminants to the groundwater. The dissolved contaminants are then transported by the groundwater in directions and at

rates that may have no relation to the flow of the immiscible liquid.

> At some waste disposal sites, it is suspected that dense halogenated hydrocarbon liquids have moved downward and have settled as pools on top of impermeable beds in dead-end fractures. The pools would then act as a long-term source providing dissolved hydrocarbons to the flowing groundwater. Scenarios can be envisioned whereby isolated zones of immiscible liquids exist at considerable depth below the waste disposal site and locally contribute hazardous concentrations of dissolved contaminants to the groundwater. Because of low solubility these contaminant sources could persist for hundreds of thousands of years. They would be difficult or impossible to detect using normal monitoring networks. They could produce unpreditable small-scale contaminant plumes. In some circumstances, numerous little pools or zones of immiscible liquids from numerous leaky drums in a landfill could result in a rather chaotic pattern of input of halogenated hydrocarbons to the groundwater flow system.

Thus, by the time contamination is detected in groundwater (if it is detected), there may have been significant contamination of the vadose zone and the aquifer which can continue to slowly re-enter the groundwater even after it is initially cleaned up.

It is seen from the previous discussion how useful it would be to detect leachate contamination in the vadose zone beneath a hazardous waste disposal site before it reaches groundwater. Groundwater cleanup costs and alternative water supply costs might be avoided and human health and the environment better protected. EPA does require vadose zone monitoring for land treatment of hazardous wastes* in the standards for EPA permitted facilities of July 26, 1982. The preamble to the regulations states that "EPA believes that adequate technology and expertise is available to develop effective and reliable systems." (47 FR 32329) Yet in the same regulations vadose zone monitoring is

*This method is used for less than one percent of wastes land disposed; also known as land spreading or land farming of wastes.

not required for landfills, surface impoundments and waste piles where the need and the benefits would appear to be far greater.

The technology for which there is the most experience in waste disposal monitoring in the vadose zone is the suction lysimeter, a porous ceramic cup placed in the vadose zone to collect a sample of the fluids there. In the interim status standards for existing land disposal facilities, EPA rejected the use of lysimeters with this explanation in the preamble of May 19, 1980 (45 FR 33191):

> Available leachate monitoring technology generally involves the placement of probes (lysimeters) beneath the disposal facility. Since each probe is not generally capable of monitoring a large area, many of them would have to be placed under a facility in order to detect a localized flaw in the landfill design. It may not be possible to place such devices below an existing landfill or surface impoundment without completely removing the waste and redesigning the facility. Moreover, once such a system is in place, the probes tend to fail over time due to deterioration or plugging. It is difficult to determine when such a failure occurs and, if discovered, the damage is generally irreparable. Under these circumstances EPA does not believe that leachate monitoring should be a general requirement for landfills and surface impoundments during interim status.

Other commentors have pointed out that lysimeters do not work well in sub-freezing or conditions of low soil moisture (50) or very hot and dry conditions (49).

Upon close examination, many of these points do not stand up. The first point, that the "probe is not generally capable of monitoring a large area" is contradicted by field experience. At a recent conference on vadose zone monitoring a paper was presented which indicated that a suction lysimeter located 10 feet below an impoundment could measure a distance of 10 to 30 feet laterally (61). Secondly, placing suction lysimeters under existing land disposal sites can and has been done by the simple technique of drilling at a slant. Thirdly, the plugging problem can be largely overcome by packing the sampler with silica flour (68), a standard technique which even appears in EPA manuals (69). Fourthly, the statement that the "damage is generally irreparable" is unclear since what has been placed ought to be replaceable.

As for the other comments, it is largely irrelevant that lysimeters do not work well in conditions of freezing or low soil moisture since these are not conditions in which there would generally be leachate. And as for hot and dry conditions, as pointed out later, vadose zone monitoring is currently being conducted in Beatty, Nevada. In any event, it is not necessary that lysimeters work perfectly (no technology does) or that they be convenient to use. The important point is whether they are cost-effective in reducing groundwater cleanup costs.

Lysimeters have been used for many years for monitoring land disposal sites. At least one state, Texas, uses them for regulatory monitoring (51). Wisconsin has been requiring vadose zone monitoring since the mid 70's and there are currently 19 hazardous waste sites in that state with either suction lysimeters or collection lysimeters (64). California has proposed regulations which would require vadose zone monitoring in new installations.

The United States Geological Survey has installed suction lysimeters (albeit, not without difficulty) at two existing low level nuclear waste landfills. This research projected was started by USGS in 1981 (67).

A two year study of three sanitary landfills by Thomas M. Johnson of the Illinois State Geological Survey (52) placed lysimeters under the existing landfills; he found that all three had contamination in the vadose zone which had not been detected by groundwater monitoring wells. In one site the lysimeters showed that a clay liner had been ruptured and in another site the lysimeter monitoring showed that contamination detected by a monitoring well was coming from a different site. The Illinois researchers did not experience the difficulties reported by EPA.

There is also field experience with geophysical vadose zone monitoring techniques. A commercial hazardous waste disposal facility in Oregon uses a vadose zone monitoring system which "integrates lysimeters, dual purpose tensiometers/lysimeter units, and geophysical arrays to provide an early warning leak detection and sampling system." (61) A firm in Las Vegas has installed three resistivity grids since 1980 at hazardous waste lagoons, and they are all reported to be working well (65).

Keros Cartwright of the Illinois State Geological Survey points out that (48):

> Numerous techniques have been developed for monitoring the movement and quality of water in the unsaturated zone, including tensiometers, soil moisture blocks, and neutron logging techniques to monitor soil water content and pressure. Water quality is generally monitored by soil sampling using porous ceramic cups similar to those used in tensiometers. Whereas soil sampling requires repeated drilling for extended analyses, soil water sampling using suction or pressure vacuum lysimeters allows repeated sample collection.
>
> The usefulness of soil water samplers for monitoring soil water quality in the vicinity of waste disposal sites has been demonstrated by several workers in Pennsylvania (Apgar and Largmuil, 1975; Parizek et al., 1975; Parizek and Lane, 1970; and Johnson and Cartwright, 1980). More recent applications, incorporating additional refinements, include the use of pressure vacuum lysimeters to monitor soil water quality at depths to 33 meters (108 ft) beneath artificial recharge sites in Texas (Wood, 1970) and, in a study contemporaneous with this one, three landfills in Wisconsin were instrumented (Gerhardt, 1977) to generate data on the attenuation of leachate in the unsaturated zone.

As Cartwright points out, there is a fair amount of literature evaluating the many techniques available for monitoring in the vadose zone for both new and existing land disposal facilities. In particular, in 1980 L.G. Wilson of the University of Arizona Water Resources Research Center reviewed a number of techniques for vadose zone monitoring below waste disposal sites for EPA (42). See table 7. Many of these are commercially available and are in common use. Another survey of state-of-the-art techniques and techniques under research or development which are capable of localizing a liner leaks was made for the EPA Cincinnati laboratory (46). Table 8 lists the technologies evaluated in this study.

Vadose zone monitoring techniques are not generally easy to use nor are they inexpensive. No one technique is universally applicable and to get a reasonable assurance of detecting leachate, several of them may have to be used at any given site. However, as discussed previously, the techniques for groundwater monitoring are also difficult, fallible and expensive. The cost of cleaning groundwater which is often in the tens of millions of dollars, is proportional to the amount of contamination. Thus, even if the technology for vadose zone monitoring is more difficult and less reliable than groundwater monitoring there are substantial benefits from early detection of pollution in the vadose zone.

EPA, in rejecting the use of vadose zone monitoring in 1982 (47), referred to the work of Wilson but only discussed one of the 26 techniques he evaluated, the suction lysimeter. This technique was rejected largely because of cost, although no analysis was made of the trade-off of avoiding the cost of cleaning the contaminated groundwater. There was apparently no review made of the many applications of vadose zone monitoring.

Table 7

TECHNIQUES REVIEWED BY WILSON (42) FOR MONITORING IN THE VADOSE ZONE

Techniques for observing storage changes in the vadose zone at a waste disposal site:

- Monitoring the spatial distribution of water levels in wells to delineate the areal thickness of the vadose zone.
- The gamma ray attenuation method to characterize bulk density and water content of vadose zone sediments
- The neutron moderation method for defining the water content distribution in the vadose zone
- Tensiometers for estimating water content at discrete points in the vadose zone
- Electrical resistance blocks for estimating water content at discrete points

Methods for monitoring water movement (flux) and associated parameters in the vadose zone:

- Estimating infiltration rates by infilotrometers and test ponds
- Characterizing the quantity of water moving beneath the soil zone using the water balance approach
- Determining the direction of unsaturated water movement and associated hydraulic gradients using tensiometers, psychrometers, and the neutron moderation method
- Measuring the unsaturated flux of water by adapting laboratory techniques to the field, using water content profiles, estimating from suction cup response, and using direct techniques such as flow meters
- Determining saturated flow in perched groundwater zones using piezometers and observation wells
- Outlining techniques for determining the saturated hydraulic conductivity in the soil zone and deeper vadose zone

Indirect methods for monitoring movement in the vadose zone:

- The four-electrode method for soil salinity
- The EC probe for monitoring soil salinity
- The four-electrode conductivity cell for observing soil salinity
- The earth resistivity approach for delineating pollution plumes

Table 7 (continued)

Techniques for solids sampling in the vadose zone for determination of associated pollutants are reviewed.

Direct techniques for water sampling during unsaturated flow:

- o Ceramic-type samplers (suction lysimeters and filter candles)
- o Cellulose-acetate hollow-fiber filters
- o Membrance filter samplers

Methods for sampling from shallow perched groundwater zones:

- o Sampling tile drain outflow
- o Collection pans and manifolds
- o Wells
- o Piezometers
- o Multilevel samplers
- o Groundwater profile samplers

Sampling from deeper perched groundwater:

- o Collecting cascading water
- o Installing special wells

Table 8

SUMMARY OF CANDIDATE METHODOLOGIES FOR DETECTING AND LOCALIZING LEAKS IN LANDFILL LINERS FROM WALLER AND DAVIS (46)

Technique	What is Measured in the Ground?
Electric	
Resistivity	Resistance over a length vs. horizontal & vertical position
SP	Voltage generated by electrochemical actions
Electromagnetic	
Low Frequency Electromagnetic	Conductivity vs. horizontal and vertical position
High Frequency Electromagnetic	Dielectric properties vs. horizontal and vertical position
Acoustic	
Seismic	Elastic properties vs. horizontal and vertical properties
Acoustic Emission	Sounds emitted from fluid flow in soils
For planned sites	
TDR Grid	Dielectric properties vs. position on transmission line
DC Grid	Change of resistance of a wire due to corrosion caused by leak

DELAYS IN STARTING CORRECTIVE ACTION

Under the Part 264 EPA standards for EPA permitted facilities in a detection monitoring mode (40 CFR Part 264, Subpart F), if hazardous constituents are detected by the groundwater monitoring system a "compliance monitoring" program must be instituted. This program consists of two parts. First, the EPA permit writer will establish a "groundwater protection standard" for the unit, which will be specified in the permit for the facility. Second, a new groundwater monitoring program will be instituted to determine whether the unit is in compliance with its groundwater protection standard. This new program will consist of monitoring at the compliance point, i.e. the edge of the disposal area, to detect any statistically significant increase in the concentration levels of hazardous constituents specified in the groundwater protection standards.

The groundwater protection standard includes the hazardous constituents to be monitored or removed if necessary, the concentration limits for each hazardous constituent that trigger corrective action, the "point of compliance" for measuring concentration limits, and the compliance period.

The regulations require that the concentration limits be set at: the background level of the constituent in the groundwater; or for any of the 16 hazardous constituents covered by the National Interim Primary Drinking Water Regulations (see table 3), the maximum concentration limits for drinking water established in these regulations, if the background level of the constituents is below this. The facility owner may ask for a variance to establish an alternate concentration limit if he can demonstrate that the constituent will not pose a substantial present or potential hazard to human health or the environment as long as the alternate concentration limit is not exceeded.

If the groundwater protection standard is exceeded, then still another step, the "corrective action program" is instituted. The objective of of this program is to bring the facility into compliance with the groundwater protection standard by removing the hazardous waste constituents from the groundwater or treating them in the aquifer. The regulations require that corrective action measures be taken to clean up the plume of contamination that has migrated beyond the compliance point but not beyond the property boundary.

Earlier it was shown that even in a well designed and properly functioning groundwater detection monitoring system, a long time, even decades, could elapse before contamination from a leak from a hazardous waste disposal site reached a detection monitoring well. However, because of the structure of the EPA regulations, a long time could also elapse between the time the contamination reaches a monitoring well and the time anything is done about it. Table 9 shows a scenario where this elapsed time is over two years. This example does not present a "worst case" scenario, but simply illustrates times required to work through the many steps prescribed by the regulations.

Furthermore, it should be pointed out once again that the action required to be taken is that the plume of groundwater contamination be cleaned up from the edge of the disposal area to the property line. There is no requirement to clean up the contamination beyond the property line; there is no requirement to find the source of the leak and to repair it; and there is no requirement to cease disposal operations.

Table 9

SCENARIO FOR INSTITUTING CORRECTIVE ACTION AT A RCRA PERMITTED SITE IN DETECTION MONITORING

January 1, 1984	Contamination reaches groundwater detection monitoring well.
April 1, 1984	Sample is drawn from monitoring well. Well must be sampled semi-annually (40 C.F.R. 264.98(a)). Assume average time to detect contamination is three months.
May 1, 1984	Determination is made that there is a statistically significant increase over background. This determination must be made "within a reasonable time period" (264.98(g)(2)). Assume one month, however, discussion in next section will show this is optimistic.
August 1, 1984	Submit request to EPA for permit modification to establish compliance monitoring program. This must be done within 90 days (264.98(h)(4). Include notice of intent to seek a variance for alternate concentration limits under part 264.98(b) (264.98(h)(4)(iv)).
November 1, 1984	Submit data to justify variance under part 264.94(b) for every hazardous constituent identified under part 264.98(h)(2). This must be done within 180 days of the time that a determination is made that there is a statistically significant increase over background (264.98(h)(5)(ii)(B)).
March 1, 1985	EPA rejects request for variance and issues draft revised permit for compliance monitoring. No time limit specified in the regulations. Assume it takes four months for EPA to review the data and prepare a draft permit. Notice is given for public comment.
April 15, 1985	End public comment period. Regulations require 45 days (124.10(b)).
May 15, 1985	EPA issues revised permit. No time limit specified in regulations. Assume it takes EPA one month to review public comments and revise permit accordingly. Compliance monitoring begins.
August 15, 1985	Submit request to EPA for permit modification to establish corrective action program. This must be done within 90 days (264.99(i)(2) and 270.14(c)).
September 1, 1985	Submit engineering feasibility plan for corrective action program. This must be done within 180 days of the time that the request for variance is rejected, i.e., March 1, 1985. (264.98(h)(5)(ii)).

December 1, 1985	EPA issues draft revised permit for corrective action. No time limit specified in the regulations. Assume it takes four months for EPA to review the data and prepare a draft permit. Notice is given for public comment.
January 15, 1986	End public comment period. Regulations require 45 days (124.10(b)).
February 15, 1986	EPA issues revised permit. No time specified in the regulations. Assume it takes EPA one month to review public comments and revise the permit. Corrective action begins.

Total elapsed time: two years one and one half months not including delays from statistical analysis.

STATISTICAL ANALYSIS

In the previous discussion it was assumed that when contamination had been found in a well, a finding of a statistically significant increase over background levels would be made within one month. In fact this is very unlikely.

In sampling groundwater, there is considerable variability due to factors other than the introduction of waste related contamination. These include such things as seasonal fluctuations, geochemical processes, perturbations introduced by the monitoring well, contamination or other changes introduced by the sampling technique, natural and non-waste contamination, variability in chemical analysis, and a great many others. It is necessary to distinguish changes in groundwater due to contamination from those due to random or periodic effects. The EPA regulations for both Part 264 and Part 265 state that when a sample of the groundwater is taken from a monitoring well and analyzed for the required contaminants, that the results be compared with the previously determined background levels to see if there is any "statistically significant" increase in contamination (40 CFR 264.97(h) and 265.93(b)). Statistical significance is determined by one of several mathematical formulas approved by EPA.

There are four possible outcomes from such a calculation:

1. The test could indicate that groundwater is contaminated when in fact it is not (false positive).
2. The test could indicate that groundwater is contaminated when in fact it is (true positive).

3. The test could indicate that groundwater is not contaminated when in fact it is (false negative).
4. The test could indicate that groundwater is not contaminated when in fact it is not (true negative).

In designing a test for statistical significance one wishes, of course, to minimize the false positives and the false negatives. This can be done by increasing the sample size, i.e. by increasing the number of monitoring wells, the frequency of sampling and the number of samples taken. But for a given sample size, any test of statistical significance which reduces the probability of false negatives also increases the probability of false positives and vice versa.

There are two ways to design a test for statistical significance. One is to decide in advance the probability of detecting groundwater contamination one wishes to achieve (the probability of detection being one minus the probability of a false negative). In this case the probability of a false positive will be a function of the sample size and the variability of the data. Another way is to determine in advance the probability of a false positive (called the level of significance) and allow those same factors to determine the probability of detection. In the former case the probability of a false positive will not be known in advance and in the latter case the probability of detecting contamination will not be known in advance. EPA has chosen the latter approach.

The cost of a false positive could be several thousand dollars e.g. the cost of additional sampling and testing to establish that there is actually no contamination. The cost of a false negative, groundwater contamination which has gone undetected, could be substantial: in the worst case, millions of dollars in additional clean up costs and increased threats to human health and the environment. And if the plume of contamination had passed the property boundary or if the owner cannot afford the necessary corrective action, the site would become a candidate for CERCLA action. Minimizing the occurrence of false positives reduces the short range costs of disposal site operators but this analysis found no mention in any EPA document of why this approach was chosen over the other.

EPA proposed standards for monitoring interim status sites on December 18, 1978 (43 FR 58982) which proposed a statistical test with a probability of false positives (the level of significance) of five percent. In the final regulations for interim status sites of May 19, 1980, EPA decreased the probability to one percent. But this increased the probability of false negatives. In the preamble discussion of this change (45 FR 33195) it is implied that the change was made because of industry concerns over the cost of a false positive. There is no mention of an attempt to balance this against the cost of false negatives borne by industry and the public.

In the regulations for EPA permitted sites published July 26, 1982, EPA raised the probability of false positives to five percent once again, explaining (47 FR 32303):

> EPA is fixing the level of significance for the Student's t-test at 0.05 for each parameter at each well. When the Agency proposed this significance level for interim status groundwater monitoring, it received some criticism that this would produce too many notifications of contamination where none had actually occurred.
>
> EPA recognizes that this could be a problem, particularly when there are many comparisons being made for different parameters and for different wells. However, EPA is concerned that a lower significance level would unduly compromise the ability to detect contamination when it did, in fact, occur.

EPA did not, however, raise the probability of false negatives from one to five percent at the approximately 2000 existing interim status sites which, as was mentioned before, may be leaking. No explanation was given for not including interim status facilities in this decision.

Considerable effort has been expended by OTA to find any estimate by EPA of the probability of detecting groundwater contamination by this statistical procedure. While EPA reports and background documents contain many discussions and calculations of false positives, no estimate of a false negative can be found. The only related material that has been found is a study for EPA by JRB Associates (4) which was supposed to "estimate the 'false positive' and 'false negative' probabilities for various statistical procedures" (11). However, they estimated the probabilities of false negatives for only one statistical procedure, and that one is not the one that EPA uses for detection the reason for this is not given. However, since this is the only estimate of detection probability found, a sample calculation is presented in table 10.

Table 10 shows the probability of detection, i.e., the probability of concluding that there is a statistically significant difference, when the level of contamination of TOX in the detection wells is in fact double the background level. It can be seen that the probability of detection in one test is only nine percent and that even after five years of sampling twice a year, the probability of detecting the contamination is only forty percent. The JRB study claims that this statistical procedure gives lower detection probabilities than EPA's procedure. Attempts to ascertain from JRB and EPA the significance of these results, in relation to the EPA statistical procedures, have not been successful.

Table 10

PROBABILITY OF DETECTING TOTAL ORGANIC HALOGEN CONTAMINATION

NUMBER OF TESTS	YEAR	PROBABILITY OF DETECTION
1	1	9.0%
2		14.6
3	2	20.0
4		24.6
5	3	28.6
6		32.0
7	4	34.2
8		35.8
9	5	37.8
10		40.0

Assumptions:
- background mean equals 20
- monitoring well mean equals 40
- averaged-replicate test is used at one percent level of significance
- other parameters are average of data from 52 sites studied

Source: JRB Associates (4)

COMPLIANCE MONITORING

The purpose of compliance monitoring at permitted facilities is to determine the degree and extent of the groundwater contamination or at least that part of it which is inside the disposal site property boundaries. This is especially important in designing and evaluating corrective actions. This is a very difficult and expensive proposition as EPA has testified in Congressional hearings held in 1980 (40):

> In a typical case. . .determining the extent and severity of a plume emanating from one single source in a shallow aquifer requires dozens of monitoring wells and hundreds of samples. It also takes a great deal of time and several hundred thousand dollars. If the geology is more complex or several potential contamination source exist, the cost will be on the order of $0.5 million. In a case where the aquifer is deep or surface features cannot help in determining the hydrogeology, costs could soar to two or three million dollars.

Here again, as with the placement of the wells for detection monitoring, the science of hydrogeology enters but with the additional requirement to model and predict underground contaminant flow. However, groundwater modeling with an emphasis on the flow of contaminants and not merely water is not a routinely available technique like well drilling or chemical analysis. Such modeling is state-of-the-art scientific research generally carried out in universities and a few companies. Even in those cases where modeling groundwater flow is possible, predicting contaminant flow may still be very difficult (see section on vadose zone) if possible at all (45). Groundwater consultant David Miller pointed this out at Congressional hearings in 1982 (41):

> Unlike detection monitoring, compliance monitoring with its dependence on predictions of contaminant migration through the subsurface may be beyond the current state-of-the-art of the groundwater science. It is not presently possible to determine how

thousands of individual chemicals will react in the groundwater environment or to confidently predict the aggregate effects of numerous processes such as attenuation, dispersion, and diffusion. A vast amount of field data would be required to develop a reliable basis for such predictions.

It is frequently suggested that modeling could serve as an adequate predictive tool for this purpose. However, even detailed investigations which might cost on the order of $250,000 to $500,000 per site may not provide enough data to develop a model to be used in this capacity. Furthermore, a relatively successful model based on adequate data can only be expected to yield results within an order of magnitude of the actual situation. This level of accuracy may not be acceptable when public health is at risk and critical concentrations are measured in parts per billion.

The process of obtaining the data for predicting groundwater conditions, interpreting the information and making accurate decisions to implement compliance monitoring is a scientific endeavor. It can only be carried out in a confident manner by well trained groundwater technicians. There is presently a severe shortage of trained groundwater scientists in the public and private sector, and it is doubtful that there is sufficient talent available to work on more than a relatively small percentage of the existing sites that would fall under the compliance monitoring aspects of the new hazardous waste regulations.

Similar views were put forward by Professor John Cherry at the aforementioned National Science Foundation Workshop (26):

The ability of hydrogeologists to determine the present position of zones of migrating contaminants and to develop reliable predictions of future contaminant migration and of the effects of proposed remedial measures is critical to the task of evaluating the degree of risk and the cost/benefit ratios of remedial action. Unfortunately, the processes of contaminant migration are poorly understood in all except the most simple hydrogeological conditions. The study of contaminant migration processes in groundwater is in its infancy. Because knowledge of the processes affecting contamination migration in groundwater is slight, the predictive capabilities of current mathematical models for all except unusually uniform grandular deposits or clayey, diffusion-controlled deposits are inadequate or unknown.

EPA shares this opinion of the shortcomings of the science of modeling and predicting contaminant flow when it comes to using such techniques to evaluate the geological suitability of a site location. The preamble to the regulations state (47 FR 32283):

> EPA wants to make sure that the issuance of a RCRA permit for a facility means that a certain level of protection is provided and that the public can be assured that the prescribed level of protection will be achieved. The way to meet this objective is to avoid regulatory schemes that principally rely on complicated predictions about the long term fate, transport, and effect of hazardous constituents in the environment. Such predictions are often subject to scientific uncertainties about the behavior of particular constituents in the hydrogeologic environment and about the effects of those constituents on receptor populations.

However, the RCRA permit writers manual in its instructions for evaluating the design of a corrective action program takes a somewhat different view of the capability of hydrogeology in predicting contaminant flow (43):

> On the basis of the proposed design, the applicant should also provide an analysis that identifies the expected hydraulic impact of the recovery system on groundwater flow at the site. This analysis should include prediction of flow rates to wells and drains. Predictions of groundwater flow patterns throughout the contaminated areas, including the drawdowns and hydraulic gradients, that will be established by the recovery system should be provided. On the basis of predicted withdrawal rates, estimates should be provided for the time required to exchange an amount of groundwater equivalent to that originally contaminated.
>
> The applicant will need to use either analytical solutions or numerical (computer) models to provide these predictions of the response of groundwater on site to the proposed recovery system. Where aquifer conditions are simple or can be easily simplified, the use of analytical solutions will generally be most appropriate. If the groundwater flow system is complex or irregular boundaries are involved, the use of numerical models may be more appropriate.

To summarize, the requirement that compliance monitoring predict plume movement is a regulatory requirement that depends on a technology which does not really exist. As has been seen before, EPA puts more reliance on state-of-the-art technology to clean up pollution than it does to <u>prevent</u> pollution.

CORRECTIVE ACTION

The RCRA corrective action regulations for permitted facilities call for contaminated groundwater to be cleaned up to background levels. Since background contaminant levels can be, and frequently are, at extremely low levels, the regulations require a technology which is capable of removing contaminants to below the level of detection. Even more so than with compliance monitoring, the corrective action requirements of RCRA are requirements for a technology which does not really exist. This fact is acknowledged by EPA in the preamble to the regulations requiring the technology which states that "the technology of performing corrective action is new. The Agency's and the regulated community's experience in conducting remediation activities (beyond the feasibility study stage) is fairly limited to date" (47 FR 32313). The standards are based on the hope that technology will become available in the future as stated in the preamble which says that "The national experience with groundwater cleanup . . . is relatively limited at this time. EPA expects that over time, the state of knowledge about groundwater cleanup measures will improve" (47 FR 32286).

The most comprehensive study of attempts to clean up sites where groundwater had been polluted was made by EPA in 1980 (25). This was a study of 169 hazardous waste sites requiring remedial action. Groundwater was polluted at 110 sites. In most of these cases the groundwater supply was abandoned and replaced by a pipeline to another source. In very few cases, because of the high costs, was there any attempt made to clean up the groundwater, and none were cleaned to background levels.

Although there is little or no experience in restoring polluted groundwater to zero detection levels, there is experience in attempting to restore groundwater to some degree. It is difficult, very expensive and the results have been mixed. Typically, treatment of a plume is considered adequate when levels of volatile organics are at or below 100 ug/l (18). It is possible to have cleanup costs for a single site of over a million dollars a year for 20 or 30 years. Groundwater consultant Kenneth Schmidt summed up his experiences in a recent paper (19).

> Substantial efforts are now being made to reclaim polluted groundwater. In the southwestern U.S., where highly prolific alluvial aquifers are common, a number of problems can be encountered when attempting to reclaim polluted groundwater. First, many of the zones of polluted water are large--often in the range of thousands or tens of thousands of acre-feet. This results in the need to pump substantial amounts of water, which must then be treated and/or disposed. Decades will be required to remove polluted water in many situations. Second, pumpage of groundwater for reclamation often has legal constraints. Third, land ownership often present a formidable problem, because polluted zones frequently extend beyond property controlled by the responsible entity. Fourth, relatively deep water levels usually allow substantial amounts of pollutants to be in the vadose zone, where pumping is not effective. Fifth, pumping schemes are inherently inefficient in heterogenous, non-isotropic alluvial aquifers, due to inflow of unpolluted water during pumping. Because of the many limitations of reclamation, groundwater quality management should focus on aquifer protection.

The regulations allow for two basic approaches for corrective action. The first is to pump out the contaminated groundwater. This is not always so simple as pointed out by the American Petroleum Institute (28):

> . . . . in very arid portions of the country, groundwaters are generally located well below the ground surface. Therefore, it may be extremely difficult, if not impossible, to pump such underground waters. In complex geologic environments, contaminants may perch on clay layers. In such circumstances, even if pumping of surrounding waters were possible, such pumping would not succeed in bringing contaminants to the surface. In addition, in these circumstances, the depth of the contaminant layer may prohibit trenching to reach the contaminants. . . .Shallow aquifers may not have sufficient

waters to permit effective pumping. In addition, certain tight clay formations may prohibit effecting pumping from shallow aquifers. In these circumstances, if excavation is not possible, it is impossible to remove all contaminants.

The EPA RCRA permit writers guide recognizes these difficulties and points out the technological approaches for handling them (18). Where there is insufficient groundwater for efficient pumping, then fresh water must be injected into the aquifer by injection wells so as to flush out the plume of contamination. But the plume itself is the lesser problem.

> . . . . in most cases compliance with the groundwater protection standard will not be achieved after the removal of only an amount of groundwater equivalent to that originally contaminated. Rather, the removal of additional amounts of water, frequently many times in excess of that originally contaminated, will be required to reduce contaminant concentrations to acceptable levels. . . . Many of the hazardous constituents present in any plume of contamination migrating from a hazardous waste management facility will likely be subject to some amount of adsorption to the geologic materials on site. . . . as contaminated groundwater is removed from the subsurface and replaced by water of lower contaminant concentrations, contaminants will desorb from subsurface solids and establish new equilibrium concentrations of contaminants in the groundwater. Thus, the process of restoring groundwater quality will become a process, in most cases, of not only removing contaminants originally present in groundwater but also of removing contaminants adsorbed to subsurface solids.

This describes a very expensive process of pumping huge amounts of water for many decades with no guarantee that it will ever achieve the EPA standard. The issue of whether EPA will insist on the full measure of compliance with its standards when faced with such costs, becomes important. In addressing such public concerns, an EPA official recently wrote "It may be costly and take decades, but it can be done and under the regulations the owner is required to undertake it." (29) However, EPA's instructions to their permit writers are much less optimistic (32):

> . . . . the permit writer should also consider the relative costs of these measures when determining the adequacy of flushing rates predicted for proposed recovery systems. Increasing flushing by increasing pumping rates and the number of wells, well points, and/or drains will certainly increase the costs associate with the recovery system. Similarly, requiring the use of injection wells and/or increasing their number and rates of injection will increase cost. In some cases, particularly as flushing rates become higher, the cost of increasing flushing rates by requiring these design changes will become disproportionally high relative to the additional flushing achieved and the advantages gained.
>
> Thus, the permit writer will need to balance a number of factors when reviewing the adequacy of flushing rates expected from a proposed recovery system.

The EPA permit writers guide also points out many problems which may be encountered in attempting corrective action and it does not have solutions to all of them. For example, the problem of cleaning up immiscible fluids, mentioned earlier by Professor Cherry is poorly understood.

> Experience in the recovery of separate layers of immiscibles is currently limited and pertains almost exclusively to the recovery of lenses of light hydrocarbons, most notably petroleum products, floating on the surface of the water table (53). . . .Procedures for the cleanup of dense, immiscible contaminants are even more poorly documented and more experimental in nature than those for the cleanup of light, immiscible contaminants (54). . . .At the present time the state of the art in monitoring immiscible fluid content is imprecise. . . .The Agency is planning to develop further guidance on this topic as the state of the art is advanced. (55)

Once the contaminated water is pumped out of the ground, something must be done with it. One solution is to filter out the contaminants and return the cleaned water to the aquifer. This has been tried at some CERCLA sites. Table 11 shows some examples of the kind of levels of cleanup which can be practically (albeit at great cost) achieved using the most commonly favored techniques. Although impressive, these results are far from what would often be background levels, or even what are generally accepted to be safe levels.

Table 11

REMOVAL OF SELECTED SPECIFIC ORGANICS FROM GROUNDWATER
FROM ABSALON AND HOCKENBURY (16)

Organic Compound	Process Effluent Concentration Range*		
	Adsorption	Stripping	Biological
phenol	<10	--	10-50
toluene	<100	<10	10-50
benzene	<50	<10	10-100
ethyl Acetate	--	--	10-20
formaldehyde	--	--	50-100
aceton	--	--	10-20
methyl Ethyl Ketone	--	25,000	10-20
aniline	<10	--	10-50
nitroaniline	50-100	--	10-50
methanol	--	15,000	10-50
isopropanol	--	10,000	10-50
isobutanol	--	40,000	10-50
methylene Chloride	<100	200	<50
trichloroethylene	<10	5-10	<10
1,1,1-Trichloroethane	<10	50	10-50
1,1,2-Trichloroethane	<10	50	10-50
tetrachlorethylene	5-10	5-10	10-200
nitrobenzene	<10	--	100-1000

* Note: All values in ug/l or ppb.

A second technology which the RCRA groundwater protection standards allow for corrective action is "in situ" treatment. This is the introduction of chemical or biological agents into the aquifer to react with and destroy the hazardous constituents without pumping out the groundwater. If anything, there is even less known about these technologies than the previous ones, as the permit writers guide points out (56):

> . . . . to date in situ treatment has been applied in only limited circumstances, and little experience is available that can be related directly to the cleanup activities required in Part 264 corrective actions programs. . . . In most cases, use of these techniques will assume the character of a field experiment.

FINANCIAL RESPONSIBILITY

An additional problem with compliance monitoring and even more so with corrective action at permitted facilities is the question of assurance that there will be funds available for the huge expenditures these programs involve. A great many of the sites being cleaned up under CERCLA simply went bankrupt when the costs of groundwater cleanup became greater than the company's assets. EPA regulations are supposed to prevent this from happening at RCRA regulated sites and to this end EPA regulations do require financial assurance for closure costs and the costs of post-closure maintenance. However, there are no financial assurance requirements for the very expensive requirements of compliance monitoring and the even more expensive corrective action. Therefore, when companies are faced with these huge costs, some may chose bankruptcy and the costs will be borne by CERCLA as they have been in the past.

Because pollution will not be detected in the vadose zone and because corrective action may not begin promptly, greater build-up of groundwater contamination may occur. Since the cost of groundwater clean-up is roughly proportional to the quantity of groundwater polluted (57), these delays built into the regulations increase the cost of clean-up and enhance the probability that the site owners will not be able to afford the clean-up costs and that the sites will have to be cleaned up with CERCLA funds.

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