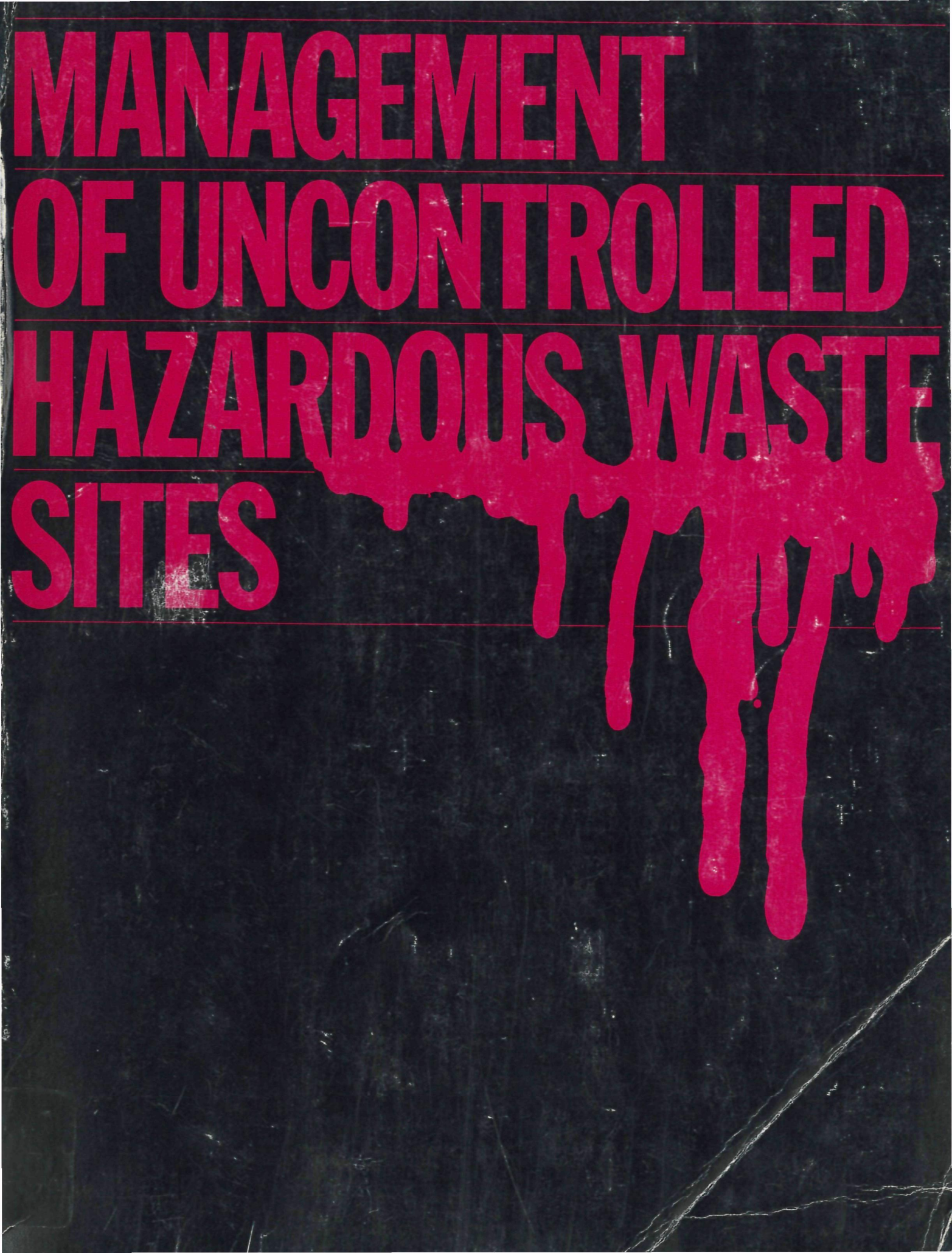
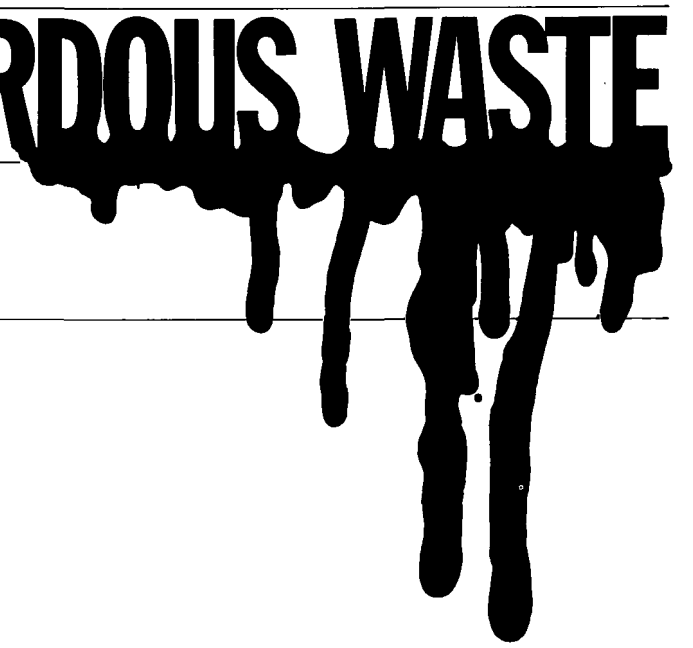
MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES



National Conference on

MANAGEMENT OF UNCONTROLLED HAZARDOUS WASTE SITES



October 28-30, 1981
Washington, D.C.

Co-sponsors

U.S. Environmental Protection Agency
Hazardous Materials Control Research Institute

In Affiliation with

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ACKNOWLEDGEMENT

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The concentrated effort necessary to publish a Proceedings of this size and scope in the time allotted is certainly 'above and beyond'. Our special thanks to Dr. Gary Bennett, Professor of Biochemical Engineering, The University of Toledo, and Hal Bernard, HMCRI whose editing allowed for a more uniform Proceedings; to the typesetters and graphics team who managed to meet the impossible deadlines set; and to the staff of HMCRI, in particular, Beverly Walcoff, Project Manager and Paula Geary, for coordinating the many aspects and activities of this Conference.

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CMA POSITION ON DEGREE OF HAZARD

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It is timely to clarify CMA's position on so-called "degree of hazard" in the context of EPA's hazardous waste management regulations under RCRA. CMA supports continued recognition of degree of hazard considerations in these regulations. At the same time it is necessary to point out that this term has taken on somewhat different meaning as EPA's RCRA regulations have evolved.

Regulations proposed by EPA in December 1978 contained a complex and broad-reaching scheme for identifying hazardous wastes. It was so sweeping it covered innocuous materials such as wood ash and soft drinks. All wastes identified by this scheme were to be managed in facilities subject to stringent, inflexible design standards.

In response to these sweeping regulatory proposals, CMA recommended that the Agency substitute a "degree of hazard" waste classification scheme and couple it with flexible facility standards appropriate to the varying nature and degree of hazard posed by different wastes. It is to this *waste classification* scheme that the term "degree of hazard" originally referred.

In its May 1980 interim final regulations, EPA substantially altered its scheme for identification of hazardous wastes so as to embrace a significantly more limited universe of materials. In addition it relinquished an approach based almost exclusively upon "characteristic" protocols in favor of one emphasizing identification and listing of particular waste streams. This change of approach by EPA had reduced CMA's concerns about degree of hazard in *identification* of materials as hazardous waste. Real concern remains, however, because of the Agency's failure to identify concentration thresholds with regard to toxic constituents deemed to make particular wastes hazardous. In the absence of such thresholds it is difficult or impossible to obtain delisting of particular wastes or waste residues at particular sites, even though they may, because of very low concentrations of toxic constituents, present a negligible degree of hazard.

Degree of hazard concerns remain alive in a second, important respect relating not to classification of wastes by relative intrinsic hazardousness, but rather to appropriate management for differing wastes. EPA shares these concerns and is examining a scheme for categorization of wastes in light of appropriate management options for these wastes. CMA supports this effort, so long as it does not lead to inflexible results such as outright prohibitions on land disposal of particular toxic constituents. Examples of steps that EPA is actively considering to tailor its facility standards to various waste categories include the following:

- Not subjecting wastes deemed hazardous solely because of ignitability, corrosivity or reactivity to the full array of incineration regulations.
- Giving "permits by rule" to impoundments used solely to neutralize solely reactive wastes.
- Giving "permits by rule" to impoundments used solely to neutralize corrosive wastes.
- Extending permits by rule to tank-type facilities used to neutralize solely reactive wastes.
- Amending and clarifying its "mixture rule" to avoid unnecessary regulation of wastewater streams involving *de minimus* incidental quantities of hazardous materials.

CMA supports these and other efforts EPA may undertake to frame facility requirements appropriate to the nature and class of wastes involved and to clarify the reach of its RCRA regulations. Further, it strongly urges EPA to establish thresholds or *de minimis* levels below which residues or mixtures involving listed hazardous wastes, no longer need to be managed as hazardous wastes.

THE ASCE ENVIRONMENTAL ENGINEERING DIVISION'S ROLE IN UNCONTROLLED HAZARDOUS WASTE SITE MANAGEMENT*

DR. JOHN P. COLLINS**
WAYNE K. TUSA

INTRODUCTION

The phrases Love Canal, Valley of the Drums, Kin-Buc, Burnt Fly Bog, etc. have practically become household words. With the grace of hindsight, the reasons for that occurrence are abundantly clear. For example, each year 300 to 500 new chemicals are produced commercially in addition to the 70,000 chemicals currently produced at over 115,000 manufacturing plants throughout the United States. It has been estimated that over 60,000,000 tons of hazardous wastes were produced in 1980 alone. While these chemicals have contributed to the high standard of living enjoyed by this country, the after effects of their disposal are only now beginning to have a perceptable and negative impact on the quality of life.

The Chemical Manufacturer's Association has estimated that over the next 10 years the chemical industry will invest $5.4 billion under Superfund legislation and another $3.5 billion for compliance under RCRA. The Environmental Protection Agency has indicated that up to 30,000 disposal sites may contain hazardous wastes which could require remedial expenditures. The Superfund program includes investigation of up to 15,000 sites, of which approximately 1,500 sites will require detailed inspection and of these approximately 400 will be selected for priority clean-up.

The magnitude of the abandoned site problem offers a retrospective look at how engineers and society as a whole have made decisions and technical judgements important to the continued welfare of that society. In addition, the abandoned site problem offers a number of opportunities for ASCE to serve as a spokesman for the engineering profession, as well as for individual practicing engineers and companies to contribute to the successful resolution of that problem.

ASCE ROLE

ASCE, largely through its Environmental Engineering Division and its Geotechnical Engineering Division, has played an active role in hazardous waste management. The Hazardous Waste Management Committee, for example, was established as a standing committee of the Solid Waste Management Committee in 1979. Since then, the Committee has completed the following hazardous waste efforts:

1. Developed a policy statement on Superfund for presentation before the House Subcommittee on Commerce and Transportation
2. Sponsored approximately ten sessions on hazardous waste management at four conferences throughout the United States
3. Published "The Hazardous Waste Dilemma: Issues and Solutions," a compendium of papers from the July 1980 ASCE Environmental Engineering Division Conference
4. Provided peer review on several draft technical resource documents for the USEPA Office of Solid Waste relating to RCRA Subtitle C regulations
5. Sponsored several local seminars/presentations on hazardous waste management
6. Completed a policy paper on hazardous facility siting

Society member companies and individuals have also successfully contributed by actively becoming involved in the development of federal and state regulations, the development and implementation of site investigation procedures, and the engineering of proposed remedial measures. To a limited extent to date, Society engineers have also assisted in remedial construction and construction management activities.

PROBLEM IDENTIFICATION

The experience engendered by the Hazardous Waste Management Committee, as well as by practicing society professionals, has resulted in the identification of a number of problems which must be confronted by the engineering professional in applying applicable skills to the abandoned sites problem.

Perhaps the most evident problem relates to the fact that abandoned site management is still an art and not a

*This paper has been prepared by the Hazardous Waste Management Committee and as such represents the views of that committee acting as a spokesman for the Environmental Engineering Division of the American Society of Civil Engineers.

**Dr. Collins is the upcoming Vice Chairman of the Solid Waste Management Committee and is a past chairman of the Hazardous Waste Committee. Mr. Tusa is currently Chairman of the Hazardous Waste Management Committee.

science. Developing a set of construction plans and specifications for an abandoned site remedial project, while relying in large part on established skills and procedures, is much different from designing a conventional retaining structure or a twelve story office building. The engineer must make technical decisions based upon varying amounts of data from a number of engineering and scientific disciplines. Final decisions are in part judgements that attempt to weigh the risks of potential environmental and public health impacts against the costs and relative effectiveness of alternative engineering approaches. To a large degree, this dilemma is compounded by inadequate data in those scientific disciplines which come into play in making those technical decisions. Furthermore, the potential for leachate migration through a confining clay layer, the potential for health impacts due to long-term low-level hazardous air emissions and the potential long-term chemical interaction of waste materials and the proposed materials of construction are all issues impacting the selection of a final engineering alternative.

In part, the problem of inadequate data and practical experience has been complicated by rapidly developing and often changing regulatory guidance at the federal and state levels. This challenge must also often be met within the constraints of innumerable regulatory guidelines which are often more procedurally than technically complete. For example, one of the areas most lacking related to the necessity of criteria or guidance to determine acceptable risk levels. For many waste constituents there are no standards or criteria for acceptable concentrations in groundwater, surface water or ambient air. As a consequence, these issues are often reconsidered at each abandoned site and overall goals or acceptable risks levels may vary not only from state to state but also from site to site.

The complexity of technical issues related to abandoned sites often challenges the "interdisciplinary" approach between the engineering and scientific disciplines. While a large number of training mechanisms have been developed in the last two to three years (i.e., seminars and short training courses), most experienced professionals appear to have received the bulk of their training via the well established trial and error method. Unfortunately, at the university level, very few programs are in place to specifically train young professionals in the waste management area.

Information Transfer

Another problem is the lack of information transfer throughout the engineering and scientific professions with regard to abandoned site management. While this conference certainly is helpful, not all readers will be familiar with the turkey baster method of air velocity measurement, the construction details of a shallow trench-well for monitoring relatively impermeable surface soils and the operation of a ground penetrating radar device? While in part this lack of knowledge is understandable due to the rapidly changing state-of-the-art, for the same reason it is particularly unacceptable due to the pressing need for new and better techniques.

One of the most pressing information transfer needs relates to adequate safety practices for engineers completing inspections as well as engineering and construction teams actively implementing proposed remedial plans. While teams currently active under EPA contracts have addressed these issues in depth, in the near future a much larger number of engineering firms and employees will be involved in site-specific efforts. A real need exists for the dissemination of this type of information both to a wider range of recipients and to what is essentially a newly developing cadre of hazardous waste personnel, i.e., those who will be directly involved in digging the wells, moving the earth and treating the waste residuals.

Liability and Insurance

Another issue of significance is liability and insurance requirements for the engineering firm involved in hazardous waste management. As of this date, not all the liability issues have been resolved for those firms which will be involved in implementing EPA's Superfund program.

Who will be liable if an interim solution installed at one of the 100 EPA interim priority sites does not eliminate all forthcoming environmental and public health impacts? Which parties will be required to participate in any eventual court settlement: the engineer, the construction contractor, the land owner, the waste generator?

Perhaps equally important is the issue of insurance. While a number of the larger insurance companies are offering or are currently developing programs to offer non-sudden RCRA insurance, there appears to be in some cases little interest in offering engineering companies "errors and omissions insurance" specifically relating to hazardous waste work.

An interesting sidelight of the liability issue and an additional problem area relates to the development of innovative techniques for abandoned site management. Unfortunately, while there may be a great need for better and less costly approaches to abandoned site management, the development and utilization of new techniques, particularly in the private sector, is thwarted by the liability issues involved if those techniques cannot be guaranteed to be 100 percent effective.

CONCLUSIONS

What needs to be done to resolve some of the problems identified above? Clearly more waste management training mechanisms are needed at both the university and professional levels. It would be particularly useful to work under a consistent, equivalent and definitive set of regulations nationwide. While obviously that is not currently possible, it suggests that as much emphasis as possible must be placed on the development of those regulations in the shortest time span possible.

In addition, engineers believe that substantial additional efforts should be particularly directed toward information transfer activities. The liability and insurance issues also deserve much closer scrutiny. After all, should an engi-

neering firm accept the risks associated with a hazardous waste contract, if it cannot enjoy the privilege of the adequate financial protection it enjoys in other business areas practiced by the firm?

In keeping with its policy to provide, where appropriate, technical guidance to society as a whole, ASCE, and specifically the Hazardous Waste Management Committee, would like to offer its services in resolving some of those issues identified above. The committee, for example:

1. Intends to continue to provide peer review services on proposed technical resource documents
2. Is considering sponsoring an ASCE Environmental Engineering Division Conference solely on hazardous waste management
3. Is expanding its role at the local chapter level relating to the development of seminars/presentations on hazardous waste management
4. Is continuing to monitor advances in siting procedures
5. Is developing a recommended curriculum in waste management for university level students
6. Is establishing a sub-committee to investigate liability and insurance issues and to develop appropriate recommendations

The Committee is also open to suggestions from the scientific community at large and would welcome specific recommendations.

A DYNAMIC NATIONAL RESPONSE MECHANISM

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INTRODUCTION

In preparation for writing this paper, I reflected on the Management of Uncontrolled Hazardous Waste Sites Conference held here in Washington during October of 1980. At that time I expressed the hope that Superfund would soon be operative, and that late 1980 would see the development of an intelligent revision to the National Contingency Plan which would adequately address uncontrolled waste sites. Superfund did not quite make it by October of that year, but it was not far behind.

Since the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, or Superfund, the U.S. Coast Guard and U.S. Environmental Protection Agency have encountered and overcome a number of difficult problems which have proven that the ties between them are strong and enduring.

PROBLEMS SOLVED

311 Fund Transferral

The first obstacle which had to be overcome was the transfer of one-half of the Clean Water Act 311(k) fund balance to the Response Trust Fund established by Superfund; initially, this did not appear to present a major problem. However, when it was learned that the Department of Treasury believed that those transferred monies could not be spent until an appropriation to Superfund was made, the Coast Guard and the EPA became alarmed that the Clean Water Act Section 311(k) revolving fund balance of some seven million dollars would become depleted before its request for supplemental appropriation, expected in July 1981, was authorized.

In our view, the Congress did not intend that those monies transferred lie dormant. At the very least, they were intended to remain available for hazardous waste site response which met 311(k) criteria, that is, water-related and discharging or threatening to discharge one of the hazardous polluting substances named pursuant to the Clean Water Act. With the help of the National Response Team and Congressman Florio of New Jersey, and a dangerously low level of the 311(k) fund, Treasury was convinced to release the money and we were able to use it for the intended purpose.

Contracting Procedure

But the problems were not over. EPA had not yet devised a contracting mechanism capable of addressing Superfund type problems. Even with the funds released by Treasury, there were still only limited monies available to continue oil spill, chemical spill and hazardous waste site responses.

What followed was a complex series of events but it was the "handshake" agreements, Coast Guard contracting help and a general spirit of cooperation which permitted the combined funds to continue to address oil and chemical spills as well as limited numbers of hazardous waste sites. This was a difficult period which required EPA to take a tough stand on what sites would or would not be addressed and the Coast Guard to continue in a business it really never wanted.

Eventually, with the help of Congressman Florio and the Office of Management and Budget, a supplemental appropriation was authorized nearly two months earlier than expected. No responses to acute discharges failed to occur.

All of this activity took place during a period when we were working concurrently on developing an Executive Order to implement Superfund and the required revision to the National Contingency Plan. The same spirit of cooperation is continuing as we make the necessary handoffs of waste site response cases from the 311(k) fund to Superfund and as we work to establish Coast Guard access to the Superfund for emergency response.

SUPERFUND IMPLEMENTATION

The primary interests of the Coast Guard, in Superfund implementation, are the revision to the National Contingency Plan, the establishment of necessary response authority and the assurance of adequate resources to respond to a broader spectrum of acute releases than previously afforded under Section 311 of the Clean Water Act. As you know, the Coast Guard has a long history of responding, in coastal areas, to oil discharges and releases of the Section 311 designated hazardous polluting substances into, or threatening, the wasters of the United States.

The Coast Guard has executed that responsibility as a member of the National Response Team established in the highly successful and acclaimed National Oil and Hazardous Substance Pollution Contingency Plan. In our view, the strength of the National Response Team has been based on the equal involvement and standing of the twelve Federal member agencies. This cooperation has enabled open and candid discussion of what it has done well, what it could have done better and to make adjustments when necessary.

NATIONAL CONTINGENCY PLAN REVISION

The Coast Guard is now engaged, as are all of the members of the National Response Team, in assisting the Environmental Protection Agency in redeveloping the Plan to deal with a broader spectrum of releases into the environment—not necessarily associated with water or its adjoining shorelines. This is a difficult task and one on which all of our membership has been working very hard to accomplish. A few of the features I believe must be included in the new Plan are:

(1) To the maximum extent possible, the new Plan must draw on the present Plan for its organizational structure. The terms, acronyms, organizational relationships, etc., do not need re-invention. Likewise, Federal, state, or local response authorities do not need the confusion of a Plan distinctly different from the one we are now using;

(2) The concept of using the coastal and inland areas for assigning Federal response officials must be preserved; the Coast Guard should respond in the coastal areas, and the EPA in the inland areas except that for waste sites it is appropriate for EPA to have the authority in both the coastal and inland areas

(3) Response to oil spills must occupy a distinct place in the Plan so that those using the Plan in Clean Water Act related matters will not be encumbered by terms having meaning only when associated with Superfund

(4) The Plan must not become overly complex, for it will affect a broader spectrum of interests than just Federal or other response oriented agencies

(5) State and local governments should continue (in fact expand their role) as our partners in pollution response activities, rather than as bystanders confused by an unnecessary array of Federal officials

(6) The field On-Scene Coordinators must continue to have sufficient latitude and authority to aggressively and adequately protect the public health and welfare.

We in the Coast Guard also believe that the Plan should receive intense public review prior to finalization and that such a review will help us to ultimately publish the very best Plan possible. The Coast Guard will continue to assist the Environmental Protection Agency and other members of our National Response Team in Developing a rational and effective Plan which the public can understand. By the way, we in the Coast Guard are extremely comfortable with the EPA as the steward of the National Plan.

CONCLUSION

It is extremely important that the National Response Mechanism, which is presently in place, be preserved. I have repeatedly said that the National Plan is one of the most enlightened documents the government has developed. Its success is a tribute to all of the Agency members who have worked together to provide the public the excellent service it deserves. All of us must resist any attempt to diminish the importance of this Plan, or to modify it for purposes other than real service to the public.

THE EPA RESEARCH PROGRAM IN SUPPORT OF SUPERFUND

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INTRODUCTION

Hazardous waste is one of the nation's most significant environmental problems. Chemicals once thought benign have been shown to cause cancer, birth defects and a variety of other harmful human health effects. Toxic wastes lie in abandoned and often long-buried sites, some of which are slowly poisoning underground water supplies. Practices which have been and continue to be widespread include uncontrolled incineration, poorly designed and sited landfills, industrial waste lagoons with leaking bottoms and weak dikes and the indiscriminate, often illicit dumping of dangerous waste materials. These past, environmentally unsound disposal practices are a threat to soil, air and water and hence, to human populations and ecosystems.

Hazardous materials are also released to the environment as a result of accidental releases (spills) of oil and hazardous substances. Such incidents originate from transportation accidents as well as discharges from storage tanks, pipelines, holding lagoons and industrial plants used in the manufacturing and processing of chemicals.

In December 1980, Congress provided authority for Federal response to the release of hazardous materials to the environment from uncontrolled waste sites as well as spills and in all media when it passed PL96-510, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The Environmental Protection Agency (EPA) has been delegated a lead role in the implementation of this Act. EPA established the Office of Emergency and Remedial Response (OERR) to carry out its responsibilities. The Office of Research and Development (ORD) in turn established a Hazardous Emergency Response Research Committee, co-chaired by ORD and OERR, to plan the ORD technology programs in support of response activities implementing CERCLA.

PROGRAM OBJECTIVES

The program offices are the primary "users" of the ORD program outputs and as such, they establish the focus and the requirements for technical support and field evaluations. The EPA CERCLA program is aimed at providing effective emergency cleanup response in spill situations and effective remedy of the problems at uncontrolled hazardous waste sites. The application of technologies for performing these tasks is relatively new and their long-term reliability and effectiveness have not been fully evaluated. If the legislative mandate for rapid and effective response is to be met, EPA needs to assess the technologies and methods proposed for those actions. In addition, the risks to human health and the environment from spills of hazardous materials and from uncontrolled sites need to be evaluated as accurately as possible. The ORD program focuses on these major short-term needs of the Agency.

THE OFFICE OF RESEARCH AND DEVELOPMENT PROGRAM

The overall goal of the ORD support program is to provide a core of scientific and technical information and expertise in response to the implementation requirements of CERCLA and the enforcement actions designed to perform necessary cleanup and containment actions under this Act. In general, the program addresses the immediate problems of providing the data required to support a hazard assessment program, expert witnesses for enforcement cost recovery actions, initial assessment, analysis and evaluation of alternatives as well as containment and removal and ultimate disposal and site restoration. The development of techniques for evaluation of potential impacts on the public and the environment is also addressed.

Specifically, this program concentrates on the evaluation of equipment and techniques for discovering, assessing, preventing, controlling, removing and ultimately disposing of hazardous substances released to the environment from spills or from uncontrolled waste sites. It also provides methods for assessment of the ecological and human population impacts from releases and the equipment and techniques suitable for restoring the environment to a healthy state.

The program covers two major areas, (1) emergency response (removal activities) and (2) remedial action response. Emergency response generally applies to spills of hazardous materials but also applies to waste sites which are discovered to be posing an immediate threat to human health and/or the environment. Remedial response denotes a planned effort for permanent remedy of the problem site and, therefore, more time is afforded before this type of activity is initiated.

The objectives of the emergency response (removal) program are to evaluate and demonstrate new or improved equipment, devices, systems and data analysis techniques for the prevention, identification, containment, control and removal of hazardous substances released to the environment. This includes the cleanup and recovery of hazardous substances from spills as well as from uncontrolled hazardous waste sites.

The outputs must meet the regulation development, enforcement and technical support needs of the Office of Emergency and Remedial Response (OERR), the Office of Waste Programs Enforcement and the Regional Offices. Regulation development must be implemented through technical background development, such as, updating the list of designated hazardous materials and the reportable quantity regulations. Regulation support is provided by evaluating new techniques that will be incorporated in the regulations by reference.

In this area, ORD provides user manuals for response equipment, sampling and analysis, technology evaluation, monitoring techniques, and guidance for on-scene response personnel. Enforcement support is provided by ensuring the use of proper chain-of-custody techniques for sample collection, analysis and reporting, providing expert witnesses for enforcement cost recovery actions and providing technical support for hazardous waste enforcement investigations.

The objectives of the remedial response research program are to assess and validate new or improved remedial action technologies or schemes to minimize pollutant release from uncontrolled hazardous waste sites. This activity includes quality assurance programs and pilot, field, cost-effectiveness and model studies to validate control technologies as related to surface water control, groundwater control, plume management, chemical immobilization and excavation and reburial.

Technical resource documents will be provided for the user communities to describe the best engineering judgments for the various technologies. Enforcement support is provided to assist in devising the remedial measures and to testify on the need for and evaluation of those remedies for negotiations and litigation.

The program is performed at several ORD laboratories. Environmental engineering solutions to problems are being evaluated by the Municipal Environmental Research Laboratory, Cincinnati and its branch in Edison, New Jersey. Monitoring and quality assurance programs are performed at the Environmental Monitoring and Support Laboratories in Las Vegas, Nevada, Warrenton, Virginia, Cincinnati, Ohio and Research Triangle Park, North Carolina.

Techniques for environmental measurement are being evaluated by the Environmental Research Laboratories in Research Triangle Park, North Carolina; Ada, Oklahoma; Athens, Georgia; Corvallis, Oregon; Duluth, Minnesota; Gulf Breeze, Florida and Narragansett, Rhode Island. Finally, hazard assessment support is provided by the Environmental Criteria and Assessment Office in Cincinnati, Ohio.

HAZARD ASSESSMENT

CERCLA specified a Federal response to releases or threatened releases of hazardous materials to the environment from spill sites and waste sites. Before a "response" can be executed it is necessary to characterize the nature and magnitude of the health and ecological hazard. Therefore, evaluation of adverse health impacts and the hazard potential of substances released from spills and defective abandoned waste sites is a necessity if response funds are to be used to their maximum benefit.

ORD will provide information on the acute and chronic toxicities of identified compounds in order to select the best safety measures for protection of cleanup crews as well as to determine acceptable residual levels (extent of cleanup). Currently, ORD-maintained data on chemicals for which adequate acute, subchronic or chronic data exist will be used to prepare tabular summaries of adverse health effects for previously investigated compounds, health profiles and guidelines, and methodologies for rapid (24 hours) hazard assessment of chemical mixtures. Toxicity indexes based on no-effect levels, type of effect, and chemical class are also being developed. The methodologies are being developed for incorporating route-specific toxicology into a site ranking system to be used for identifying the nation's highest priority sites for remedial action.

TECHNOLOGY EVALUATION AND ASSESSMENT

Engineering guidance and control technology evaluation will be provided to Federal, State and local agencies for immediate response to hazardous emergency removal and remedial action at spill sites and abandoned waste sites. ORD will address the construction and field evaluation of equipment and technologies for onsite treatment/destruction of hazardous wastes, leachates and contaminated groundwater. It will also evaluate and assess the best existing remedial or abatement action and control technologies to minimize pollutant releases from uncontrolled hazardous waste sites and maximize the applicability and transfer of this information to the user community.

CERCLA specified that response to releases may be removal or remedial. But this raises important questions such as "when is the emergency over, i.e., stabilized, so that remedial action can begin?" and, "when remedial action begins, to what extent should the cleanup be executed?". Work is currently underway to prepare guidance manuals for use by response personnel, such as On-Scene Coordinators, to help them make these critical decisions.

MONITORING AND QUALITY ASSURANCE

The program will meet the monitoring requirements of removal and remedial actions by providing the latest techniques in measurement, monitoring and quality assurance. The tools and methods for field support and sampling, laboratory analysis, and remote monitoring

will be applied to site discovery and characterization, as well as mitigation and cleanup. The program includes quality assurance through laboratory audit and intercomparison and chain-of-custory for enforcement actions.

A comprehensive quality assurance program has been initiated to evaluate contractors involved in the site program. The program includes evaluation and standardization of sampling and analysis methods and chain-of-custody. In an effort to meet the demand for an Agency capability, a contractor operated laboratory has been established to analyze field samples and complex samples taken by Regional field teams. The program includes the standardization of mobile emergency labs for removal operations. A comprehensive program to monitor air quality in and around sites has been started, including the development of a personal exposure monitor for volatile organics.

An extensive nationwide program has been instituted to acquire aerial photographs of sites, characterize the problems and prioritize the need for cleanup. The unique, in-house capabilities of ORD scientists have been made available through this program to accomplish special monitoring studies. The capability provides the Agency with special studies of air, surface and groundwater and site characterization.

ENVIRONMENTAL MEASUREMENT

Assessment and evaluative procedures for determining the potential ecological effects of hazardous substances spills and releases from abandoned waste sites will be provided by ORD. A primary goal will be to provide user-oriented material on situation assessment along with evaluating and developing ecologically sound isolation, removal, restoration and disposal methods.

In support of field response personnel requirements, a uniform set of operational procedures for environmental characterization and assessment will be prepared. This will provide uniform "extent of contamination" assessments and cleanup operations planning. A manual on proper utilization and choice of dispersants for cleanup, from an environmental point of view, is in preparation. This is a critical need because a poor choice of dispersant could compound and extend the damage.

PRIVATE SECTOR ATTITUDES AND CONCERNS WITH SUPERFUND

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BACKGROUND AND PURPOSE OF RESEARCH

As Superfund was proceeding through the legislative process to final enactment in December, 1980 the Environmental Protection Agency commissioned a group of studies to facilitate its implementation. One such study, the subject of this report, was planned to indicate the implementation capabilities of the private sector, obtain a qualitative appraisal of the likely level of private sector response to the program, and identify constraints and "bottlenecks" with respect to its timely execution. Briefly then, the questions to be answered were: (1) "Are the necessary private sector resources available?" (2) "Will the private sector respond effectively?" and (3) "What possible problems of private sector firms must be considered in program procedures?"

As the Workplan for the study was being carried out, it became apparent that before a study of the magnitude and scope originally contemplated could be completed, actual implementation of Superfund would have been started. The initial results of this implementation process could logically be expected to answer the questions originally posed in the study endeavor. Under this set of circumstances, it was considered appropriate to limit this investigation of Private Sector Attitudes and Concerns toward Superfund to the work already accomplished or immediately to be accomplished and prepare this Insight Report for current use. It has been the authors' experience that a timely report often is of greater value than a deferred submission of greater depth or scope.

ORGANIZATION AND WORKPLAN

The original workplan in its final version was transmitted to EPA in Washington on December 24, 1980. The principal elements of this Workplan are briefly described below.

Review of Capabilities Required by EPA from Private Sector Firms

In addition to talks with EPA in Washington, discussions were conducted with EPA officials in Region II and with staff of the (New Jersey) Department of Environmental Protection. These discussions provided necessary information as to the type of services required of the private sector by the Superfund program.

Pilot Study Area

Originally interviews were planned in New York, New Jersey and California. By the cut-off date for active field work, interviews were conducted both in New York and New Jersey with some additional emphasis on the latter State.

Rosters of Firms Possessing the Required Capabilities

The bibliography provides a listing of the rosters and directories assembled for use in structuring the study. In addition to the formal sources, the study utilized personal referrals as appropriate.

Preparation of Preliminary Draft of Interview Form

Preliminary drafts of interview questions were prepared and submitted to EPA-Washington for comments. As a result of these comments and the field experience described below, a revised interview form was prepared.

Testing of Interview Guidelines and Approach

The original guidelines were tested with a General Contractor and subsequently modified to the format attached. Further refinements were planned, if necessary, as the larger scale interviewing was undertaken. A single interview format was designed to be applicable to all the firms surveyed.

Administration of Interviews

Prior to the decision to limit the scope of this study, URS offices in Philadelphia and San Francisco were alerted to participate in the interview effort and provided with copies of the Workplan and Interview Guidelines. Contractor associations were interviewed to obtain suggestions as to the firms to be selected for personal contact. As already noted, the larger effort was discontinued.

Interviews

The types of firms to be interviewed included, but were not intended to be limited to:

- •General Contractors
- •Testing Laboratories
- •A/E Firms (Architectural/Engineering)
- •Hazardous Waste Management Firms
- •Other Professional/Technical Organizations

The following tabulation summarizes the number of interviews obtained and includes interviews with both Federal and state (New Jersey) officials. (Since URS Company has extensive architectural/engineering capabilities, it was not considered necessary to interview additional firms as part of initial effort).

Type of Firm or Agency	Number of Persons Interviewed New York	New Jersey	Total
EPA-Region II	2	3	5
N.J. DEP		2	2
General Contractors	2	3(A)	5
Testing Laboratories		1	1
Hazardous Waste Mgmt		1	1
Other Professional	3(B)		3
Totals	7	10	17

Notes: (A) Includes Associations
(B) Includes Coast Guard.

Although the number of interviews was not as great as would eventually have been obtained, most interviewees proved completely responsive and it is problemmatical whether a more extensive effort would alter the report findings significantly. The results of these interviews and the problem areas uncovered are described in the following pages.

FINDINGS

The interview process generated information on attitudes toward Superfund and permitted the identification of specific problem areas: (1) General Attitudes, (2) Demand for Professional Skills, (3) Some Equipment Limitations and (4) Specific Problem Areas.

General Attitudes

The impact of Superfund had not, as yet, been felt at the implementation level. There appeared to be a "wait and see" attitude in the private sector; it is probably fair to say that the same attitude, to a less pronounced extent, also prevails in the public sector.

As far as contractors are concerned there was a pervasive attitude that they "can do anything." Certainly there are reservations in regard to some specific problems, as will be discussed, but the general attitude was one of confidence both in innovative ability and in equipment and manpower capabilities and resources.

With regard both to contractors and other professionals, there was a dichotomy between the public and private sectors. Government officials apparently believed the private sector will respond, but without the requisite skills and commitment. The private sector, on the other hand, appears to wonder how real "Superfund" is and what its specific impact would be on existing operations.

Perhaps these general attitudes can be summarized as follows—both the public and private sectors were awaiting further developments with the public sector somewhat dubious as to the availability and actual commitment of required skills and the private sector equally dubious as to the reality, timing and scope of the program, and its possible benefits and impacts with respect to individual firms of various types.

Demand for Professional Skills

From discussions with representatives of the private sector and with government officials who will be involved with Superfund, it became apparent that two professional categories—chemists and hydrogeologists—may be limiting factors during the program's initial implementation. These shortages of trained, experienced professionals are especially significant because litigation may be required to establish financial responsibility for some of the clean-up activities. In such instances, the expertise and professional qualifications of the witness will come under close scrutiny, and it is the authors' understanding that many tests and interpretive analyses cannot be delegated to technicians subject only to professional review. Basically, particularly in the case of mass spectrographic techniques, the chemist performing the analyses is responsible for their credibility.

In the case of hydrogeologists, there are probably less than 150 graduated each year and many of these will enter private employment. This shortage can be alleviated to some extent by approximately two years of training of an individual with a background in geology or other scientific discipline. In this regard, because of the current energy shortage, petroleum companies have continuing requirements for graduate geologists so there is competition for these skills. Because of the possible litigations involved, high levels of demonstrable expertise will be required.

The identification of these two professional categories as possible problem areas is not intended to imply that shortages in other skills do not exist. However, the shortage of both chemists and hydrogeologists are believed to be the most serious and least amenable to "quick fix" solutions.

Some Equipment Limitations

Mass spectrographic equipment appeared to be another problem area. These units with ancillary and related equipment cost approximately $250,000 each and thus represent a significant investment for a private laboratory with no assurance of amortization through use. While it can be safely assumed that this equipment can be manufactured in sufficient quantity to meet demand, maintenance is said to be a continuing problem, and trained, experienced chemists, as noted in the previous section, may be in short supply.

In addition, some construction contractors expressed concern over the availability of suitable tank trucks to handle possible combinations of corrosive, toxic and flammable liquid wastes.

Specific Problem Areas

The study disclosed certain specific problem areas which may hamper the initial implementation of Superfund. These areas of concern, not necessarily arranged in order of importance, are:

- Conflict of interest
- Expert testimony
- Safety training
- Insurance
- Permits and licenses
- Availability of disposal sites
- Financial arrangements
- Some other concerns
- Bureaucracy

CONFLICT OF INTEREST

Many laboratories and firms specializing in hydrogeology have developed longstanding relationships with the private sector, often with those chemical companies who may be the focus of aspects of the Superfund program. Conflict situations may arise, and even if a conflict does not exist, a firm identified with the private sector may not wish to participate in government prosecuting efforts.

EXPERT TESTIMONY

Closely related to "conflict of interest," the requirement of expert testimony suggests that it may be difficult in some instances to obtain the services of recognized experts in support of the efforts to assign financial responsibility for cleanup activities. Probably many of the recognized experts are either employed by or closely associated with the private sector and may be unavailable. How serious this situation will be is impossible to assess at this time.

SAFETY TRAINING

Several private sector contractors have mentioned the need for some predetermined procedures to assure the safety of personnel both in cleanup and transport and handling of hazardous wastes. Presumably, if such procedures do not already exist, an established check list could be developed for different categories of hazardous wastes. It was further suggested by one respondent that EPA should provide some type of seminar or training program for contractor supervisory personnel; incidentally, the response to such program would be an indication of active interest in the Superfund program.

INSURANCE

The problem of proper insurance for protection against personal injury and damages and professional liability was cited as a possible deterrent to participation in Superfund. (Other respondents tended to minimize this problem on the assumption that the necessary insurance is or would become available at a cost which would be included in the bid price.) It was also suggested that the contractor might insert a "hold harmless" clause in any contract.

If insurance develops into a costly or significantly deterring factor, EPA may wish to self-insure, at least above some maximum amount covered by the Contractor's "normal" insurance. This procedure would have the effect of eliminating small "nuisance" claims from Agency responsibility and significantly reduce insurance costs to the individual contractors. (The Washington Metropolitan Area Transportation Authority uses a "self-insurance" system for its contractors.)

PERMITS AND LICENSES

Under this general category may be included the "paperwork" and "documents" necessary to begin or carry out specific tasks which the contractor is otherwise prepared to execute. These delays, particularly after mobilization, are viewed as arbitrary, costly and detrimental to efficient work performance. The identification of and responsibility for obtaining necessary documentation should be clearly defined.

While it was suggested that contractors provide necessary documentation, another more practical suggestion was that EPA or a designated State agency provide a comprehensive checklist of federal, state and local permits and licenses to the contractor for his compliance. Such a government agency would be more knowledgeable in such matters than the Contractor and could outline procedures to be followed to minimize contractor effort and uncertainty in reflecting such measures in his bid.

AVAILABILITY OF DISPOSAL SITES

The problem of adequate disposal sites is recognized at all levels of government and industry. From the contractor's point of view, the problem is one of having a place and/or approved technique which is suitable for his immediate needs. This problem is in a sense related to "Permits and Licenses", and reflects the contractor's concern with delays and "red tape."

FINANCIAL ARRANGEMENTS

Some concern was expressed about the problem of "getting paid". (Some government bodies—federal, state and local—have reputations as "slow pays".) Given cur-

rent high interest rates, it has become increasingly difficult to finance work as well as carry it out. Assurances and conformance to a definite predetermined payment basis and schedule should mitigate these fears. However, almost any payment terms and schedule can be fully reflected in a bid and cause a contractor no concern at all. Compliance with such terms is the crucial aspect that will determine whether the private sector will continue to respond to Superfund needs.

SOME OTHER CONCERNS

It was stated that contractors are most effective in their local areas, and should not be expected to move their men and equipment to distant sites. There were suggestions that some government agencies were unfamiliar with contractors' work and general business problems; thus it was suggested that working through an overall General Contractor or Trade Association might help communication. (Some cleanup jobs are not expected to be large in dollar volume and it is important to minimize procedural difficulties.) Having regional contractors advisory councils providing "up front" advice to EPA is another method of addressing this concern.

BUREAUCRACY

One respondent, who performed work for all levels of government on an *ad hoc* basis, would prefer to work for private clients because of the "bureaucracy" involved. Additional personnel, it was feared, would have to be hired to cope with paperwork and the administration attendant on government contracts. There is probably nothing to be done about this problem but it suggests that there is a reservoir of talent available which regards government work as a last resort.

DISCUSSION

The foregoing problem areas were identified during the Study but it is improbable that other concerns exist which were not uncovered because of sample-size limitations. Despite this caveat, the authors believe the results indicate that while some significant (and many less important) problem areas do, in fact, exist, most appear capable of resolution as the Superfund program is fully implemented.

CONCLUSIONS

Basically, except for certain skills in the fields of hydrogeology and chemistry, no evidence of insufficient technical and management capabilities in the private sector to implement Superfund has been found.

Problem areas include: a lack of suitable disposal sites, costly or inadequate insurance coverage, inordinate effort to identify and obtain required permits and licenses, potential conflicts of interest with respect to needed firms and experts, the provision of safety training and the need to develop suitable contract terms which reflect contractor concerns and special considerations inherent in the Superfund work. None of these problems, in and of itself, is insuperable, but the aggregation seems likely to inhibit participation to some extent unless each is fully addressed.

A majority of the firms contacted would be willing to participate in Superfund. The level of participation will depend on general business activity, alternative uses of equipment and personnel and successful resolution or mitigation of the problem areas previously described.

In general, based on discussions in New York and New Jersey, there is sufficient contractor capacity to meet the likely level of demand generated by Superfund activities and no specific areas of expansion appeared necessary. A likely shortage of mass spectrographic equipment and professionals to operate such equipment has been noted.

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RANKING SYSTEM FOR RELEASES OF HAZARDOUS SUBSTANCES

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INTRODUCTION

In recent years, hundreds of incidents involving hazardous substances have occurred in the United States, including rail and barge spills, hazardous waste explosions, direct contact poisonings, food crop contamination, toxic air pollution, as well as ground and surface water contamination. The Environmental Protection Agency (EPA) has identified over 10,000 inactive hazardous waste sites, many of which continue to threaten the public. In addition, thousands of hazardous substance spills occur each year. A number of major rivers have become contaminated with persistent toxic pollutants, often due to poor waste handling practices long since discontinued.

The large number of problems and the high costs of investigation and cleanup activities have forced those public agencies responsible for hazardous substances programs to set priorities for response. In general, this has been done at the State level, largely on the basis of professional judgment. In this paper, the authors describe the status of a system currently under development for setting priorities for remedial actions to address hazardous substances releases.

In passing the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), Congress recognized the need for a systematic approach to setting priorities. CERCLA Section 105(8) requires the President to include criteria for setting priorities among releases and potential releases of hazardous substances as a part of the National Contingency Plan. The criteria are to take into account population at risk, the nature of the hazardous substances, the potential for contaminating drinking water supplies, the potential for direct human contact, potential for destruction of sensitive ecosystems, State preparedness and other appropriate factors.

In addition, the Act requires the States to apply these criteria to establish priorities for remedial actions at facilities and submit them to the President. The President must then establish a National Priority List of at least 400 facilities based on the criteria and taking into consideration the States' priorities. The National Priority List is to be used in selecting the most serious hazardous substance problems for remedial action.

In response to the program needs and legal requirements for a system for setting priorities, EPA along with the MITRE Corporation undertook development of a method for ranking facilities according to risks to health and the environment. The objectives of the project were:

- To develop a system for ranking facilities according to risks
- To develop a system that would give consistent results when applied by various user organizations
- To develop a system that could be applied by the States, with the results then used by EPA to form a national priorities list

Several other considerations were important in shaping the development of the system. Since approximately 400 out of thousands of facilities are to be listed, the system should discriminate most accurately among the very worst problems. In the course of developing a list of at least 400, as many as several thousand facilities might be evaluated using the criteria; thus, costs to collect data and apply the criteria are a major concern. In practice that means that accuracy in results has been balanced against costs of data collection. Finally, from the outset the EPA established the general policy that public health considerations would outweigh environmental effects.

GENERAL APPROACH

Ideally, in order to evaluate the harm to public health and environment for the priorities list, investigators would simply measure all effects and convert them to some common denominator (e.g., dollars). In addition, where effects have not already happened, the potential for harm would be expressed as a quantitative risk assessment; for example, one might predict the number of increased cancers in a given population. Unfortunately, demonstration of health effects due to exposure to harmful substances is extremely costly, if not generally infeasible. Likewise, EPA studies indicate that precise quantitative risk assessments of hazardous waste facilities are not generally feasible due to uncertainties surrounding the health effects of mixtures of chemicals and the difficulties of accurately predicting migration of groundwater contaminants.[1] Finally, even assuming the technical ability to perform such analyses, the costs

would be entirely too high to warrant their use in implementing CERCLA. A simpler system is required.

Three existing general approaches to setting priorities were then identified: classification systems; judgment by "experts"; and scoring systems. Classification systems, used by several State and local agencies, have the distinct disadvantage that in order to be useful in setting priorities, every member of one class must be higher in the distinguishing characteristics (risk) than every member of the next lower class. The variety and combinations of hazardous substance problem types is not amenable to reduction to such a classification system.

Judgment by "experts" has been the most widely used approach to setting priorities, and within a single organization may be the best approach. However, it is doubtful that such an approach would be consistently applied from State to State. Perhaps even more importantly, while such a system might accurately rank facilities within a State or region, it offers no mechanism for merging results from all States to create a National Priorities List. A scoring system of some sort was deemed the most desirable approach.

REVIEW OF EXISTING APPROACHES

Several models have been developed for rating the relative hazard to public health and the environment posed by various hazardous substance facilities. These include the LeGrand and Surface Impoundment Assessment (SIA) models, the EPA Solid and Hazardous Waste Research Division (SHWRD) Predictive Method (SPM), and the Rating Methodology Model. The first two of these are concerned only with groundwater contamination, whereas the SPM might be applicable to a variety of routes and the Rating Methodology Model addresses both ground- and surface water contamination. The characteristics of these models are outlined in the following sections.

The LeGrand Model

The LeGrand Model[2] describes the potential for contamination of water wells by waste disposal sources. The final rating reflects the potential hazard of the wastes, the likelihood of the wastes reaching the groundwater, and the vulnerability of the groundwater to contamination. However, the model does not address air or surface water pollution problems.

The Surface Impoundment Assessment (SIA) Model

The SIA Model[3] expands on the scope of the LeGrand Model to evaluate the potential threat of contamination to groundwater itself, rather than the potential threat of contamination of wells. However, the model does not address surface water pollution, air pollution or other types of risks caused by hazardous substances.

The SIA Model has been adapted in a modified form by the State of Michigan Department of Natural Resources to rank their hazardous waste sites. The toxicity factor has been revised, and factors have been added for considering the number and proximity of drinking water wells and of people using these wells in the immediate proximity of the site.

SHWRD Predictive Method

The SHWRD Predictive Method[4] involves the application of multivariate analysis to perform two functions:

- Evaluate the relative importance of various rating factors (e.g., distance to groundwater)
- Classify sites into 2 or more categories as to their potential for an impact (e.g., 3 categories such as "good", "minimal", and "bad", according to compliance with accepted environmental standards)

Classifying facilities into a number of classes would probably not provide adequate discrimination among them to effectively implement the priority list requirements of CERCLA. In addition, constructing a representative mathematical function resembling a regression equation to deal with the multiple routes and an infinite classification (i.e., no pre-established cut-off points) would require more information than would generally be available at each facility. The approach of the method might be very useful in refining rating factors and weights once a number of sites have been scored and data on the sites is available for multivariate analysis.

The Rating Methodology Model

The Rating Methodology Model[5] was developed primarily to assess landfills, surface impoundments and other types of land-based storage and disposal facilities for the purpose of setting priorities for technical investigations. The hazard is rated in four general areas:

- Receptors
- Pathways
- Waste characteristics
- Waste management practices

"Receptors" are humans and other living beings and their environment that may be affected adversely by the hazardous wastes. "Pathways" are the routes or media (e.g., groundwater, air) that the waste is likely to traverse in reaching the receptors. "Waste characteristics" are the hazardous properties of the waste including mobility, toxicity and ignitability. "Waste management practices" refers to the designs and procedures that have been used in managing and containing the waste.

Thirty-one factors were identified as a means of rating, on a scale of 0 to 3, the potential contribution of the four areas of the overall hazard. If factors do not apply to a specific site or cannot be evaluated due to lack of data, they may be omitted. Alternatively, extra factors may be added to account for special considerations that are not addressed by the 31. A fixed multiplier associated with each factor serves to weight that factor's relative importance. The final score is obtained by adding the products of all the factors and their corresponding multipliers and by normalizing the result on a scale of 0 to 100.

The State of New Jersey Department of Environmental Protection has adopted the Rating Methodology Model and converted it into a classification system. All of the sites in the State are grouped into one of three priority

classes and there is no distinction drawn within each class when assigning the remedial action priority to a site.

Hazard Ranking System

The Hazard Ranking System is a scoring system designed to address the full range of problems resulting from releases of hazardous substances. Unlike the four approaches previously discussed, it is designed to address surface water, air, fire and explosion, and direct contact, in addition to groundwater contamination.

The system applies a structured value analysis approach, similar to the Rating Methodology Model. Three migration routes of exposure, groundwater, surface water and air are evaluated and their scores are combined to derive a score representing the relative risk posed by the facility. Two additional routes of exposure, (1) fire and explosion and (2) direct contact, are measures of the need for emergency response.

The system differs from the Rating Methodology Model primarily in that the routes are scored independently and the dependent nature of the variables is reflected by multiplying where appropriate rather than simply adding. Also, unlike the Ranking Methodology Model, the Hazard Ranking System was designed specifically for the purpose of ranking facilities for remedial action. The system therefore requires a greater amount of more detailed information.

Description

Application of the Hazard Ranking System results in three scores for a hazardous waste facility. One score, S_M, reflects the potential for harm to humans or the environment as a result of migration of a hazardous substance away from the facility by routes involving groundwater, surface water or air. S_M is a composite of separate scores for each of the three routes. Another score, S_{FE}, reflects the potential for harm from materials that can explode or cause fires. The third, S_{DC}, reflects the potential for harm as a result of direct human contact with hazardous materials at the facility (i.e., no migration need be involved).

The score for each hazard mode (migration, fire and explosion, and direct contact) or route is obtained by considering a set of factors that characterize the hazardous potential of the facility. A comprehensive listing of factors for all of the hazard modes is given in Table I.

Each factor is assigned a numerical value (generally on a scale of 0 to 3, 5 or 8) according to prescribed guidelines. This value is then multiplied by a weighting factor to yield the factor score. The factor scores are then combined by following established guidelines: scores within a factor category are additive but the factor category scores are multiplicative.

In computing S_{FE} or S_{DC}, or an individual migration route score, the product of its factor category scores is divided by the maximum value the product can have and the resulting ratio is multiplied by 100, thus normalizing scores to a 100-point scale.

Computation of S_M is slightly more complex since S_M is a composite of the scores for the three possible routes: groundwater (S_{gw}), surface water (S_{sw}) and air (S_a). S_M is obtained from the equation:

$$S_M = \frac{1}{1.73}\sqrt{S_{gw}^2 + S_{sw}^2 + S_a^2} \qquad (1)$$

The factor 1/1.73 arises from the vector addition of the three route scores after the individual scores are normalized to a common denominator. This means of combining them gives added weight to routes with higher scores.

The Hazard Ranking System does not result in quantitative estimates of the probability of harm from a facility or the magnitude of the harm that could result. Rather, it is a device for rank-ordering facilities in terms of the potential hazard they present. Risks are generally considered to be a function of the probability of an event occurring and the magnitude or severity should the event occur. Applying this approach to hazardous substance facilities, the probability and magnitude of a release are generally functions of the following areas:

- The manner in which the hazardous material is contained
- The route by which its release would occur
- The characteristics of the harmful substance
- The amount of hazardous substance
- The likely targets

These areas have been examined and representative factors were chosen to address each.

The scoring guidelines for each factor and the weight accorded to each factor were developed based on judgment initially. The weights and guidelines were then adjusted based on tests using data from 43 facilities.

Using the Hazard Ranking System

Use of the Hazard Ranking System requires considerable information about the facility, its hazardous substances content, its surroundings for distances up to three miles and the geological character of the area down to the depth of aquifers that may be at risk. Complete data may not be available and the individual assigning scores may have to use some judgment in applying the guidance provided.

Geology, hydrology, chemistry and the ecological sciences are the most relevant disciplines and scoring is best accomplished using a team of individuals knowledgeable in these disciplines. A format for recording general information regarding the facility being evaluated is shown in Figure 1. This figure can also serve as a cover sheet for the work sheets used in the evaluation. Sample work sheets are shown in Figures 2 through 7.

Where data for a factor are unavailable, it should be assigned a value of zero. However, if the factor for which the data are missing is the only factor in a category (e.g., containment or waste quantity), then the factor is given a score of unity. If data are lacking for more than one factor in connection the evaluation of S_{gw}, S_{sw}, S_a, S_{FE} or S_{DC}, that score is automatically set at zero.

Detailed instructions and guidance are provided in the guidance manual for using the Hazard Ranking System. As mentioned previously, if sufficient data are available, three scores are computed, S_M, S_{FE} and S_{DC}; S_M being a

Table I.
Comprehensive List of Rating Factors

HAZARD MODE	FACTOR CATEGORY	FACTORS		
Migration		Ground Water Route	Surface Water Route	Air Route
	Containment	• Containment	• Containment	
	Route Characteristics	• Depth to aquifer of concern • Net precipitation • Permeability of unsaturated zone	• Site slope and interviewing terrain • 1 Year 24 hour rainfall • Distance to nearest surface water • Flood potential	
	Waste Characteristics	• Physical State • Persistence • Toxicity	• Physical State • Persistence • Toxicity	• Volatility/Physical State • Reactivity • Incompatibility • Toxicity
	Hazardous Waste Quantity	• Total waste quantity	• Total waste quantity	• Total waste quantity
	Targets	• Ground water use • Distance to nearest well down gradient • Population served by ground water drawn with 3 mile radius	• Surface water use • Distance to a sensitive environment • Population served by surface water drawn within 3 mile radius	• Distance to nearest human population • Population within 1 mile radius • Distance to sensitive environment • Land use
Fire and Explosion	Containment	• Containment		
	Waste Characteristics	• Direct evidence of ignitibility or explosivity • Ignitibility • Reactivity • Incompatibility		
	Hazardous Waste Quantity	• Total waste quantity		
	Targets	• Distance to nearest human population • Distance to nearest building • Distance to sensitive environment • Land use • Population within 2 mile radius • Number of buildings within 2 mile radius		
Direct Contact	Accessibility	• Accessibility		
	Containment	• Containment		
	Waste Characteristics	• Toxicity		
	Targets	• Population within a 1 mile radius • Distance to a critical habitat		

composite of separate scores for three release routes: groundwater, surface water and air. It is this composite migration score that is used to rank facilities for remedial action priorities.

SYSTEM TESTING

The equations and factors described above were settled on after a comprehensive review and selective testing was performed on previous drafts. The review included EPA Regional personnel, contractors and industry representatives. Major anomalies were pointed out, particularly in the case of a city of 50,000 population with a threatened drinking water supply and a composite migration score of 28. The results of preliminary testing are shown in Figure 8.

The ideal distribution for maximum discrimination is a straight line with a slope of 1.0. The preliminary data was skewed toward the higher values because the 43 test facilities were not chosen randomly but were generally those sites considered "bad" by the EPA regional offices. This trend would be expected even under ideal conditions since it is unlikely that individuals would spend time and money to score facilities that are apparently a very low priority.

A sensitivity analysis was done to analyze the sensitivity of the final ranking score to changes in individual factor scores. This analysis showed that the hazardous waste quantity score had the greatest effect on the final ranking score. A change of one point in a factor value could, under worst case, effect the final score by 5.7%. The sensitivity analysis assumed that individuals assigning values according to the guidelines would not err more than one point on any factor.

Facility Name: _____

Location: _____

EPA Region: _____

Person(s) in Charge of the Facility: _____

_____

_____

Name of Reviewer: _____

General Description of the Facility

(For example: landfill, surface impoundment, pile, container; types of wastes; location of the site; contamination route of major concern; types of information needed for rating; agency action, etc.)

_____

_____

_____

_____

_____

_____

_____

Scores: S_m = (S_{gw} = + S_{sw} = + S_a =)

S_{fe} =

S_{dc} =

Figure 1.
Model Cover Sheet

GROUNDWATER ROUTE WORKSHEET

	Rating Factor	Assigned Value (Circle One)	Multiplier	Score	Max. Score
1	Observed Release	0 45	1		45
	If observed release is given a score of 45, proceed to line [4]. If observed release is given a score of 0, proceed to line [2].				
2	Route Characteristics				
	Depth to aquifer of concern	0 1 2 3	2		6
	Net Precipitation	0 1 2 3	1		3
	Permeability of unsaturated zone	0 1 2 3	2		6
	Total Route Characteristics Score				15
3	Containment	0 1 2 3	1		3
4	Waste Characteristics				
	Physical State	0 1 2 3	1		3
	Persistence	0 1 2 3	2		6
	Toxicity	0 1 2 3	2		6
	Total Waste Characteristics Score				15
5	Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1		8
6	Targets				
	Groundwater use	0 1 2 3	3		9
	Distance to nearest well downgradient	0 1 2 3	3		9
	Population served	0 1 2 3 4 5	6		30
	Total Targets Score				48
7	If line [1] is 45, multiply [1] x [4] x [5] x [6] If line [1] is 0, multiply [2] x [3] x [4] x [5] x [6]				259,200
8	Divide [7] by 259,200 and multiply by 100			S_{gw} =	

Figure 2.

As a result of the review comments received, the preliminary test results and the sensitivity analysis, major changes were made in the original Hazard Ranking System. Among these were:

- Elimination of fire and explosion and direct contact as routes to be considered for facility ranking
- A reduction in the number of factors
- Revision of the population factors to increase the System sensitivity to human populations
- Revision of the hazardous waste quantity factor.

FUTURE DEVELOPMENT

Development and testing of the system is continuing, and some revision is expected prior to implementing the National Priorities List of 400 facilities. Areas of development include:

SURFACE WATER ROUTE WORK SHEET

Rating Factor	Assigned Value (Circle One)	Multiplier	Score	Max Score
1 Observed Release	0 45	1		45
If observed release is given a value of 45, proceed to line 4. If observed release is given a value of 0, proceed to line 2.				
2 Route Characteristics				
Site Slope and Intervening Terrain	0 1 2 3	1		3
1-yr. 24-hr. Rainfall	0 1 2 3	1		3
Distance to Nearest Surface Water	0 1 2 3	1		3
Flood Potential	0 1 2 3	2		6
Total Route Characteristics Score				15
3 Containment	0 1 2 3	1		3
4 Waste Characteristics				
Physical State	0 1 2 3	1		3
Persistence	0 1 2 3	2		6
Toxicity	0 1 2 3	2		6
Total Waste Characteristics Score				15
5 Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1		8
6 Targets				
Surface Water Use	0 1 2 3	3		9
Distance to a Sensitive Environment	0 1 2 3	2		6
Population Served	0 1 2 3 4 5	6		30
Total Targets Score				45
7 If line 1 is 45, multiply 1 x 4 x 5 x 6				243,000
If line 1 is 0, multiply 2 x 3 x 4 x 5 x 6				
8 Divide 7 by 243,000 and multiply by 100		S_{sw} =		

Figure 3.

AIR ROUTE WORK SHEET

Rating Factor	Assigned Value (Circle One)	Multiplier	Score	Max. Score
1 Observed Release	0 45	1 1		45
If line 1 is 0, then S_a 0. Enter on line 6 If line 1 is 45, then proceed to line 2				
2 Volatility/physical Staff	0 1 2 3	1 1		3
Reactivity	0 1 2 3	1 1		3
Incompatibility	0 1 2 3	1 1		3
Toxicity	0 1 2 3	2 2		6
Total Waste Characteristics Score				15
3 Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1		8
4 Distance to Nearest Human Population	0 1 2 3	2		6
Population Within 1-Mile Radius	0 1 2 3 4 5	5		25
Distance to Sensitive Environment	0 1 2 3	2		6
Land Use	0 1 2 3	1		3
Total Targets Score				40
5 Multiply 1 x 2 x 3 x 4				216,000
6 Divide 5 by 216,000 and multiply by 100		S_a		

Figure 4.

- Cost of securing data
- Anomalies
- Testing
- Quality assurance

The cost of securing data is of concern because of the quantity of detailed sampling and analysis that is required to score a facility. A method is needed to screen sites before spending funds to collect extensive data for a site that will not rank above a given level.

Anomalies, facilities that have extreme characteristics outside the scope of the system will occur regardless of the complexity of detail required by the Hazard Ranking System. Where a class of anomalies can be identified, the system can be modified to more accurately rank facilities according to risk.

Field testing is required to measure the ability of the system to discriminate and rank sites with independent judgment. A method has been proposed to use an independent panel of experts to rank a selected group of sites and then compare these results with the Hazard Ranking System scores. The two ranking lists would then be analyzed for a statistical correlation.

	S	S^2
Groundwater Route Score (S_{gw})		
Surface Water Route Score (S_{sw})		
Air Route Score (S_a)		
$S_{gw}^2 + S_{sw}^2 + S_a^2$		
$\sqrt{S_{gw}^2 + S_{sw}^2 + S_a^2}$		
$\sqrt{S_{gw}^2 + S_{sw}^2 + S_a^2} \,/\, 1.73$		S_M =

Figure 5.
Worksheet for Computing S_M

Quality assurance is necessary to ensure that there is consistency in the application of the Hazard Ranking System among the individuals assigning scores.

FIRE AND EXPLOSION WORKSHEET

	Rating Factor	Assigned Value (Circle One)	Multiplier	Score	Max. Score
1	Containment	1 3	1		3
2	Route Characteristics				
	Direct Evidence	0 3	1		3
	Ignitability	0 1 2 3	1		3
	Reactivity	0 1 2 3	1		3
	Incompatibility	0 1 2 3	1		3
	Total Waste Characteristics Score				12
3	Hazardous Waste Quantity	0 1 2 3 4 5 6 7 8	1		8
4	Targets				
	Distance to Nearest Population	0 1 2 3 4 5	1		5
	Distance to Nearest Building	0 1 2 3	1		3
	Distance to Sensitive Environment	0 1 2 3	1		3
	Land Use	0 1 2 3	1		3
	Population Within 2 Mile Radius	0 1 2 3 4 5	1		5
	Buildings Within 2 Mile Radius	0 1 2 3 4 5	1		5
	Total Targets Score				24
5	Multiply [1] x [2] x [3] x [4]				6912
6	Divide [5] by 6912 and multiply by 100			S_{fe}=	

Figure 6.

DIRECT CONTACT WORKSHEET

	Rating Factor	Assigned Value (Circle One)	Multiplier	Score	Max. Score
1	Observed Incident	0 45	1		45
	If line [1] is 45, proceed to line [4] If line [1] is 0, proceed to line [2]				
2	Route Characteristics Accessibility	0 1 2 3	1		3
3	Containment	0 15	1		15
4	Waste Characteristics Toxicity	0 1 2 3	5		15
5	Targets				
	Population within a 1-mile radius	0 1 2 3 4 5	4		20
	Distance to a critical habitat	0 1 2 3	4		12
	Total Targets Score				32
6	If line [1] is 45, multiply [1] x [4] x [5] If line [1] is 0, multiply [2] x [3] x [4] x [5]				21,600
7	Divide line [6] by 21,600 and multiply by 100			S_{dc} =	

Figure 7.

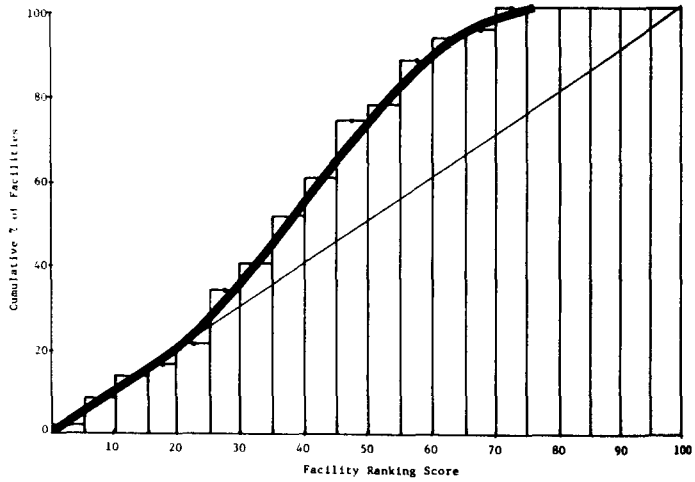

Figure 8.
Frequency Distribution of Facility Ranking Scores for 43 Preliminary Test Facilities (April 1981)

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STATE-FEDERAL SUPERFUND COORDINATION: WHO WILL RUN THE PROGRAM?

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INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), better known as "Superfund," provides the institutional framework for Federal and State agencies to respond to emergency response needs at abandoned hazardous waste sites. It focuses primarily on waste sites presenting an imminent danger to the public, removal of wastes and/or remedial actions taken at those sites and coordination between Federal and State agencies engaged in those activities.

At present, an implementation strategy for Superfund is being fine-tuned to specify the Federal and State roles for immediate or planned removal efforts and subsequent remedial actions. In addition, the National Contingency Plan is also being revised to include a national hazardous substance response plan which will establish basic criteria for emergency action response as well as those for site evaluation and ranking.

Since the mid-1970's, several States have taken the initiative in establishing their own implementation plans and funds to deal with past negligent waste management procedures and emergency response. In this paper, the authors examine the intended role of Superfund and State funding mechanisms and analyze potential problems which may be encountered by States as they attempt to coordinate their own program efforts with federal Superfund activities.

SUMMARY OF SUPERFUND

The Resource Conservation and Recovery Act (RCRA) was enacted by Congress in 1976 to upgrade existing state and local waste management programs to a uniform Federal level to assure protection of human health and the environment and conserve valuable materials and energy resources. Subtitle C of RCRA specifically sets forth a regulatory protocol to track hazardous materials from "cradle to grave" (i.e., generation/storage/transportation/disposal) and any real or potential release to the environment that might result in these operations.

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CEDRCLA), better known as superfund, was enacted in 1980 to specifically address existing waste sites presenting imminent health and environmental dangers as a result of past waste management practices. The law provides the institutional framework for Federal agencies and the States to respond to hazardous waste incidents and emergency spills not covered by the rigorous RCRA protocol. It establishes a liability system for specific pollutant releases, provides for long-term care for removal of waste and/or remedial actions at sites presenting imminent dangers (as well as short-term cleanup), calls for a coordinated national strategy for quick response in the event of an emergency spill or accident, and establishes a fund to finance such immediate response.

The two laws complement each other and, hopefully, together with the assistance of the regulated community, will demonstrate government's concern and intent to the now highly sensitized and volatile public.

In the past, the ultimate responsibility for cleaning up abandoned waste sites or the dangers imposed by hazardous substances and dealing with the political, legal, and financial expenses involved, was borne almost exclusively by state and local governments. Since the mid-1970s, moreover, states have taken the initiative in establishing their own implementation plans and funds to deal with both negligent management procedures and emergency response.

It, therefore, seemed practical that when the Superfund legislation was making its way through the Congressional process and finally enacted, state and local governments, because of their prior experiences, should have an intimate role in shaping the legislation. The public's concern with the abandoned site issue has become so volatile that state and local elected officials alone have the ekxperience to promote the necessary public trust and curb the political sensitivity that now exists.

Superfund recognizes the need for a state/federal partnedrship and, through Congressional intent, provides the flexibility for extensive state participation should EPA be willing to adopt such an approach. However, the states are finding it difficult to implement the programs mandated by Superfund because of the lack of direction and clarification of responsibilities provided thus far by EPA.

To better determine where those difficulties lie, examine the Congressional intent of Superfund and the directive it mandates: The goals of the law include:

(1) An inventory of inactive hazardous waste sites in a systematic manner

(2) Establishment of priorities among the sites based on relative danger
(3) Accelerating the elimination of unsafe hazardous waste sites
(4) Systematic program of funding to identify, evaluate and take responsive actions at inactive hazardous waste sites to assure protection of public health and the environment in a cost-effective manner.

Location of sites housing hazardous substances known or abandoned and spills of hazardous substances in releasable quantities of one pound or greater as specified by Section 311 (b) (4) of the Federal Water Pollution Control Act must be reported to the National Response Center or the Administrator of EPA or face civil action or fine of $10,000. (Interim or final RCRA sites are excluded).

If it is determined that a hazardous substance or release of any pollutant or contaminant impinges on the environment or presents a substantial threat and endangerment to the public health or welfare, the President is authorized to act, consistent with the National Contingency Plan. In the event that the responsible party cannot be found or takes inadequate or no action, he is authorized to remove, provide for removal of, or take remedial action relating to such hazardous substances, including those specified by RCRA, Section 311 of the Clean Water Act, Section 112 of Clean Air Act, Section 307 of Clean Water Act, Section 7 of TSCA and any others designated by Superfund. Direct response actions, however, are limited to a six month or $1,000,000 ceiling, unless an emergency or immediate risk to public health exists.

Moreover, remedial action may only be taken after consultation with the affected state(s), in the form of a cooperative agreement to assure that:
•States will assume all future maintenance of such actions
•There is available an acceptable disposal facility
•The state will assume 10% of the costs, or 50% in the case of state-owned facilities

Credit is granted those states having expended funds for releases since January 1, 1978. Such costs must be direct and documented.

National Contingency Plan

Section 105 of the law mandates promulgation of a National Contingency Plan within 180 days after the law's enactment to establish procedures and standards for responding to releases of hazardous substances, pollutants and contaminants. The plan must include:
•methods for discovery and investigation
•methods for evaluation and remedy of releases
•methods and criteria concerning the appropriate extent of response
•appropriate roles of all government or non-governmental entities
•provision for equipment and supplies
•provision for reporting of federally owned facilities
•a method to assure that actions are cost-effective
•priority criteria based on a variety of health and environmental risk factors, and state preparedness to assume state costs and responsibility

Site Priority List

Subsequently a national priority list, composed of at least 400 of the highest priority facilities will be established based on these criteria. The top 100 of these sites must include at least one site per state, as specified by individual state priority lists. Abatement action may then be sought by the Attorney General in the event of danger and threat or by Presidential orders forcing violators to comply with such orders or be fined up to $5,000 per day. Promulgation of guidelines using this response authority, moreover, must be published by EPA in consultation with the Attorney General with 180 days enactment of the bill.

Section 107 establishes a mechanism for quick recovery of monies expended from the Hazardous Waste Response Fund from the liable parties. Owners and operators who arranged for disposal or transportation of hazardous substances at the time of disposal or transportation of hazardous substances at the time of disposal or who accepted such substances for disposal at facilities are deemed liable in accordance with Section 311 of the Clean Water Act for costs incurred consistent with the National Contingency Plan and for damage to natural resources. Monetary limits regarding liability have been established for vessels, motor vehicles, aircraft and pipelines. The remaining limits are to be established by regulations.

Financial responsibility for vessels must be established and maintained by owners and operators, and enforced by the Department of transportation. For facilities, the level of financial responsibility will be based on the establishment of facility classification (within three years) and consistent with the degree and duration of risk associated with the production, transportation, treatment, storage, or disposal of hazardous substances. Regulations imposing such responsibilities must be promulgated no later than six years after the date of Superfund enactment.

Financing and Spending

Monies for allowable expenditures are drawn from the Hazardous Waste Response Fund in the Treasury of the United States. Sources are as follows:
•Fees collected on crude oil (received at a U.S. refinery), petrochemical feedstocks and certain inorganic elements and compounds
•Monies recovered under liability provisions
•Reimbursements from actions taken
•Penalties collected under the Act
•Appropriated funds

Approximately 86% of the fund will be received from taxes and 14% from appropriations. For the proposed five-year period, approximately $1.6 billion dollars will be collected or transferred into the fund. EPA estimates that this will accomplish at least 85% of the cleanup actions, provided claims total no more than 15% of the total. Uses are limited to the following:
•Response costs
•Claims for response costs by any persons consistent with the National Contingency Plans
•Outstanding Section 311 claims

•Assessment, restoration and rehabilitation of natural resources, including
enforcement and abatement
epidemiological studies, registry and diagnostic testing
equipment and supplies for Superfund and Section 311 (subject to appropriations)
worker health and safety program
authorized appropriate advances

Claims against the fund will be negotiated between the claimant and responsible party, should that party be located and deemed responsible. In the absence of a responsible party, the fund will negotiate a settlement with the claimant. Each will be paid on a first come first serve basis. The statute of limitations is three years from the date of enactment or discovery of the loss, whichever is later. Should a state have its own fund, Superfund exercises the right of preemption, i.e., no contributionf can be required to any State fund for claims for response or damages compensated under Superfund. Furthermore, double compensation is not allowed.

STATE FUNDING MECHANISMS

As of August, 1981, twenty-four states had authorized the creation of thirty-two funding mechanisms to meet this financial challenge. In the accompanying matrix (Chart I) the major elements addressed in these state funding laws are shown, including the purposes for which the funds were created, sources from which fund monies are collected, functions for which the funds may be utilized and other key points including liability clauses, fund ceilings and actual fund balances to date.

In order to illustrate the wide range of responsibilities and actions which these state funds encompass, the following descriptive narrative is included to clarify and detail major provisions contained in each state funding law.

Purposes

Michigan first enacted legislation establishing a "water cleanup emergency fund" in 1974, followed five years later by the creation of two other funds to address emergency response and perpetual care activities. Louisiana, which established a Hazardous Waste Protection Fund in 1979, amended its law in 1980 to create two additional funds which address general emergency response and abandoned site cleanup. Kansas, Tennessee, Texas, and Wisconsin have each created two distinct funds within their respective laws to meet specific hazardous waste management concerns.

Most state funds are multi-purpose in nature, and authorize payment for a host of problems resulting from hazardous waste incidents. Eighteen funds address varying activities associated with emergency response, nine funds can be utilized for the maintenance and perpetual care of TSD facilities, and seven are authorized to clean up spills in navigable waters or on land. Thirteen other funds may be used to cover such expenses as program administration and management, initial facility closure, site reclamation, or state costs associated with the implementation of the federal Superfund.

Sources of Funds

State laws authorizing the establishment of funds often explicitly spell out the sources from which the fund is to collect its money. Eleven states (AS, CA, FL, GA, IL, KS, MD, MI, OH, TN, WI) assess a fee or tax on a TSD facility owner/operator. Kansas bases its fee on the volume of hazardous wastes received at the facility, not to exceed 25¢/ft.[3] Illinois collects fees on a quarterly basis amounting to 1¢/gal. or $2.02/yd.[3] of waste received. Wisconsin charges disposal site owners a tipping fee of 15¢/ton if the owner elects to be responsible for long-term care of the facility for 30 years, or 35¢/ton if he elects a 20-year long-term responsibility. Fees are 1/10th of that for solid waste disposers. Missouri requires hazardous waste landfill operators to collect, on the state's behalf, a tax equal to 2% of the gross charges and fees charged to generators and transporters for waste disposal at the landfill site. This tax is separate from other fees levied on generators, which are based on tonnage of waste generated per year.

Six states (CA, FL, KY, ME, MO, NH) assess the generators of hazardous waste. California charges an off-site generator/producer $1 for each load of hazardous waste weighing one ton or less which is disposed of on land or applied to land; $1 for each load or $1/ton, whichever is greater, for each load weighing more than one ton which is disposed of on land or is applied to land; and $1/ton for all hazardous waste delivered by pipeline. Fees are also assessed the operator of on-site disposal facilities—the disposer collects the fee from the generator and remits it to the General Fund. These assessments are $1/ton on the first 2,500 tons of hazardous waste disposed of on, into or applied to land in any one month, up to $2,500 per month. Fees can be waived if the operator shows that the wastes have been rendered nonhazardous.

Florida levies an excise tax on generators of hazardous wastes at the rate of 4% of the price of disposal, storage or treatment, in incremental amounts to be paid between 10/1/80 and 9/30/84. Kentucky assesses fees on generators based on the volume received and the method of disposal; on-site fees are one half those of off-site assessments, and the assessments will shift to the hazardous waste disposer on July 1, 1984.

Maine's 1981 law establishes a fee schedule to cover cleanup actions taken on-site and off-site of generation. Generators who produce more than 1,000 kg of hazardous waste in any calendar month are required to pay 12¢/gal on wastes disposed of on-site. This amount decreases to 3¢/gal if the waste is stored on the generation site for more than 90 days but less than six months. Generators of more than 1,000 kg of hazardous waste in any calendar month are charged 15¢/gal for wastes transported off-site to a licensed hazardous waste disposal facility, or 9¢/gal if transported to a licensed treatment facility. If the waste is taken to a licensed storage facility and stored for between three and six months, the generator pays 6¢/gal; after six months, the rate decreases to 3¢/gal. A 6¢/gal fee also applies to generators who ship wastes off-site to be beneficially used, reused, reclaimed, or recycled.

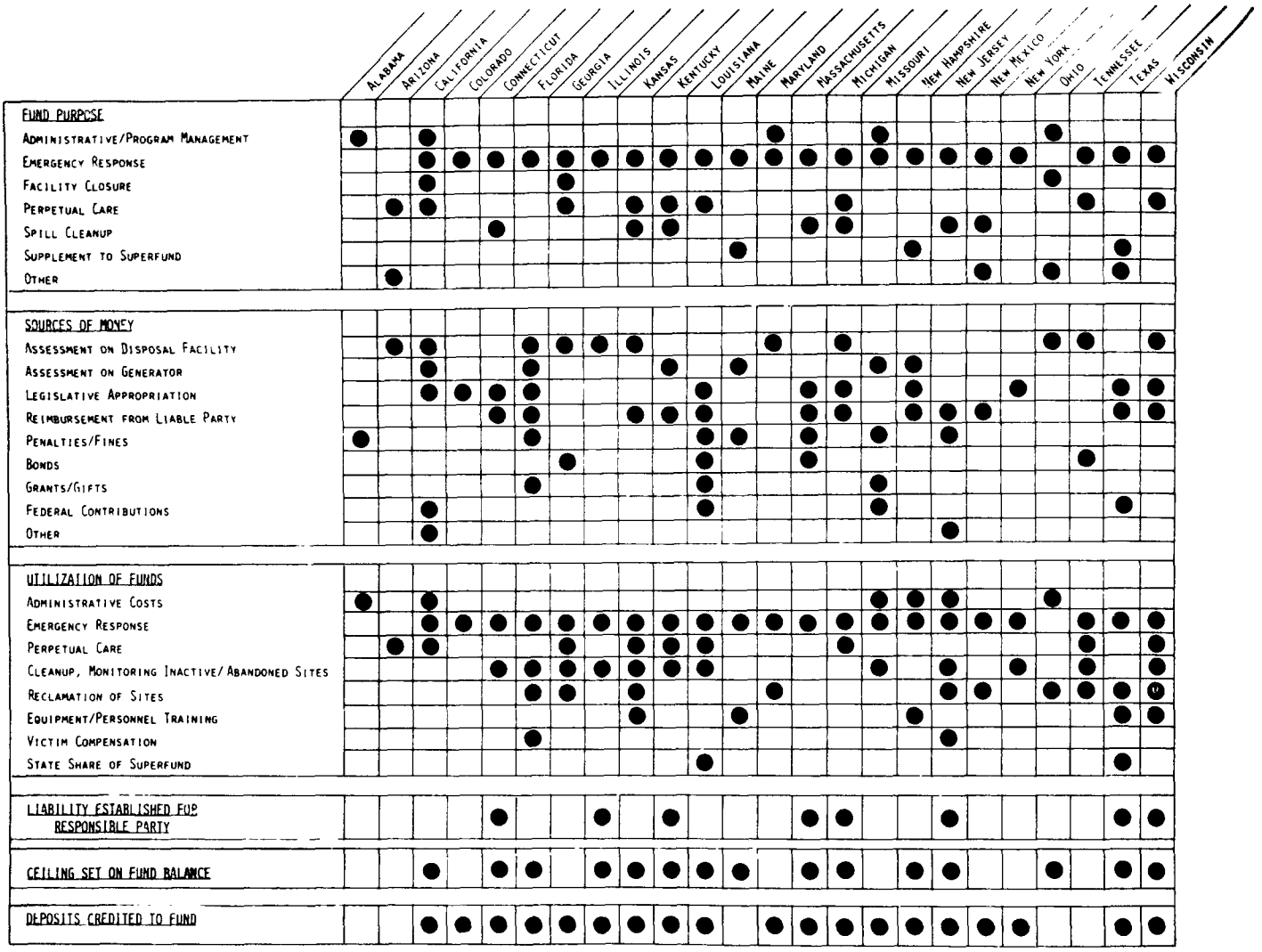

Chart 1.
Major Provisions of State Hazardous Waste Funds

Missouri will begin levying a fee on generators effective January 1, 1982 of up to $1/ton of hazardous waste registered with the Department of Natural Resources. Fees shall not exceed $10,000 per generator per year, and no fee will be required of generators who register less than 10 tons of hazardous waste annually. New Hampshire requires generators who produce 300 kg or more of unrecycled hazardous waste within a three-month period to pay up to 1¢/kg on a quarterly basis to its Bureau of Solid Waste Management.

Eleven states depend upon legislative appropriations to support their funds, while twelve states attempt to collect funds from the parties responsible for the spill or contamination. Seven states deposit all fines and penalties collected from violators into their funds, while Georgia, Louisiana, Massachusetts and Tennessee depend upon bonds to finance their funding mechanisms. Louisiana relies partially on grants and state/federal allocations to support its three funds. Fifty percent of California's Hazardous Waste Control Account is funded by RCRA grants, and the state also relies on monies received from liens imposed on site property. Florida, Louisiana, and Missouri accept grants and gifts from public and private agencies to deposit into their funds; New Jersey taxes the transfer of petroleum products and hazardous substances at a rate of 1¢/bbl or 0.4% of fair market value, whichever is greater. Texas relies partially on direct reimbursement from the federal government through the Coast Guard Fund to help keep its Coastal Protection Fund solvent.

Uses of Funds

The states utilize these hazardous waste management/emergency response funds for an assortment of diverse activities. Alabama appropriates its money to the State Board of Health to carry out the purposes of its hazardous waste management law. California's Hazardous Waste Control Account is a subaccount of its General Fund which is to be used only for covering administrative costs

of its hazardous waste management program. California also established a temporary Site Closure and Maintenance Revolving Account which was appropriated $370,000 from the General Fund to clean up the Stringfellow Quarry in 1978. Louisiana can use its Emergency Response Fund to control/contain/abate pollution sources and ensure adequate scientific/technical support of litigation arising from a pollution incident, in addition to defraying emergency response costs.

Colorado's Emergency Response Cash Fund is used for emergency response efforts where the fire department or other public agencies provide assistance outside its own jurisdiction. New York has established a General Governmental Emergency Fund which is used for all government emergencies, including environmental incidents. Monies are expended only when the legislature is not in session to appropriate special funds itself, and the Commissioner of Health must declare a state of emergency in order for the funds to be used. Texas uses one of its funds to train personnel and obtain equipment and supplies required for cleanup activities involving discharges or spills in coastal areas and offshore, including restoration of beaches and marine resources. One of Wisconsin's funds can also be used to train personnel and to procure and maintain equipment and supplies needed in emergency response cleanup efforts.

Several states can activate their funds to provide for the cleanup and monitoring of inactive or abandoned hazardous waste facility sites. Connecticut's Emergency Spill Response Fund will pay for the containment and removal of oil spills, petroleum, chemical liquids or solids, liquid or gaseous products or hazardous wastes. Florida's fund can be used to pay for restoration of areas damaged by releases from abandoned sites, while Kentucky's Hazardous Waste Management Fund will respond to hazardous substance spills and provide perpetual monitoring and maintenance of inactive sites. Georgia and Tennessee provide for the detoxification and removal of hazardous wastes, site reclamation, cleanup, perpetual care and surveillance of abandoned or inactive sites.

Louisiana's Abandoned Hazardous Waste Site Fund can be used to defray containment/control/cleanup costs, acquire rights-of-way easements or title in order to secure and quarantine a site and provide money or services as the state share of matching funds for federal grants. Illinois' Hazardous Waste Fund can be used for preventive/corrective actions necessary and appropriate when hazardous waste disposal sites can cause danger to public health or the environment, and will pay for abandoned site cleanup if the Governor decides that an emergency exists. The Kansas Perpetual Care Trust Fund will pay for extraordinary costs of monitoring inactive sites, repair sites and environmental damage due to a post-closure occurrence, and authorizes up to 20% of the fund balance to be used on an emergency basis for the investigation, engineering, equipment, and construction needed to treat or dispose of hazardous wastes. Missouri's fund will pay for cleanup of hazardous waste emergencies and abandoned or illegal sites, and will compensate other state agencies for services rendered.

Arizona limits its trust fund to paying for the operation, maintenance and perpetual care of state-owned hazardous waste sites and facilities, or for mitigating imminent and substantial threats to public health or the environment created by the site or facility. Michigan's dual fund system will pay for both prospective hazardous waste emergencies as defined by agency rules and for the costs of long-term care of inactive disposal sites; Massachusetts' Division of Waste Pollution Control was appropriated $300,000 in FY 80 to use to clean up oil and hazardous waste spills.

New Mexico's emergency fund can clean up and dispose of hazardous substances and make repairs to or replace state property damaged by a hazardous substance incident. Louisiana can obligate its protection fund to defray emergency response costs, maintain and care for disposal sites, and assure financial responsibility in case of damages from an accident or negligence. Wisconsin's Waste Management Fund is used for the long term care of inactive sites after owner liability has terminated, or for site and environmental reclamation needed for damages caused by an unanticipated incident. Ohio's fund concentrates on facility closures and air/water pollution abatement but also authorizes up to $500,000 to be expended over a three year period in the form of grants to municipalities to encourage the siting of hazardous waste facilities in their jurisdiction.

Four states address spills into waters within their jurisdictions. Maryland allows its fund to be used to defray program administrative costs, identify and restore natural resources, and remove or mitigate the effects of hazardous substances contained in their waters. Kansas can use its Pollutant Discharge Cleanup Fund for emergency responses to spills in waterways but Florida prohibits the use of its trust fund to clean up spills being removed from navigable waters by a federal agency, or spills being removed from coastal waters by the state. Michigan's "water cleanup emergency fund" can reimburse contractors called to the scene of a spill for cleanup expenses, and collects money from liable parties.

Florida and New Jersey are the only states so far to institute a victim compensation scheme into their funding authority. Florida will pay for provable property damage resulting from a hazardous waste release, while New Jersey will reimburse the costs of restoring, repairing or replacing real or personal property damaged by a discharge. This includes income derived from the damaged property, the costs of restoring natural resources damaged by the discharge, and the loss of tax revenue by state and local governments due to property damage.

Three states have created funding mechanisms in their 1981 legislative sessions in direct response to coordination efforts with the federal Superfund, and at this writing, both houses of the California Legislature are considering bills which would enable that state to meet its responsibilities in order to qualify for credit under Superfund.

Maine's Hazardous Waste Fund may be disbursed to pay for, among other things, the purchase of necessary hazardous waste response equipment and supplies, per-

sonnel, and training for such personnel, but the law stipulates that no money may be disbursed for response or damage claims which may be compensated under the federal Superfund.

The New Hampshire Hazardous Waste Cleanup Fund shall be used to provide for adequate and safe containment and cleanup of sites within that state, after certification has been received from the Governor that a threat to the environment and public health exists. The Bureau of Solid Waste Management may enter into contracts and use the fund for hiring consultants and personnel, purchasing/leasing/renting necessary equipment and paying for other necessary expenses and administrative costs. The fund shall not duplicate Superfund functions, nor pay compensation for claims which may be compensated under the federal fund.

Texas established a Disposal Facility Response Fund to be used only to provide the state's required share of funds under Section 104 of Superfund, and to pay for removal and remedial actions as required by the federal law. Funds may not be used for the normal administrative and operating expenses of the Department of Water Pollution Control.

Liability

Eight states set liability standards for owners/operators of hazardous waste facilities in conjunction with the establishment of a funding mechanism to deal with emergency response activities. Connecticut holds the party responsible for the hazardous waste or oilspill liability for up to 1½ times the cost and expenses incurred by the state for the spill cleanup.

Kentucky's 1980 law stipulated that applicants for hazardous waste disposal permits must submit estimates of the annual cost of post-closure monitoring and routine maintenance, which will determine the annual cash payments to be made by the disposer into a post-closure monitoring and maintenance fund for up to 20 years. The applicant must also provide evidence of financial responsibility through liability insurance, self-insurance or other evidence for the purpose of satisfying claims arising out of injury to persons or property resulting from the release or escape of hazardous wastes into the environment.

Massachusetts expects owners/operators of a faulty vessel, vehicle, railroad car, container or facility to promptly notify the Division of Water Pollution Control of any spill or face a fine of up to $5,000. Persons who caused the spill, and all owners/operators of vehicles or containers which released hazardous wastes are liable for the costs of investigating and cleaning up the spill. Owner/operators of hazardous waste disposal facilities in Michigan must file a surety bond or other suitable instrument to cover the costs of closing, monitoring and maintaining a disposal facility after its capacity is reached, based upon a reasonable estimate of the costs over a 15-year period or less.

New Jersey's Spill Compensation and Control Act, amended in 1979, stipulates that dischargers or persons responsible for hazardous substances which result in spills will be strictly, jointly and severally liable and all common law defenses such as contributory negligence by the government or a third party liability claim will no longer be reasonable excuses. Texas will attempt to collect reimbursement from the owner/operator and/or other parties responsible for a spill and Wisconsin owners of solid or hazardous waste sites established after May 21, 1978, are required to care for the sites for 30 years after operations cease or 20 years if they pay higher fees into the waste management fund.

Fund Balances

Fifteen states specifically establish maximum limits on the amount of money to be collected for their funds, ranging from $50,000 in the Kansas Pollutant Discharge Cleanup Fund to $50 million in New Jersey's fund. The remaining funds are open-ended and do not specify a ceiling on fund contributions.

However, the fact that a state has legislatively authorized creation of a funding mechanism to deal with hazardous waste management programs does not necessarily imply that money is available in the fund to carry out its objectives. Although over half the states have deposited monies into their funds—CA, CO, CT, FL, GA, IL, KS, KY, LA, MD, MA, MI, MO, NH, NJ, NM, NY, TX, WI—most of the contributions are meager in comparison to anticipated revenues, and would be quickly depleted if tapped for a major emergency response effort. Some states (AZ, OH, TN) are waiting for authority to issue permits for new (or existing) facilities to trigger their fund collection process. Others depend upon legislative actions to appropriate needed funding (CT, FL, KS, MI, NH, NM, NY, TX). Only a handful of states have fee systems in place to generate fund revenues, or have taken legal actions which have resulted in fines being credited to their fund accounts.

The matrix in Chart 2 shows specific state funding mechanisms, maximum limits on fund contributions and actual fund balances as of July, 1981.

Clearly, these states have begun to confront their hazardous waste problems by establishing funding options to meet the financial burdens associated with a hazardous waste incident. Some funding programs are still in the initial stages of development/implementation due to time-consuming state regulatory processes or delays in obtaining permitting authority from EPA. Other states have forged ahead despite institutional and political barriers to maintain sizable fund balances. The states are now looking to EPA for guidance and/or reassurance as to how their funding mechanisms can coordinate with Superfund efforts when and if emergency response actions are to be taken which prove too enormous for the state alone to handle.

POTENTIAL PROBLEMS IN STATE/ FEDERAL SUPERFUND COORDINATION

The ultimate responsibilities for Superfund in administration and implementation should be afforded to the states, provided technical capabilities and interest on their

STATE	NAME OF FUND	FUND CEILING (BY LAW)	FUND BALANCE
ALABAMA	HAZARDOUS WASTE MANAGEMENT FUND	NOT SPECIFIED	$0 (COLLECTIONS BEGIN JUNE 1981)
ARIZONA	HAZARDOUS WASTE TRUST FUND	NOT SPECIFIED	$0 (TIED TO SITING NEW FACILITY)
CALIFORNIA	HAZARDOUS WASTE CONTROL ACCOUNT	NOT TO EXCEED AMOUNT NEEDED TO ADMINISTER PROGRAM	$628,500 (AVAILABLE FOR APPROPRIATION)
	SITE CLOSURE & MAINTENANCE REVOLVING ACCOUNT	NOT TO EXCEED $500,000	PHASED OUT BY 1981 LAW
COLORADO	EMERGENCY RESPONSE CASH FUND	NOT SPECIFIED	$ 20,000 BY APPROPRIATION
CONNECTICUT	EMERGENCY SPILL RESPONSE FUND	$200,000 BY APPROPRIATION	$150,000
FLORIDA	HAZARDOUS WASTE MANAGEMENT TRUST FUND	UP TO $10 MILLION	$600,000
GEORGIA	HAZARDOUS WASTE TRUST FUND	NOT SPECIFIED	$ 22,000
ILLINOIS	HAZARDOUS WASTE FUND	NOT TO EXCEED $25 MILLION	$400,000
KANSAS	PERPETUAL CARE TRUST FUND	NOT SPECIFIED	$ 25,000
	POLLUTANT DISCHARGE CLEANUP FUND	NOT TO EXCEED $50,000	$ 50,000 IN FY81
KENTUCKY	HAZARDOUS WASTE MANAGEMENT FUND	NOT TO EXCEED $6 MILLION	$121,855
LOUISIANA	HAZARDOUS WASTE PROTECTION FUND	NOT SPECIFIED	$0
	ABANDONED HAZARDOUS WASTE SITE FUND	NOT SPECIFIED	$400,000
	EMERGENCY RESPONSE FUND	$1 MILLION	$1 MILLION BY APPROPRIATION
MAINE	HAZARDOUS WASTE FUND	NOT SPECIFIED	$0 (COLLECTIONS BEGIN SEPT. 1981)
MARYLAND	HAZARDOUS SUBSTANCE CONTROL FUND	NOT SPECIFIED	$348,000
MASSACHUSETTS	SPILL FUND	$300,000 BY APPROPRIATION	$300,000 (+ $1 MILLION FROM BOND)
MICHIGAN	WATER CLEANUP EMERGENCY FUND	$ 25,000 BY APPROPRIATION	$ 25,000
	DISPOSAL FACILITY TRUST FUND	LIMITED TO $2 MILLION/YEAR, UP TO $30 MILLION	$140,000
	HAZARDOUS WASTE SERVICE FUND	$1 MILLION	$500,000
MISSOURI	HAZARDOUS WASTE FUND	NOT SPECIFIED	$ 12,000
NEW HAMPSHIRE	HAZARDOUS WASTE CLEANUP FUND	NOT SPECIFIED	$200,000 BY APPROPRIATION
NEW JERSEY	SPILL COMPENSATION FUND	$50 MILLION, TO BE REDUCED TO $26 MILLION AFTER 3 YEARS FOR PORTION OF FUND USED FOR INCIDENTS OCCURRING AFTER 4/1/77; $6 MILLION IN FY81 FOR ABANDONED SITE CLEANUP -- UP TO $1.5 MILLION/SITE	$12 MILLION
NEW MEXICO	HAZARDOUS WASTE EMERGENCY FUND	NOT SPECIFIED	$ 5,000 BY APPROPRIATION
NEW YORK	GOVERNMENTAL EMERGENCY FUND	NOT SPECIFIED	$9 MILLION
OHIO	HAZARDOUS WASTE FACILITY MANAGEMENT SPECIAL ACCOUNT	$20 MILLION	$0 (TIED TO FACILITY PERMITTING)
TENNESSEE	PERPETUAL CARE TRUST FUND	NOT SPECIFIED	$0
	HAZARDOUS WASTE TRUST FUND	NOT SPECIFIED	$0 (TIED TO FACILITY PERMITTING)
TEXAS	TEXAS COASTAL PROTECTION FUND	NOT TO EXCEED $5 MILLION	$1 MILLION
	DISPOSAL FACILITY RESPONSE FUND	NOT SPECIFIED	$5.6 MILLION BY APPROPRIATION
WISCONSIN	WASTE MANAGEMENT FUND	NOT TO EXCEED $15 MILLION	$180,000
	HAZARDOUS SUBSTANCES SPILL FUND	NOT SPECIFIED	$125,000 (FY80 FIGURES)

Chart 2.
State Funding Mechanisms: Ceiling Amounts and Fund Balances (as of July, 1981)

part is demonstrated. This state/federal partnership, however, precipitates the existence of major differences which must be resolved in order to achieve Superfund's objectives. Issues to be resolved include:

- Preemption
- State match of funds
- Selection of contractors
- Definition of the state role

Interpretation of Section 114 (C) of CERCLA, the preemption clause, may impede successful state/federal fund coordination efforts and hinder promotion of a viable state/federal partnership. To prevent affected industries in a state from paying a double tax into both a state fund and Superfund for the same emergency response activity, a state may not require an industry to contribute to a fund that would be used for the same purposes as CERCLA. Section 114 (C) fixes the prohibition as any fund "the purpose of which is to pay compensation for claims for any costs of response or damages or claims which may be compensated under this title." State general revenue funds may be used and an industry tax may be imposed to purchase cleanup equipment, train personnel, or otherwise prepare for response to an accident. This will have far-reaching ramifications for states with a number of problem sites only a fraction of which will qualify under the act. Some officials at EPA candidly admit that CERCLA may only mitigate half the number of sites in the National Priority List of 400. Indeed, most of these 400 are concentrated east of the Mississippi in states that are suffering from financial crises.

At the same time, the responsibility for waste management programs is being shifted back to the states without a corresponding shift in funding support. The capacity of a state's general revenues to pay for these environmental programs, in addition to the site cleanup demanded by residents, will likely be severely strained. There is good cause for concern that a state with a number of sites eligible to receive Superfund monies will not be able to finance their portion of the cleanup that is needed and called for by residents because of the prohibition on raising sufficient funds through an industry tax. A narrower interpretation either by the courts or by Congressional action might avoid preempting these states from recovering costs at those non-Superfund sites utilizing a state-imposed industry tax.

As previously mentioned, some states already have funds financed by industry taxes to address hazardous waste damages. After CERCLA was enacted, other states established funds which have tried to avoid the constraints imposed by this preemption clause by including provisions in their laws that monies cannot be used to compensate claims which will be covered by Superfund. However, questions still exist as to how states will be able to finance their portion of the cleanup costs, and which costs may be preempted by Superfund.

At present, eligibility requirements for Superfund have not yet been clearly delineated. States are looking to the courts for direction. New Jersey, for example, has filed suit in Federal Court for a declaration judgment since their state fund is financed by transfer taxes on petroleum and hazardous waste products and a $100 million bond issue has been placed on the November ballot. In other states, Indiana for example, the questionable issue of compensable state costs is of prime importance, since their top priority site is publicly owned and therefore requires a 50% match and long-term maintenance care. Draft strategies developed by EPA require the match (10% or 50%) to be satisfied by a cash commitment. However, when costs are totalled—previous expenditures for cleanup, state match, funds for sites not covered by Superfund—state expenditures will probably exceed federal outlays, and that 10 or 50% match will, in actuality, be far greater. States just do not have those monies. They overwhelmingly agree that state costs should be judged similarly to EPA eligible expenditures. Rather than a cash commitment, this would include as eligible:

- state in-kind contributions
- long-term operation and maintenance costs
- past expenditures for partial or complete remediation incurred after January 1, 1978

In addition, states feel that use of their own personnel will prove more expeditious and cost-effective than use of contractors. This, in turn, will not only reflect the true spirit of the law as Congress intended but also provides incentive for states to expand the scope of their own programs.

Selection of prime contractors with their own employees in supervisory capacities is gaining strong support from the states. Due to their long-standing experience in the utilization of contractors states feel that they can effectively select and manage contractors cognizant of state specific problems.

EPA, however, has recommended to OMB that the National Contingency Plan designate the Army Corps of Engineers as the lead agency for design and construction at Superfund sites. rather than regionalized prime contractors managing a number of subcontractors. Since the Corps is a public agency and would be accountable to EPA, overhead costs (of prime contractors) would be eliminated. However, their lack of statutory authority, personnel, or past experience would create serious impediments to rapid program implementation.

Current program estimates by EPA anticipate the use of $120 million over the next five years by states and the remaining $700 million to be used by the Corps for their clean-up activities. Such a projection is causing alarm within states. Concern has been expressed that state involvement in deciding and implementing state clean-up activities will be minimal, and that the extent and design action implemented by the Corps will overlook solutions tailored to specific state needs. All-in-all, the states foresee themselves as being excluded from involvement in lieu of a federally dominated program.

It is critical that optional procedures available to the states for participation in Superfund be delineated in the forthcoming National Contingency Plan. Provision for a flexible approach with a range of options should be adopted and reflected in contracts or cooperative agreements between federal and state governments. Maximum state participation is desired and provided for under the law.

There are certain issues yet to be resolved which are currently barriers to expeditious Superfund implementation. It behooves EPA, therefore to address and consult with the states on the following:

- Definition of roles available to the states
- Definition of fiscal policies and requirements: allowable costs, credit/reimbursement policies, scope of contractual agreements
- Definition of response action objectives; criteria for cost-effective approaches
- Guidelines in the event of disagreement concerning extent of response actions
- State involvement as far as technical requirements are involved, i.e., safety requirements and procedures, and technical assistance to states for training of local officials to assure long-term maintenance of Superfund sites

CONCLUSION

As of August, 1981, the implementation strategy for the Federal Superfund program has not yet been clearly defined and those problems affecting the overall coordination of Superfund with existing State funding programs remain unresolved. The question posed in the title of this paper—who will run the program—is clouded by these delays, and therefore remains unanswered.

However, daily communication with State Solid Waste Directors and State emergency response actions undertaken thus far indicate that States are not sitting by idly and waiting for complete clarification of their role. States are concerned with the health and welfare of their citizens and are expending monies when possible to forestall further degradation and deterioration of selected abandoned hazardous waste sites. Funds are being stretched to their limits, however, and the States will welcome the opportunity to cooperate with federal agencies and coordinate on-scene federal cleanup efforts when the Superfund program is finally operational.

States are fully aware that a State/Federal partnership must be developed to provide the adequate funding relief necessary for Superfund activities and had, therefore, initiated lines of communication with the EPA/Superfund office soon after the change in Administration. The Association of State and Territorial Solid Waste Management Officials, likewise, has established a Superfund Task Force to work directly with EPA in this role definition.

However, even with these combined efforts, the Congressional mandate that provides a State role in Superfund and the new Administration's policy efforts to return responsibility to the States, a real ambiguity exists as to whether the States will actually have a substantive role under CERCLA and what that role will demand.

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RECORDS MANAGEMENT SYSTEMS AS UTILIZED BY THE TEXAS DEPARTMENT OF WATER RESOURCES AND THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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INTRODUCTION

In an effort to effectively deal with the problems posed by uncontrolled hazardous waste sites prior to the implementation of the National Hazardous Waste Management program, the United States Environmental Protection Agency (EPA) developed and implemented the Hazardous Waste Site Enforcement and Response System. Although not specifically mandated by federal legislation, development was based upon regulations and grant provisions issued in conformance with the: (1) Resource Conservation and Recovery Act (RCRA) of 1976, (2) Safe Drinking Water Act of 1974, (3) Federal Water Pollution Control Act of 1972, and (4) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, or "Superfund".

The system was designed for use by regional EPA offices and the states for records management purposes in the identification and screening of potentially hazardous waste sites and in the management of resulting enforcement and remedial actions.[1] To verify the need for such a system, various studies performed for the EPA's Office of Solid Waste indicated that there were between 32,000 and 50,000 hazardous waste dump sites throughout the United States. Few of these sites had been inventoried and the risks posed by them were unknown.[2]

In comparison, the State of Texas also has its share of potentially hazardous waste disposal sites. According to Paul Sweeney in an article in *The Texas Observer*, of the twenty largest chemical corporations in the United States, nineteen have manufacturing operations in Texas. The largest 53 chemical companies have 159 plants in Texas and over half of the nation's manufacturing capacity for the petrochemical industry is located along the upper gulf coast, from the Louisiana border south to Freeport. Additionally, the state's petroleum refineries, utility power generating stations, rubber and tire manufacturing plants and copper and lead smelters also contribute enormous amounts of waste.

During 1978, the Texas chemical industry produced 3.9 million tons of industrial solid waste, which was approximately ten percent of the nation's total. This large quantity places Texas sixth among the states in yearly output of chemical waste.[3] Also in 1978, Texas businesses generated approximately 60 million tons of Class I industrial solid waste;[4] "Class I" is the ranking for the most dangerous of the industrial wastes.[5] Therefore, because of the extensive manufacturing performed in Texas and the resultant massive amounts of waste, Texas has great potential for both reported and unreported hazardous waste problem sites.

In support of the EPA Hazardous Waste Site Enforcement and Response System and related records management system, the State of Texas is currently conducting a statewide Imminent Hazard Survey. The survey of uncontrolled hazardous waste sites encompasses prescribed EPA procedures and decision-making points. Procedural steps are supported by records management forms designed to assure a common vocabulary and procedural standardization relative to the acquisition, recording and reporting of information.

The purpose of the state survey is to assist the EPA in identifying, evaluating and initiating corrective actions at potentially hazardous waste disposal sites which present an imminent hazard to public health and the environment. In this paper, the authors describe the current records management system utilized by the Texas Department of Water Resources and discuss the overall EPA records keeping system as it relates to uncontrolled hazardous waste sites within the state. General background information, system differences, similarities and problems will also be presented.

TEXAS SOLID WASTE MANAGEMENT

Prior to the enactment of the Texas Solid Waste Disposal Act in 1969, there were no effective state regulations governing the disposal of solid wastes. In many cases, waste was dumped indiscriminately without records or environmental safeguards. With the passage of the Act, the 61st Texas Legislature assigned jurisdiction of industrial solid waste management to the Texas Water Quality Board which is now the Texas Department of Water Resources (TDWR). The Texas Department of Health (TDH) was given responsibility for managing municipal solid waste and any industrial solid waste mixed with municipal waste.[6]

The dual jurisdiction over the management of solid waste results in both departments (TDWR and TDH) having authority to carry out the state's Imminent Hazard

Survey of industrial and municipal uncontrolled hazardous waste sites.

IMMINENT HAZARD SURVEY

The state Imminent Hazard Survey which deals with selected uncontrolled industrial hazardous waste sites is conducted by the Enforcement and Field Operations Division of the TDWR. The division maintains thirteen district offices throughout the state (Figure 1) with a combined staff of approximately 22-25 specially trained field personnel. Designated field personnel with backgrounds in biology, chemistry and geology are solely responsible for the acquisition of information on the hazard potential posed by each industrial hazardous waste site evaluated. The evaluation of each site is based upon information obtained from existing files within each district office and by one or more on-site inspections.

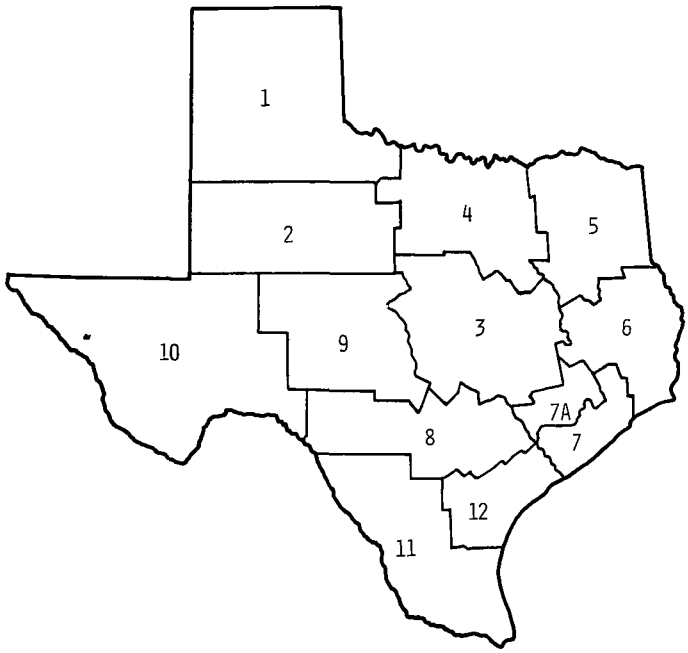

Figure 1.
TDWR District Field Offices

An evaluation, as mentioned throughout this presentation, will refer to the following prescribed sequence of steps or events which must be followed by field personnel according to EPA procedural requirements:

- Identification information is obtained and submitted for all sites (assigned or unassigned)
- A preliminary assessment to determine potential hazard is conducted
- An on-site inspection is performed—depending upon preliminary assessment results
- Disposition in terms of remedial or enforcement measures are determined (optional)
- A final strategy is determined and initiated (district and central office effort)

All acquired information, which includes identification data, is recorded on EPA management forms and submitted to the division's central office. Each form is examined for completeness, reproduced for central office use and originals transmitted to the PEA Region VI office for review and computer input. All forms are completed by district personnel with the exception of the Final Strategy form(s). These are completed by the central office enforcement staff after consulting with district offices and examining all relevant information.

Since commencement of the TDWR Imminent Hazard Survey in December 1979, the number of listed TDWR sites increased from 148 to approximately 290. The increase from 148, initially identified and selected from the Eckhardt list,[7] is attributed to input from the following sources:

- EPA and TDWR Citizen Complaint Program
- Readjustments of assigned sites (TDH, EPA and TDWR)
- The Wapora and Moffett surveys
- Incidental sites (provided by district personnel)
- Aerial reconnaissance activities

The discovery and listing of additional uncontrolled hazardous waste sites is also made possible by centralized coordination of inspections and review of RCRA Open Dump Inventory results. Should inspection results indicate the presence of hazardous waste, the site or facility is subsequently listed for evaluation under the Imminent Hazard Survey.

TDWR RECORDS MANAGEMENT SYSTEM

The unanticipated additional records keeping requirements placed on the initial records management system, by the rapidly increasing number of assignments, resulted in duplication of effort and operational inefficiency. To resolve these problems, changes were designed and initiated to enlarge and improve records keeping and site tracking capabilities and to reduce duplication resulting from assignment confusion. This was accomplished by:

- Replacing the existing index card format used for records keeping purposes with a more flexible data sheet type format (Facility Status Sheet)
- Verifying the list of assigned sites
- By coordinating and directing field activities

Although identical to the EPA Records Management System in terms of content and purpose, the TDWR system differs in data handling and operational procedures. In addition, while EPA records keeping relies on an automated system, the TDWR system is not automated and is based on the use of a facility status sheet (Figure 2) which requires manual input of information and maintenance.

Prior to operational use of the facility status sheet, all sites listed for evaluation by the TDWR were examined for correct assignment. This effort, with assistance provided by the EPA regional office and a contractor (Ecology and Environment, Inc.), resulted in a much more comprehensive and error free listing. The resulting list, distributed to survey participants for comparative purposes, provided a data base for the facility status sheet.

Haz. Site #	Facility Name	Problem	Log	Assessment	Inspection	Disposition	Strategy 1	2	Enforcement Documentation	Misc. Inf.

Figure 2.
Facility Status Sheet

The facility status sheet alphabetically lists all sites assigned to the TDWR for evaluation, provides a site tracking capability and also helps to prevent duplicate evaluations of the same site by TDWR and other survey participants (TDH and EPA). Additionally, the status sheet aids in assigning field evaluations relative to the survey, and provides a ready index to site information of benefit to other division programs and services.

The facility status sheet offers a more up-to-date activity status check capability for site tracking than the EPA computer printout. Recorded information is rapidly updated and new sites can be immediately entered into the TDWR/EPA systems following a check with the EPA regional office to avoid duplicate entries. The amount of time required by the EPA system to generate a computer printout reflecting updated or new site information is usually three to four weeks. Upon request, the facility status sheet can be updated and submitted within 2 to 3 days. Completed management forms submitted to the regional office are accompanied by an updated facility status sheet.

Coordinating and directing field activities to eliminate confusion in the acquisition and recording of appropriate information, and thereby improving efficiency, is accomplished by the use of an assignment worksheet. Each worksheet contains a list of sites to be evaluated within each district and the required management form to be completed and submitted for each entity (Figure 3). Worksheets are distributed to each district on a quarterly basis and the provided guidance assures the proper completion and submittal of information as prescribed by EPA guidelines. Worksheet assignments are determined from the facility status sheet.

As an index to available survey information on file, the facility status sheet often benefits other division business matters. The Citizens Complaint Program (industrial), superfund candidate site selection and enforcement activities draw upon information contained in the site inspection forms for background information, updating, and for general information.

UNCONTROLLED HAZARDOUS WASTE SITE PROGRAM

The EPA uncontrolled hazardous waste site program (officially known as the Hazardous Waste Site Enforcement and Response System), implemented in 1979, has operated under a variety of names throughout the Region VI five state area (Figure 4): (1) the problem sites program, (2) the uncontrolled hazardous waste sites program, (3) the potential hazardous waste sites program and (4) the imminent hazard survey.

The records management system, an integral part of the Hazardous Waste Site Enforcement and Response system, was developed with assistance from the Hazardous

DISTRICT____

FACILITY/SITE NAME	REQUIRED EPA FORM
A-1 Lee Oil - La Porte	Inspection
Associated Properties - Spring	Assessment
Baytown Tunnel Site Houston	Assessment
Bryan Mound Tar Pits - Freeport	Inspection
Church Road Site - Houston	Inspection
Acme Disposal Service - Deer Park	Inspection
Gulf Coast Disposal - Baytown	Assessment
Hall Street Site - Dickinson	Assessment
Jefferson Chemical - Austin	Inspection
Nine Bar Ranch - El Paso	Assessment

Figure 3.
TDWR Assignment Worksheet

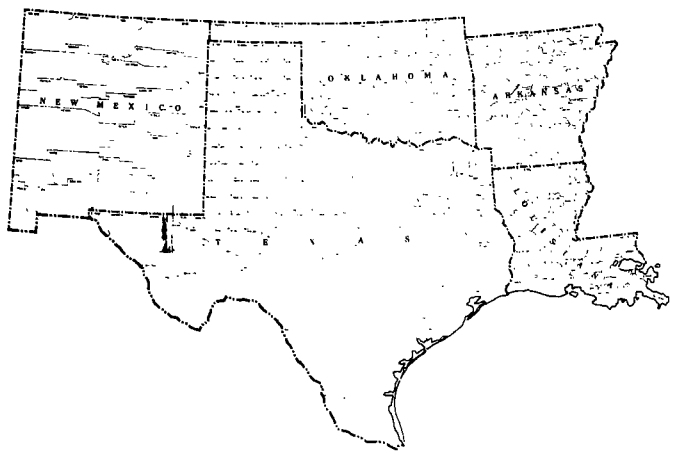

Figure 4.
EPA Region VI

Waste Enforcement Task Force (now known as the Office of Waste Programs Enforcement), EPA Oil and Special Materials Control Division, National Enforcement Investigations Center, and the EPA regional offices.[8]

The system, as currently used in Region VI, involves the continuous compilation and computer input of information received from the states on uncontrolled hazardous waste sites. Information submitted by the various states to the regional office is conveyed via Hazardous Waste Site Enforcement and Response System management forms. These forms consist of:

(1) the potential hazardous waste site identification form
(2) the preliminary assessment
(3) the site inspection report
(4) the tentative disposition
(5) the final strategy determination form[9]

Each potential site identified and tracked by the computerized records keeping system requires the completion and input of every management form. This requirement, though not always timely, allows for the complete evaluation of every listed site.

Of particular concern to Region VI records keeping activities is the problem stemming from the dual jurisdiction in the State of Texas over waste management. As previously mentioned, the TDWR is authorized the management of industrial solid waste and the TDH, the management of municipal wastes. Although Region VI deals with both Texas state waste management authorities, the greater amount of communication is with the TDWR. This is due to the fact that the TDWR retains authority over most of the uncontrolled hazardous waste sites in Texas, and has consequently been assigned a greater percentage of sites for evaluation.

The uncontrolled hazardous waste sites records management system in Region VI began with approximately 467 listed potential sites of which 259 were in Texas alone. The ratio of Texas sites to the number of sites in the region has remained somewhat constant since initial implementation of the records management system (Figure 5). There are currently 1,600 potential uncontrolled hazardous waste sites listed in the Region VI five state area with approximately 700 assigned to the State of Texas.

A major portion of the initial group of listed sites in Region VI were derived from the Eckhardt Subcommittee listing. Originally listed were 542 sites in the region; the number was reduced to 425 after duplicate listings and other discrepancies were eliminated.

The Eckhardt Subcommittee listing represented the results of a survey dealing with the process waste disposal practices (since 1950) of the 53 largest chemical companies in the United States.[10] Survey results were made available to the EPA, and the sites identified in Region VI were incorporated into the records management system. Additional sources of information from which sites were added to the list included the Wapora listing, citizens complaints, and EPA, state or "other" entity identification.

Information on newly found uncontrolled sites is submitted on the potential hazardous waste site forms. Each potential waste site is assigned its own identifying hazardous site number (HAZSIT) and the information is then entered on computer coding sheets. This procedure allows for periodic updates of the computer listing of uncon-

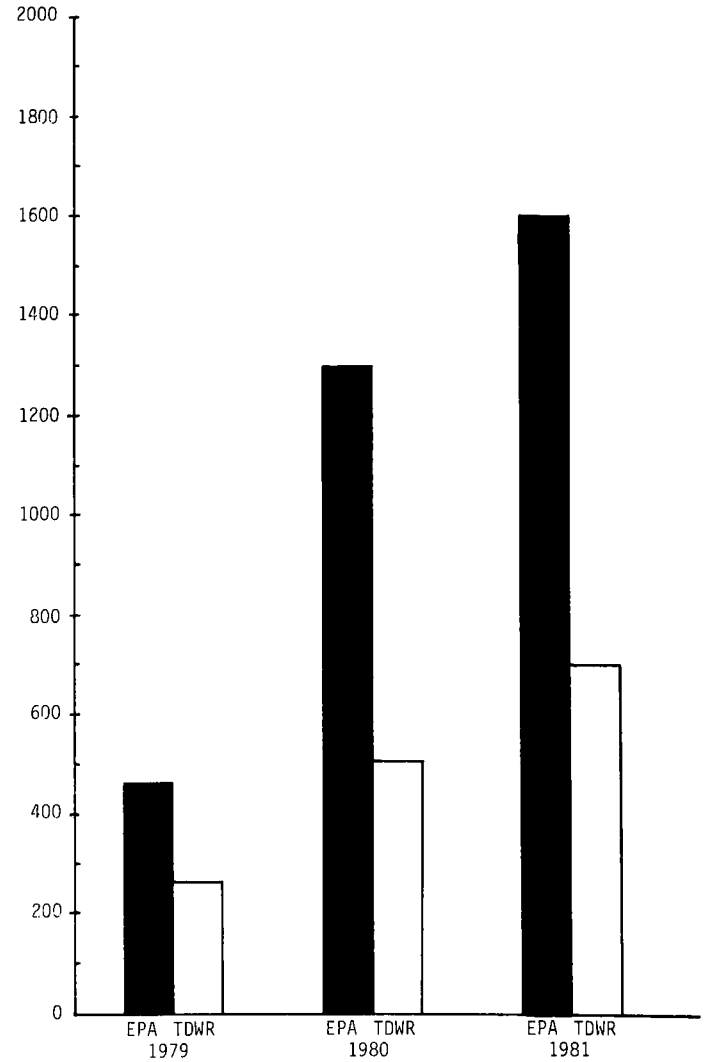

Figure 5.
Ratio of Texas Sites to EPA Sites

trolled hazardous waste sites. This practice was initially for the benefit of the Enforcement Division's Hazardous Materials Enforcement Section and as the number of potential uncontrolled waste sites in Texas increased, the amount of incoming information did also. The increase in site information led to a need for greater Agency accountability for its own, as well as the state's purposes. As a result, the Region's Hazardous Materials Enforcement Section decided that the incoming state site-related data should be shared with the states, and a computer program designed to generate current information for each site was developed.

Computer output includes the identifying hazardous site number, site name and location, actual dates of completion for preliminary assessments, site inspections, tentative dispositions, and final strategy determinations, as well as other pertinent site-specific information. This listing could reveal, upon quick examination, the status of the site investigation, the degree of hazard at the site, as well as how the site had been originally identified (Figure 6).

Site Assignment

In order that all sites identified could be properly evaluated, a certain number of sites were assigned to each responsible agency: The EPA, the TDWR, and the TDH. Assignments were based upon differing jurisdictions each respective state agency had over various waste types (as previously noted). The EPA was assigned federal facilities, sites which the Agency had already begun work on, and cases that the state felt could prove to be too politically volatile to pursue. From this point, sites were added to or taken from each specific agency's designated list of sites until all the uncontrolled hazardous waste sites had been assigned and all agencies involved were satisfied with the site designations.

Of particular concern to listing procedures was the problem dealing with the reporting (citizen complaint) of the same site to both the state and EPA. For example, a citizen complaint could be called in to the Dallas EPA office, the information recorded on a potential hazardous waste site form, and the site information entered into the records management system. If the site had no readily available information, the contract team for EPA sites investigation (Ecology and Environment, Inc.) would schedule a reconnaissance (fact-finding) inspection at the site. A great deal of confusion ensued in the event that the state had received the same complaint, TDWR would likewise schedule a site inspection. In some cases, visits to the same site by the two agencies would be separated by only one week.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
HAZSIT SYSTEM -- 24
HAZSIT SITES SORTED BY STATE/SITE NAME

HAZSIT	SITE NAME LOCATION	ENF ENG	SOURCE OF SITE IDENT.	STRAT CODE	SERIOUS CODE	PRELIM ASSESS DATE	RECON INSPEC DATE	SAMPL INSPEC DATE	TENT DISPO DATE	FINAL DISPO DATE
TX02526	A-1 Garbage Disp. Trash SV San Antonio	RWB		TDH						
TX02534	A-1 Lee Oil SVC, Inc. La Porte	RWB	STA	TDWR	M	3/4/81				
TX04545	AAA Wire Prod., Inc. Point	LDW	CIT	EPA	M	3/21/80		3/27/80	9/5/80	9/5/80
TX04812	ABC Exterminating Co. Beaumont	RWB	EPA	EPA	N	1/21/81				
TX06491	ACF Indus., Inc. Shippers Car Line Division Longview	RWB	STA	TDWR	M	9/29/80				
TX04804	Acock Lab., LTD Austin	RWB		EPA						
TX02542	Addiks Fairbk R S Co. Houston	RWB		TDH						
TX05428	Aerial Survey By Toler Mineral Wells	RWB	CIT	EPA	L	10/16/80			12/3/80	12/3/80

Figure 6.
EPA Computer Output Listing

In order to prevent this unnecessary duplication of agency efforts, a system to screen all citizen complaints referred to the agencies was established. Whenever a complaint reaches the EPA office, the TDWR contact person is called and if the complaint is initially made with the TDWR, the EPA contact is called. In this way, any available site information is shared between the agencies. If the state office is in the process of evaluating the site, the "lead" on the site is assigned to TDWR for the completion of site investigation activities. If, however, the EPA office had previously begun work on the complainant's site, the site would be placed on the Agency's sites listing for additional investigation. The development of this sites assignment system kept agency effort duplication from recurring. Communication with the TDWR is enchanced, and much valuable knowledge concerning uncontrolled hazardous waste sites complaints in Texas is exchanged.

Submittal and Review of Management Forms

Uncontrolled hazardous waste sites tracking information submitted by the State of Texas was at first sent through the Region's Air and Hazardous Materials Division (Solid Waste Branch) before being sent to the Enforcement Division for review. The purpose of this was to assure that the TDWR could account for the number of sites the agency was committed to evaluate and inspect in its RCRA grant provisions. The forms were mailed to the Texas RCRA project officer, then were forwarded to the Hazardous Materials Enforcement Section of the Enforcement Division for review and input into the system. The preliminary assessments, tentative dispositions and final strategy determinations completed by the state and by the EPA contract team were evaluated for completeness and coherency by the Section's engineers.

Those records management forms completed by Ecology and Environment Inc. that were lacking information were returned to the Region's Surveillance and Analysis Division for referral and additional input from the Ecology and Environment personnel. Those forms completed by the state that did not contain sufficient information to make a valid site determination were returned to the state through the Solid Waste Branch (again, for record-keeping purposes). This method of site forms transmittal was inefficient, and at times, very slow.

The Texas RCRA project officer was contacted by the TDWR and by the Hazardous Materials Enforcement Section's contact persons to discuss a new technique for forms submittal. They agreed that the incoming uncontrolled hazardous waste sites forms would be mailed directly to the section responsible for their review, with a copy of the accompanying letter stating the amount of site work performed simultaneously forwarded to the Texas RCRA project officer.

All completed inspection reports are reviewed by the Region's Surveillance and Analysis Division and are directed to the Enforcement Division for any necessary action. It is at this point when the decision is made to either pursue enforcement action, remedial action or to take no action at the site in question. This judgment is based upon results of samples taken at the site, as well as past regulatory actions and the actual situation of the site (i.e., geologic and hydrologic considerations, proximity to population, etc.).

If enforcement action is to be taken at the site, the action is initiated after the completion of a tentative disposition (either by the state or EPA) indicating that decision. The file information included in the records management system is considered during the construction of a Case Development Plan (CDP).

The CDP is a guide used by the Agency in pursuit of enforcement action to assure the collection of information and interpretative analysis for use during anticipated enforcement proceedings.[11] In order for a valid site determination to be made, all of the system's management forms have to be fully and correctly completed. The records management system's reason for existence is to provide the basis from which these site determinations can be derived and then pursued.

ADDITIONAL USES FOR HAZARDOUS SITES INFORMATION

The need for accuracy in the records management tracking system can be substantiated by the utilization of the system by the RCRA Permits program, as well as the "Superfund" program. The uncontrolled hazardous waste sites program has provided information to the RCRA program before that system was able to generate its own data base.

It is thought that those sites that are not included in the RCRA Permits program would fall under the purview of the Superfund. Although the CERCLA will be more selective in its use of information made available by the records management system, the information involving the site's consideration for remedial aid must be accurate and of sufficient value for use in the immediate future.

CONCLUSION

The future for the uncontrolled hazardous waste sites program, at best, appears uncertain. The program was ranked fourth (and lowest) priority for the state RCRA Hazardous Waste Programs by EPA guidance for fiscal year 1982 RCRA grants. Regardless of the fact that the number of uncontrolled hazardous waste sites increased nationwide over a one year period (from December 31, 1979 through December 31, 1980) from 4,098 to 8,677, it appears as though Superfund allocations alone will be forced to provide resources for continuing site investigation and evaluation. The information base established by the uncontrolled hazardous waste sites program records management system has been utilized by at least two ongoing EPA programs and may also be used to determine EPA resources necessary to carry out the future cleanup and enforcement activities at these sites.

Despite additional funding provided by the Superfund, the amount of support available for the investigation of increasing numbers of uncontrolled hazardous waste sites

is unknown. The CERCLA called for the revision of the National Contingency Plan (pursuant to section 311 of the FWPCA), a segment of which includes a National Hazardous Substances Response Plan. The plan would encompass, among other things: methods for discovery and investigation of facilities, methods for evaluation and remedy of releases from facilities, methods and criteria for determining the appropriate extent of response measures and criteria for prioritization among releases for remedial actions at sites.[12] Not until this plan is released, however, will the impact of Superfund resources upon the uncontrolled hazardous waste sites program be determined.

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THE CALIFORNIA SUPERFUND

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INTRODUCTION

California has just passed the most comprehensive progressive superfund legislation in the country. The California legislation provides for victims' compensation, for reimbursing local agencies for their costs and for cleaning up California problems well beyond what the federal superfund might pay for. Ironically, after a great struggle, the legislation that was passed was that sponsored by industry, not by government or environmentalists. It is therefore all the more noteworthy that the $100 million the fund will receive over the next ten years is entirely from industry-paid fees on hazardous waste disposal.

The spectre of abandoned hazardous waste dumps and toxic spills now haunt the people of this country. The possibility of discovering hidden buried wastes or of being assaulted by the contents of an overturned truck a mile away is real, based on a feeling of powerlessness and of being violated by unknown sources. In many ways, the outrage expressed by many citizens is akin to that accompanying the fear of burglary and other crime. Despite the fact that occupational exposures remain the number one toxic substances problem throughout the world, including California, spills and abandoned hazardous waste dumps remain the top political priority because they affect a broader socioeconomic range of citizens and appear to be a less expected hazard. Because the California experience with this problem appears similar to that of many other states, it may be useful to review the history and details of California's new superfund legislation.

BACKGROUND OF THE CALIFORNIA SUPERFUND

California is one of the largest users of hazardous materials and producers of hazardous wastes in the country. Since the advent of the Brown Administration, California has acquired a reputation for having the best hazardous waste control program in the country. The Resource Conservation and Recovery Act is patterned principally on California legislation, including the cradle-to-grave concept of tracking wastes. Because California industrialized later than the northeast and has long used relatively stringent regulatory controls, the state has not been subject to the same historical horror stories as some eastern states.

However, as Congress studied abandoned waste sites as a prelude to enacting federal superfund, California took similar action to search out abandoned and uncontrolled waste sites. After surveying a small number of counties with heavy industry, constituting perhaps one-third of the state's hazardous waste problem, state researchers surprisingly found 67 sites which needed attention because of their potential for adverse affects on public health or the environment. Some of these sites required costly remedial measures. For example, the General Electric site in Oakland, with a deep pool of PCB's under the ground, will cost as much as $30 to $60 million to clean up.

Altogether, it was estimated that the clean up of the 67 sites found so far would cost up to $330 million. More significantly, the state found that at 19 of these sites, whose total estimated cleanup cost was $57 million, it was doubtful that those liable for the problem would have sufficient resources to clean up.

The sheer number of these sites, combined with substantial publicity about a few problem sites in Southern California, generated substantial concern regarding the adequacy of the federal superfund to clean up these sites. The location and distribution of these problems also played a role in generating widespread concern.

The Stringfellow Quarry, located in a quasi-rural area near Los Angeles, had long been thought to be California's one major problem. However, during the fall of 1980, it became apparent that upper middle class residents in the conservative Republican suburb of Fullerton were profoundly upset by the odors emanating from the McColl dump site, which was literally in their backyards. A massive state investigation showed that residents suffered nausea, headaches and other similar acute symptons, but that the amount of hazardous constituents polluting the air from the dump site were so minor as to render proof of chronic harm very difficult. Despite the inability of scientists to prove the risks involved, the articulate residents of the community continued to press their case for removal or other elimination of the hazard.

At the same time, residents near a dump site in the congressional district of Barry Goldwater, Jr. were similarly upset, eventually causing the closure of the dump site near them due to earthquake concern. And, in the inner city near East Los Angeles, one irresponsible waste disposer was shut down in a flurry of litigation and another abandoned site of 18,000 drums was discovered.

The abandoned site, in the small industrial city of Santa Fe Springs, eventually exploded, and the resultant effluent in the flood channel killed over 250,000 fish in the Pacific Ocean near Los Angeles.

While these well publicized stories occupied the media, local governments were increasingly concerned about the high cost of responding to emergencies involving highway spills, industrial fires and other toxic chemical emergencies. Data from one small department of environmental health in a relatively less populated county (San Bernardino) showed expenditures of $33,000 in a nine month period for personnel and laboratory costs. The costs of fire fighting and law enforcement agencies were substantially higher.

POLITICAL HISTORY

Responding to the problems at Stringfellow, McColl, and the many emergency spill sites in the state, the Brown Administration in February of 1981 prepared draft legislation which was later introduced by state Senator Presley as SB 788.

As originally drafted, SB 788 would have provided a fund of up to $35 million through a tax structure identical to that of the federal superfund. Among other features, the bill declared that the generation, transportation and disposal of hazardous wastes is an ultra hazardous activity, thereby creating a standard of strict and absolute liability for all releases.

Industry was alarmed by the draft of SB 788, and immediately introduced its own bill, SB 618. SB 618 called for 100% general fund contributions by the state to match its federal superfund obligations. The bill provided for no other authority or expenditures.

After both bills passed out of their first policy committee, aborted attempts were made to work out a compromise. Intent on pushing its own bill, the petrochemical industry then began a long process of amending SB 618. Interaction between industry and the Governor's Office, with occasional input from environmentalists and local government, eventually produced SB 618 as an acceptable compromise for cleaning up California problems.

The eventual compromise reflects most of the provisions originally contained in the Administration's SB 788, with one notable exception. Industry was successful in insisting that no new standards of liability be enacted and that reliance instead be placed on existing standards of liability, such as those contained in Section 107 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, (42 USC Sec. 9601), or various provisions of state law.

THE CALIFORNIA HAZARDOUS SUBSTANCE ACCOUNT ACT

Tax Structure and Funding

The Act, which is effective immediately, appropriates $2 million to a new hazardous substance account, which is to be administered by the Director of the State Department of Health Services (Health and Safety Code Sec. 25330[1]), subject to overall site response coordination by the Governor (Sec. 25355).

The total tax imposed by the Act is equal to $10 million per year, minus the existing unobligated balance in the account as of a specified date. The Board of Equalization sets the tax rate, according to the following formula, to raise that amount of money. The tax rate is as follows:

$$\text{Base tax rate} = \frac{\$10{,}000{,}000\text{-}M}{(0.15W_1 + W_2 + 2W_3 + 0.01W_4)}$$

where:

(1) "M" is the existing unobligated balance in the fund on December 31 of the immediately preceding year.

(2) W_1 is the total amount in tons of waste and material disposed of in California, the federal regulation of which has been suspended under the Resource Conservation and Recovery Act (RCRA), plus the total amount of waste and material on a total net weight basis which has been transferred to a surface impoundment for purposes of reducing the water content by evaporation.

(3) W_2 is the total amount of hazardous waste disposed of in the state which is also regulated by RCRA.

(4) W_3 is the total amount of extremely hazardous waste disposed of in the state, which is also regulated by RCRA and is declared extremely hazardous by Department of Health Services regulation.

(5) W_4 is the total amount of hazardous or extremely hazardous mining wastes.

The Board of Equalization is provided this information by reports filed by all generators of such waste by March 1 of each year (Sec. 25342). Failure to file the report results in liability of $500 per day, and $25,000 per day for a knowing violation.

This rather complex tax structure was worked out among different industry groups. Alternatives included a graduated tax by waste volume, different rates for on and off site disposal and equal treatment for mining wastes and surface impoundments. However, the Administration took the position that its principal interest was in raising the necessary funds, not in determining the allocation of the tax among different industries.

Similarly, although the Administration originally proposed taxing feedstocks, it saw no impediment to taxing the wastes themselves. Industry asserted that a waste tax would provide an incentive for recycling and opponents asserted that a waste tax would provide incentive for midnight dumping. After some analysis, California decided that a waste tax would not create a large marginal increase in the cost of disposal, so that incentives for either activity were likely to be small.

Coverage

The California Act generally covers releases as defined in federal superfund. Releases of hazardous waste are

more broadly defined because of generally broader state regulation of such wastes. For example, geothermal materials and drilling muds are both regulated by the state, but not by RCRA.

On the other hand, the California Act excludes certain storm water drained into sewers, ash produced by a resource recovery facility utilizing a municipal solid waste stream, and the "normal application of fertilizer, plant growth regulant, and pesticides." (Secs. 25317 and 25321). The storm water exception is taken from the exceptions to reporting requirements for the State Water Resources Control Board, and should not prove to be any problem.

It is not clear whether the "normal" application of pesticides refers to application in accordance with statutes or custom. What is clear is that the state Act, in sharp contrast to the federal Act (Sec. 107(i)), excludes such pesticide applications from any response authority, instead of simply excluding such applications from liability.

Expenditures

Sections 25351 and 25352 of the Act provide for the following types of uses of the state account:

(1) Costs of administering the Act
(2) The state's share as determined in any cooperative agreement under the federal fund (42 USC 9604(c)(3))
(3) Purchase by a state or local agency of hazardous substance response equipment or other costs of preparing for responses to releases
(4) Reimbursement of all costs of remedial and removal action incurred by the state or (with approval of the Director) any local agency, in response to a release or threatened release
(5) Costs of health effects studies or costs of cooperation with the Toxic Substances Disease Registry established pursuant to Sec. 104(i) of the federal Act, up to $500,000 per year
(6) Costs of natural resources restoration, rehabilitation and replacement, except where the injury was already specified in an environmental impact statement, as set forth similarly in the federal Act

The Act contains relatively few limitations on this expenditure authority. Expenditure for natural resources restoration is the most encumbered, requiring consideration of processes of natural rehabilitation, restoration and replacement, limiting the state to act on behalf of the public as trustee of such natural resources and precluding funds for natural resources purposes where the damages occurred prior to the Act (Sec. 25353).

The Act also prohibits the usage of funds for remedial action with respect to facilities owned or operated by government entity at the time of disposal but only to the extent that the government entity would otherwise be liable for such costs (Sec. 25353). It would appear that such liability would be predicated on proprietary rather than regulatory action or inaction, given broad grants of sovereign immunity from liability otherwise contained in California Government Code Secs. 815 et seq.

The one provision that is not contained in the California Act that was originally proposed by the Administration is authorization to use some portion of the account to set up a center at the University of California to perform research regarding alternatives to landfill disposal of wastes, the development of safer substitutes for toxic materials, and expanded toxicological and epidemiological studies regarding hazardous substances. The author of the bill and its sponsors indicated their willingness to set up such a center but their unwillingness to do so with fees from industrial disposal of wastes. It is hoped that this subject can be addressed in greater detail next year.

Procedural limitations are placed on the expenditure of funds from the account. Action may not be initiated until the Director determines that action will not be taken properly or in a timely fashion by any responsible party (Sec. 25355). This provision clearly balances the need for prompt and effective action against the similarly clear need to assure responsible cleanup by responsible parties wherever possible.

Industry spokespersons also evinced a strong desire to have state priorities coordinated with those of the federal government through the National Contingency Plan (see Sec. 105(8)) of the federal Act, (42 USC Sec. 9605 (8)). However, it was clear that the federal Plan would not reach the same priorities for California as California might reach itself and that the federal Plan would certainly not call for remedial or removal action for the same number of sites as called for in California.

Early drafts of the Plan also raised grave concern over the ranking system used for such prioritization. The ranking system appeared to emphasize groundwater and other concerns and to give too little emphasis to potential fire and explosion hazards and to the potential for direct public contact and health effects stemming from contact with the site.

The state's experience at the General Disposal site at Santa Fe Springs bore out this assessment, where the explosion of 15,000 drums caused the immediate destruction of 250,000 fish and the inundation of a broad area with toxic debris. As a result, the site ranking system called for by the Act requires only that the Department take into account the criteria established in the National Contingency Plan as well as pertinent factors related to substantial protection of public health and environment (Sec. 25356).

Where expenditure of funds will be made pursuant to a cooperative agreement, or otherwise pursuant to the federal Act, costs are reimbursed only insofar as they are consistent with the regulations and guidelines contained in the National Contingency Plan. However, for response actions taken pursuant to the state Act only, costs will be allowed to the extent that the state's program is consistent "to the maximum extent possible" with the National Plan (Sec. 25350). This language, when interpreted in harmony with Sec. 25356, will allow California to determine its own needs while assuring maximum consistency with federal edfforts.

Finally, the Act provides for an appropriation of $1 million per year to take immediate corrective action to respond to substantial dangers to public health and the environment. To facilitate emergency response, the De-

partment is empowered to enter into oral and written contract without previous approval from the Department of General Services, subject to prompt reporting to the Department of Finance and the Legislature. It is anticipated that substantial funds from the immediate $2 million loan to the account will be used for this purpose.

Liability and Apportionment of Damages

As a result of negotiated compromise, the Act no where provides any standard of liability for releases of hazardous substances. In a letter to one legislator, the President of the California Manufacturers Association stated that no such statement was needed because strict liability is already the rule in California.

Students of California law believe that the standard of liability may vary depending on the circumstance. Statutory liability is predicated more on non-reporting and negligence theories, except that it would appear that disposers are strictly liable for discharges to surface or groundwater that is not permitted. As a result of this crazyquilt of liability standards at the state level, it is expected that the standards contained in CERCLA (Sec. 107) will be utilized fully by the state in enforcing its own Act. There is ample precedent for enforcing federal standards of behavior in state court.

The Act itself requires recovery from any "liable person or persons" (Sec. 25360). Liable parties are also liable to the Department for administrative costs in an amount equal to 10% of the damages.

Because it is the Department that recovers monies and does so only when costs are payable from the state account, the state account is a party in any action for recovery under the Act (Sec. 25361).

Because the funding mechanism creates what is tantamount to a pooled insurance fund on the part of industry, industry sought and obtained agreement to set up an apportionment system for liable parties. Any party that can prove by a preponderance of the evidence that only a portion of the damages are attributable to his or her actions is entitled to apportionment. If the evidence is insufficient to establish such apportionment by a preponderance of the evidence, the Act directs the court to "apportion such costs or expenditures, to the extent practicable, according to equitable principles..." (Sec. 26363). California law already provides that where an injury is indivisible in practice, even if divisible in theory, that apportionment does not take place.

The state expressed substantial concern that the provisions of the Act permitting joinder of interested parties in apportionment of damages would bar the state from going after other parties who were later discovered to have been responsible for damages, and for whom the state fund paid because of apportionment with regard to the other parties. As a result, Sec. 25365 provides that no judgment shall bar the state from later prosecuting the responsible parties. The Act also provides that the apportionment provisions in the bill do not affect any other common law or statutory remedy. The apportionment provision affects only actions by the fund for recovery of payments made from this industry-created account. Efforts by some members of the oil industry to broaden the apportionment provisions to other areas of tort law were defeated.

Finally, the Act exempts from liability federally-permitted releases, congruent with the federal Act and also exempts state-permitted releases from liability. State-permitted releases are defined more broadly than federally-permitted releases, exempting releases that are allowed by any specific permit, license, or similar authorization, including recognition of a standard industry practice by the permitting agency. Industry sought an even broader exemption, arguing that an "implied" recognition of an industry practice should lead to exemption. This industry effort was unsuccessful.

Compensation of Victims

One of the principal failings of the federal superfund is that it cleans up dirt but not people. California informed industry spokespersons early on that it would demand a provision for compensation of victims as part of a California superfund. Industry feared that the compensation provisions could use the entire amount of funding, without ensuring cleanup. The result was a compromise. The Act allows up to $2 million each year of the $10 million to be used for compensation purposes (Sec. 25381).

A party who has sustained out-of-pocket medical expenses or lost income or wages as a result of exposure to a release of a toxic substance may obtain compensation for 100% of those medical expenses for three years and 80% of wages or business income, up to $15,000 per year, for three years.

The injured party must file a claim with the California Board of Control, which administers a similar program for victims of violent crime. The victim must prove by the weight of the evidence that the proximate cause of his or her injury was the release (Sec. 25375).

The conditions of compensation exist when the person cannot identify the party liable for the injury, the source cannot be determined with reasonable diligence, the judgment against a liable party cannot be satisfied, or there is no liable party. The injured parties must describe the release and their physical injury or illness or loss. They must also furnish information regarding their last five years of residence and medical history, and figures regarding their last three years of income if such expenses are claimed. A written decision is to be rendered within 90 days.

Claims are compensable if they are filed within three years from the date of discovery. This administrative remedy need not be pursued before filing any court action. Double recovery in court and through the Board of Control is barred. Any determination made before the Board of Control is inadmissible in a judicial action.

A major omission from the compensation provision is the right of a party of obtain out-of-pocket medical expenses or lost income from an allegedly liable party, pending resolution of legal action. The Administration suggested that persons be allowed to make such claims after submitting a demand to an allegedly liable party and not

having that demand satisfied within 60 to 90 days. The Administration reasons:

(1) indigent and disabled people need that compensation,
(2) persons who do not know the identity of the source of the release should not be in a better position to make a claim than those who do know.

Rewarding the ignorant can deprive the fund itself of valuable witnesses in a later subrogation action. (The fund is subrogated to all claims and rights that the injured party has, with regard to claims paid under the fund (Sec. 25380).) In short, the current limitation on the ability to obtain compensation may be both short-sighted as well as hardhearted. It is hoped that cleanup legislation next year can address this problem.

SUNSET

The California superfund will disappear in 1991, five years after a similar demise for the federal Act. Industry strongly advocated a five year sunset provision. However, the Administration was able to argue successfully in committee that a ten year sunset clause was the least that would be needed to clean up California's subsequent problems.

California's superfund legislation is an important step forward in the control and eradication of hazards resulting from irresponsible disposal of hazardous waste. The State looks forward to cleaning up past mistakes. However, the State is ever mindful that the most important element of any government program in this area is prevention. To that end the State must provide strong enforcement of hazardous waste regulations, responsible siting decisions, and the facilitation of alternative waste disposal and waste reduction strategies.

REFERENCES

1. Unless otherwise specified, all section references are to the Health and Safety Code.

THE PENNSYLVANIA APPROACH TO UNCONTROLLED SITES

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INTRODUCTION

Pennsylvania is estimated to be the fourth largest generator of hazardous wastes in the United States. It currently has no sites that are legally able to accept hazardous wastes, although a number of licensed solid waste facilities accept a small amount of specific wastes. As a result of past disposal practices, the number of uncontrolled sites in Pennsylvania is estimated to be as high as 400, although some of these may not prove to be hazardous when evaluated.

Current state policy is to clean up orphaned sites where they present imminent hazard and to establish a state hazardous waste management plan that will provide a framework for the orderly handling of these wastes. However, uncontrolled sites will continue to be a serious problem until new disposal sites are established. Therefore, the issue of siting is integral to solving the problem of orphaned sites.

LEGAL BASIS

Legislation for the state to assume primacy in regulation of hazardous waste management was passed in the Solid Waste Management Act of 1980 (Act 97). This legislation provides for the planning and regulation of solid waste storage, collection, transportation, processing, treatment and disposal, provides for the regulation of hazardous wastes, establishes permit requirements for operating hazardous waste management facilities, as well as requiring licenses for the transportation of hazardous wastes.

A unique portion of this legislation is the provision for override of local zoning by the issuance of a "certificate of public necessity" by the Pennsylvania Environmental Quality Board to a treatment or disposal facility which has:

(1) Obtained all necessary permits
(2) Is in conformance with the Pennsylvania Hazardous Waste Facilities Plan
(3) Has satisfied the Environmental Quality Board regarding:
   a. Identification and mitigation of the impact upon adjacent populated areas and areas through which waste is transported
   b. Identification and mitigation of the impact on the municipality in which it is to be located in terms of health, safety, cost and consistency of local planning
   c. Participation in a community relations program in which the citizens have had a meaningful opportunity to participate in all phases of the site selection process

Includes in the legislation is the requirement for the Pennsylvania Department of Environmental Resources (DER) through, and with the assistance of, the Hazardous Waste Facilities Planning Advisory Committee, to develop preliminary environmental, social and economic criteria for the siting of hazardous waste facilities. The law required these criteria to be published within six months of the passage of the Act. It also required the development of a hazardous waste management plan within two years.

The criteria were developed upon a three tier concept. Level 1 criteria are exclusionary for the location of a hazardous waste treatment or disposal facility. In this area are such exclusions as coastal flood hazard areas, coastal wetlands, water supply watersheds, wilderness scenic areas and historic sites. In Levels 2 and 3, criteria were developed to indicate factors that would be positive, cautionary or negative (exclusionary) and require in depth evaluation addressing the appropriate environmental, social and economic concerns.

In June and July of 1981 a series of public meetings were held by the Advisory Committee to provide for public input. Final criteria are scheduled to be published in October.

INTERACTION WITH SUPERFUND

The Remedial Action Program instituted under the Federal Comprehensive Emergency Response, Contingency and Liability Act (CERCLA or Superfund) has been implemented. Seventeen sites in the United States have been identified for the first remedial action engineering studies to identify a feasible alternative and design the clean-up program for these sites.

The sites were selected by a screening process developed by EPA. The states worked together to identify the highest priority sites and to characterize the sites according to their potential for environmental harm. One of the 17

sites is located in the Commonwealth of Pennsylvania at Bruin Borough, 60 miles north of Pittsburgh.

The Pennsylvania site is known as Bruin Lagoon. It is an abandoned lagoon site that has been the recipient of various wastes from the 1930s through 1980. The wastes that were deposited there included petroleum refining wastes, crankcase oil reclamation waste (acid clay sludges) and coal washing residues.

The toxic nature of the lagoon contents was shown in 1968 when sludge and supernatent were spilled into Bear Creek, a tributary of the Allegheny River. The results of this 3,000 gal spill were a fish kill of 4,000,000 fish and visible foaming of Bear Creek and the Allegheny River for 200 miles downstream.

The site is perched above Bear Creek and is retained by manmade dikes. The remedial actions to be studied will focus on feasible and implementable alternatives for both on-site and off-site management of these wastes.

The state, Federal and contractor interrelationships that must be established in this program are critical to its successful implementation. For the Bruin Lagoon project, a management structure has been built between EPA, DER and the engineering services contractor to assure accurate, continuous communication; to define roles and responsibilities of the parties; and to enhance the ability of the selected alternative to be implemented in a timely fashion.

For Superfund, there is a project officer located in EPA Headquarters in Washington. This person manages the technical aspects of the contract from EPA's prospective. A Project Monitor has been assigned within EPA Region III, Division of Surveillance and Analysis, Environmental Emergency Branch to act as a local contact with DER and the contractor. The Project Monitor's responsibilities include resolving logistical problems, providing input to the work plan and evaluating and selecting the remedial action alternative in coordination with DER.

DER has identified a Project Manager who is the regional solid waste manager in the Pittsburgh Regional Office to perform the same functions as the EPA Project Monitor, only at the state level. The Project Manager was selected based on his knowledge of the specific problem at hand.

The Contractor is responsible for preparing and implementing the work plan so that the most cost effective, reliable and feasible alternatives are evaluated. After evaluation, the feasibility study is presented to EPA and DER for the selection of the remedial cleanup action. After selection of the remedial action alternative, the contractor then finalizes the engineering services tasks by developing an implementation plan, plans and specifications and bidding documents for the implementation of the chosen remedial cleanup alternative.

The Superfund Remedial Action projects are action-oriented. The engineering services, from project initiation, data analysis and data collection through preparation of a bid package, is scheduled to take 27 weeks or less. This time frame will limit the number and type of cleanup alternatives that will be analyzed. This restriction may tend to skew the alternatives selected to "procurement"-oriented programs where technologies or bidders may be pre-selected to enhance the feasibility or implementability of any chosen alternative. This type of approach puts emphasis on proper characterization of the quantity and quality of the material in the lagoon. Further, adequate characterization must be conducted so that various manners or techniques for management can be accurately and cost-effectively bid by prospective contractors.

The first remedial action cleanup in Pennsylvania is very important to the state. There are many abandoned or orphaned sites that must be cleaned up. This project will serve as a learning program and model for future activities. Superfund cannot pay for all of these; however, the most serious imminent hazards can be addressed and resolved all under this program.

TRAINING

In order to achieve the goals of the state hazardous waste management program, it is necessary to develop a staff of individuals trained and sensitive to the problems in managing hazardous wastes. A number of recent incidents have indicated that the specialized training and equipment required to inspect and evaluate sites is presently lacking.

DER has outfitted a response trailer containing all necessary protective equipment from self-contained breathing apparatus to completely enclosed suits. The trailer will also have analytical monitoring equipment required to assess sites.

However, trained personnel are needed to utilize this equipment. The type of training envisioned varies from brief seminars for DER management to intensive courses for staff members who will actually go to the site. The management seminars are intended to sensitize senior staff to the health and safety problems to which their employees may be exposed and the Department's liability for such exposure. This program should provide the knowledge and skills required to safely and efficiently handle most situations that are likely to be encountered in the field.

The people who inspect uncontrolled sites require specific training including the use of safety and monitoring equipment, background instruction in toxicology, first aid and legal procedures for maintaining an unbroken evidence chain for samples. The Department is currently reviewing methods to provide the required training. However, the staff time and funds needed to implement this extensive training program are not currently available.

PUBLIC PARTICIPATION

In Pennsylvania as in other states the emotional opposition to hazardous wastes is intense. As an example, at one public hearing on a permit, opponents of sites throughout the state converged upon the hearing location in buses and approximately 2,000 people greeted the state's representatives.

In order to develop an acceptable siting policy for all affected parties, roundtable discussions with two representatives from each of 20 groups opposing specific sites in their communities were initiated. The goal is to develop acceptable methods of siting facilities. The roundtable has met four times, twice in 1980 and twice in 1981.

As might be expected, initial meetings of the roundtable concentrated on individual concerns of their local municipalities problems. The group ultimately did discuss three items of prime concern to the participants, namely:

1. Why locate a facility in "our" community?
2. State-of-the-art of hazardous waste management technologies
3. Facility operator responsiveness and integrity.

In addressing the financial concerns of the communities impacted by a facility the roundtable has indicated a need for the facility operator to participate in the tax burden of neighbors and to protect existing landholders from financial loss due to property devaluation. One suggested approach was that the facility operator would pay:

(1) All real estate taxes within a one mile radius of the facility and 0.25 miles on either side of the access road to the facility.
(2) 75% of the real estate taxes 1.5 miles away.
(3) 50% two miles away.
(4) 25% 2.5 miles away or 0.25 miles either side of the access road to the facility.

In addition, it was felt that the facility developer should purchase any real estate offered within the zone of impact if offered within the first six months of announcement of the facility. This is to permit those individuals who do not desire to be neighbors the option to move.

A CASE STUDY

As an example of the many cleanup efforts currently underway, DER's activities at the Enterprise Avenue Landfill in Philadelphia will be summarized. The City of Philadelphia Water Department owns and operates a 57-acre landfill in southwest Philadelphia. Over a period of six years, approximately 40 acres were filled with incinerator residues, fly ash and construction/demolition debris. Later, it was found that industrial/chemical wastes had also been dumped in the landfill.

To assess the potential migration of contaminants into ground- and surface-waters, Philadelphia retained Roy F. Weston, Inc. to study and characterize the environmental impact of the landfill (Phase I). The investigation was conducted with heavy emphasis on health and safety protection. After determining the contamination levels in the soils and groundwater and collecting the necessary hydrogeological information, a remedial action plan was developed for the landfill (Phase II).

Under this plan, drums and other containers of industrial/chemical wastes are being located using a Ground Penetrating Radar Unit. Bid documents (drawings and specifications) will be prepared which will allow the City of Philadelphia to obtain the services of a contractor who will remove these drums, containers and contaminated bulk material for transport to approved disposal sites. During drum removal and subsequent site closure, continuous field inspection will be maintained by the consultant. As in the first phase, heavy emphasis will be placed on health and safety protection.

Concurrently, the ground- and surface-waters are being monitored to assess the capability of the bottom clay layer to retard contaminant migrations. Appropriate materials for covering the landfill after removal of the industrial and chemical wastes are being identified and located for use.

After these wastes have been removed, a resurvey of the site will be conducted to update the site plans and prepare post-closure plans. Post closure activities will involve continued groundwater monitoring and maintenance of the cover materials to assure their integrity.

SUMMARY

Pennsylvania is evaluating uncontrolled sites and initiating clean-up activities wherever imminent hazards to health are identified. The Commonwealth is in the process of developing a Hazardous Waste Management Plan, which envisions the establishment of new disposal facilities as essential to the management of uncontrolled sites.

HYDROGEOLOGICAL INVESTIGATION OF AN UNCONTROLLED HAZARDOUS WASTE SITE

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INTRODUCTION

Hydrogeological investigations of uncontrolled hazardous waste sites can be time consuming, expensive and dangerous. Ecology and Environment, Inc. (E & E) has developed a unified approach to uncontrolled hazardous waste site investigations which combines existing geophysical investigatory methods with field analytical techniques. This approach tries to provide preliminary information on the relative hazards associated with an uncontrolled hazardous waste site in a short period of time at minimum expense. Field analytical methods adopted by E & E and described in more detail in another section of this paper are used to closely control the costs of groundwater well installation and monitoring program and provide field personnel with air characterization data for health, safety and respiratory protection purposes.

This case history involves a hydrogeological site investigation whose purpose was to develop and implement a groundwater monitoring program to determine the extent of groundwater contamination. The location will be referred to as the Site.*

The Site is located on privately owned land which was previously used for mining operations. About ten years ago, the owner of the property began to receive 55-gallon drums containing spent solvents, sludges and other miscellaneous chemical waste. The drums were placed on the ground and stored on a portion of the owner's land in an area of approximately six acres. Many drums were in poor condition and soil staining indicated that material had been spilled. It was also suspected that some of the drums had been buried. At the commencement of the hydrogeological study, approximately half of the total number of drums had been removed during initial emergency cleanup actions. The remaining drums were placed in a bermed and lined temporary storage area.

Bulk dumping of waste chemicals was alleged to have occurred in an area northeast of the temporary drum storage area. Inspection of five year old aerial photographs revealed a depression or pit in this area which has since been filled in. The existence of this pit and the bulk dumping activity was alleged by several eyewitnesses.

*The approach presented in this case history involves the investigation of a site which was used for the storage and disposal of hazardous wastes and is alleged to have caused groundwater contamination. The actual site characteristics and analytical results described herein are fictitious. However, the procedures, engineering approach, team organization and field analyses described actually took place.

The Site is located west of a river which flows southward toward a small city. Two of the city's water supply production wells, which are located on the west side of the river about 1.5 miles downgradient from the Site, were found to contain small quantities of organic solvents. Activities at the Site were halted approximately eight months ago and cleanup operations began. Contaminants which had been spilled, leaked or dumped on the ground have either vaporized or percolated into the underlying soil and groundwater.

PRELIMINARY SITE ASSESSMENT

E & E under contract to the U.S. Environmental Protection Agency (EPA) began its hydrogeologic investigation of the Site by first conducting a preliminary site characterization which included a review of past and present land uses, preliminary waste characterization and analysis of the Site topography, cultural landmarks, aerial photographs, surface hydrology and surficial geology.

The preliminary site assessment involved an analysis of all available information on the Site. The location, accessibility, general area topography, past/present ownership/uses of the Site were determined from maps supplied by the local assessor's office and the United States Geological Survey (USGS). USGS and the Soil Conservation Service (SCS) provided preliminary information regarding the surficial geology of the Site.

Hazardous wastes that were disposed of and remain onsite in 55-gallon drums were sampled, analyzed and identified by the EPA. The analytical data and other background information indicated that most of the compounds identified in the 55-gallon drums were volatile solvents. The presence of these types of substances indicated the need to consider the fuse of respiratory protection gear while working at the Site.

After consultation with personnel at the state and local levels regarding their knowledge of disposal activities at the Site, E & E was able to complete the preliminary Site assessment without the considerable expense of several Site visits.

Site Description

Land elevation is approximately 250 feet above mean sea level to the north, west and southwest of the Site

(Figure 1). The land elevation slopes to approximately 230 feet above mean sea level to the east and southeast of the Site which is bounded by the river. Private residences whose drinking water is supplied by individual wells are located northwest, west and southwest of the Site along the county road.

Preliminary information also indicated that the Site and its surrounding environs are underlain by varying thickness of glacially deposited materials. These unconsolidated materials provide a medium for groundwater storage and movement and as such constitute a significant aquifer. The glacial sediments lie on top of the metamorphic and igneous bedrock that is capable of providing small but reliable amounts of groundwater. As previously mentioned, parts of the Site were also used for mining operations.

SITE MAPPING

As part of the engineering approach to this site investigation and groundwater well monitoring program, the Site was mapped extensively to show site-specific topography, cultural landmarks, areas of surface drainage, vegetation, locations of waste storage containers, on-site/off-site existing wells locations, accessibility to the Site, property lines, easements, building locations, surficial geology and groundwater/bedrock topography. All of this information was gathered as part of the next phase of E & E's site investigation following the preliminary assessment. It involved actual Site visits by personnel with different specialties and use of various geophysical measurement techniques to gather all the necessary data.

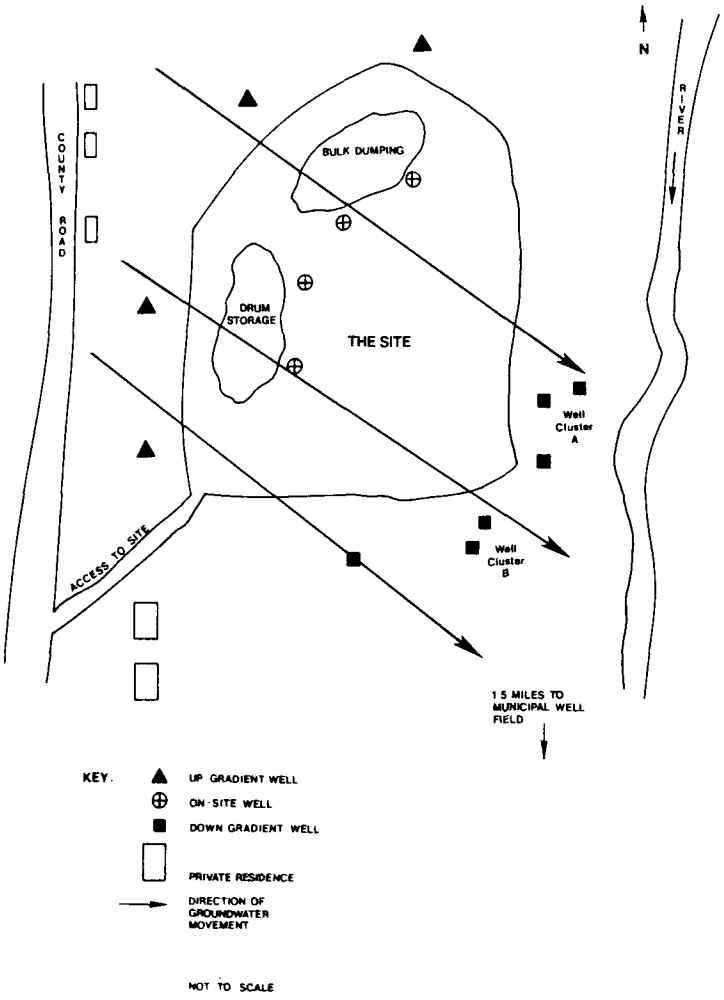


Figure 1.

The purpose of the second phase of the overall investigation was to provide enough information to develop as accurately as possible the scope of the subsequent groundwater well drilling and installation program. Drilling and installation of monitoring wells can be the most expensive phase of a hydrogeological investigation and extensive knowledge of the area where monitoring wells are to be located can save both money and time in the course of the overall site investigation.

Groundwater/bedrock mapping was developed and combined with the Site topographical base map to assist in choosing optimum monitoring well locations. The groundwater and bedrock data was augmented by the measurement of private well water depths at residences adjacent to the Site. A ground penetrating radar survey was performed on the Site to determine the presence of any buried 55-gallon drums at selected on-site well locations.

The results of the seismic refraction study and measurement of private well data depths indicated that the bedrock/groundwater contours generally reflect the surface topography, i.e., gradually sloping southeast toward the river. The corresponding groundwater flow pattern is indicated by the large directional arrows on Figure 1. The ground penetrating radar study revealed no buried hazards at the selected locations.

GROUNDWATER WELL MONITORING PROGRAM

Location of Monitoring Wells

The purpose of instituting the monitoring well program was to assess whether groundwater flowing to the Site is uncontaminated and that groundwater which flows off-site has been contaminated due to past disposal operations. A monitoring well network consisting of 14 wells was installed (Figure 1) on and adjacent to the Site.

These well locations were selected in order to detect on-site contamination and off-site migration. Two clusters of wells (well cluster A and well cluster B), each consisting two separate wells in close proximity and which terminate at different depths, were located downgradient off-site to detect contaminants in soil layers of different permeability.

Six wells were located downgradient from the Site in line with the groundwater flow from the Site. The majority of contaminants moving through the Site are transported by the groundwater into the path of these proposed monitoring wells.

Four wells were drilled and installed upgradient from the Site to act as "control" wells to assess whether groundwater flowing onto the Site was uncontaminated as

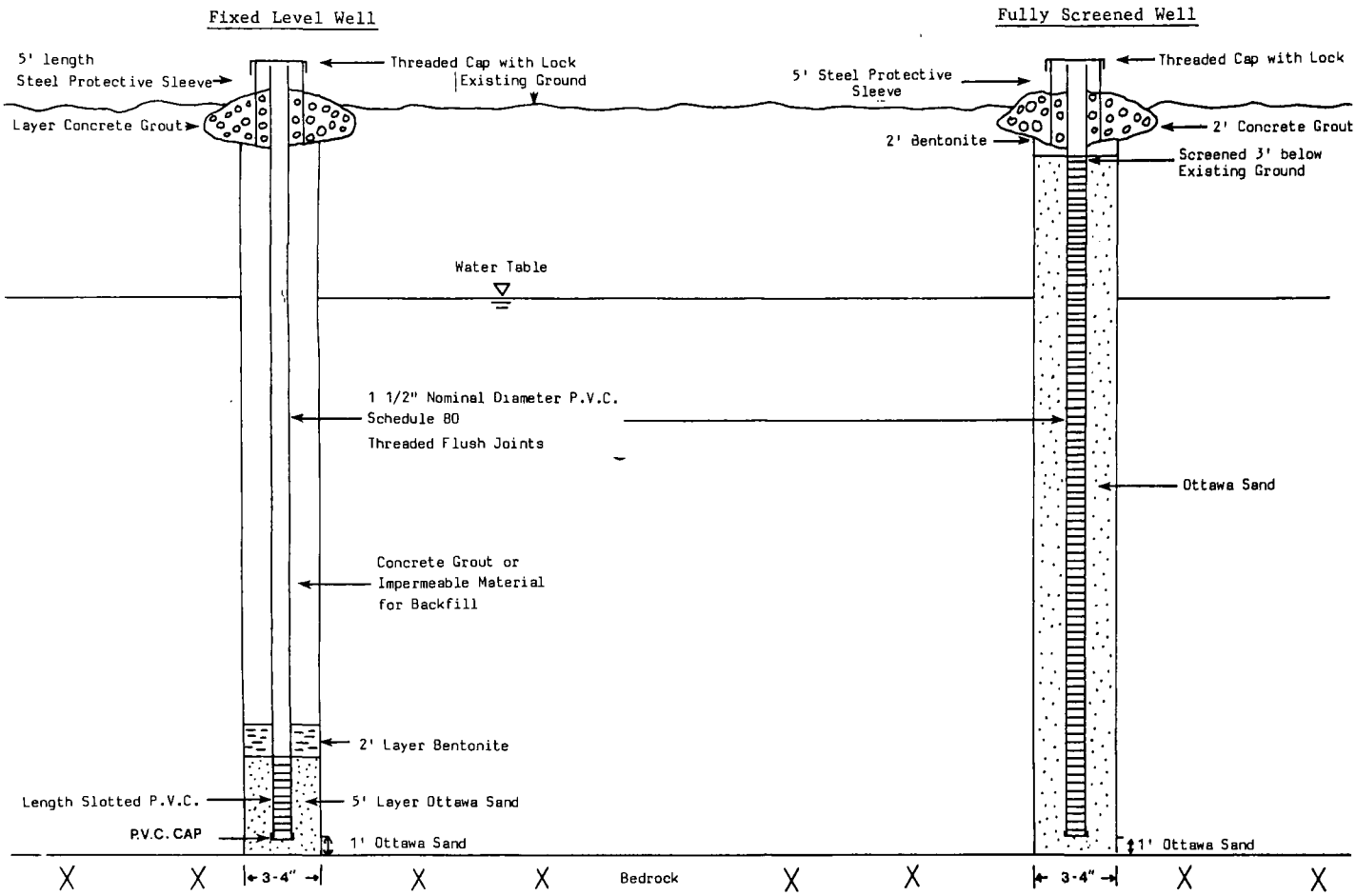


Figure 2.
Typical Detail of Monitoring Wells
(Not to Scale)

suspected and to verify the prevailing groundwater flow pattern to the Site.

The remaining four wells were drilled and installed at various locations on the Site, free from buried objects, however, downgradient from the drum storage and bulk disposal area.

Monitoring Well Construction Specifications

E & E established construction specifications and procedures for drilling and installation of monitoring wells for areas potentially contaminated with hazardous wastes. These new specifications and procedures involved issues never addressed before. Well construction specifications and procedures included safety precautions, equipment decontamination, on-site soil analysis, field determination of well depth placement, collection and disposal of potentially hazardous wastes generated by well drilling and installation, maintenance of field records and management/staffing during the drilling and installation. Safety precautions, on-site soil analysis and field determination of well depth placement will be discussed in the subsequent Field Analytical Approach section.

These specifications, based on engineering construction specifications for typical soil borings and well installations, were adapted for use on hazardous wastes sites with emphasis on the minimum amount of drilling required to accomplish the objective of the overall investigation as well as protection of the environment and the health/safety of those involved in the work.

Well Types

The two types of wells (Figure 2) that were installed, fixed-level and fully-screened, are differentiated by length of their well screens.

All wells installed on and off-site were fully screened groundwater wells from bedrock/refusal to a point approximately 4-5 ft below ground surface with the exception of certain off-site wells used to detect contaminants in soil layers of different permeabilities. These fixed-level wells were screened only for the length of contaminated soil layer.

The monitoring well casing used was PVC schedule 80 with a nominal pipe size of one and 1.5 in. The pipe extended 2.5 ft above ground and had threaded flush joints. No solvents were used as joining compounds. The pipe

used allows passage of a 1.3 in. O.D. bailer for sampling purposes. Slot size for well screens was 0.010 in. and the casing at the bottom of all wells was capped.

All monitoring wells were drilled using either the drive casing method or hollow-stem auger method. The wells were installed using an all-terrain vehicle-mounted drilling rig. Final well depths were determined in the field by E & E personnel using a portable gas chromatograph to analyze soil samples for contamination as they were brought to the surface. The exact well depths were determined as a function of contaminant concentrations. This procedure is described in more detail in a subsequent section of this paper.

As drilling proceeded, a well log containing the following information was recorded: well location, well number, depth to water table, soil classification and depths, driller's remarks, sample depth and type, well screen length and depth installed, gravel pack depths, seal depths, total well depth, date and time of the well drilling and weather conditions during drilling, E & E personnel and contractor personnel present during drilling, number of blows required for each penetration of split spoon sampler, weight of drop hammer, height of drop, monitoring well material used and lengths per well.

Only clean, non-recirculated water was used as wash water for drilling in a new well location. All drilling equipment, casing, weights, samplers, and augers, were cleaned by the driller prior to drilling the first hole and when drilling equipment was moved to any new well location.

This cleaning process consisted of:

(1) High pressure hot water cleaning of the drilling equipment
(2) Rinsing of equipment with a methanol spray
(3) High pressure hot water final rinse

All waste generated from this entire washing process was collected for possible hazardous waste disposal. E & E personnel determined in the field whether the waste material required hazardous waste disposal based on field analytical techniques. No oil or grease was used during drilling in such a manner as to contaminate the drilled hole. No equipment was removed from a drilling site at any time without first being decontaminated as previously described.

Wash water remaining after decontamination of drilling equipment and personnel decontamination was considered a hazardous waste and was not discharged into the environment. These wastes were containerized in 55-gallon drum containers for final disposal.

Well Drilling Management/Staffing

The E & E team on-site during well drilling operations included four specialists. One team member was a construction engineer as project manager who verified well installation techniques, maintained a well log and decided upon final well placement depths/location. The second specialist was a geologist who visually analyzed the soil samples and maintained the geologic field record. The third team member was a chemist who analyzed the soil samples for contaminants and who monitored the ambient air in the immediate vicinity of the well drilling (described in more detail subsequently). The fourth team member was a safety officer, stationed outside the immediate well drilling location who monitored the overall safety of the workers, and set up of decontamination stations. This team approach to well drilling and installation proved invaluable for the overall success, safety and expediency of the groundwater monitoring well program.

FIELD ANALYTICAL APPROACH

As mentioned earlier, the predominant chemical wastes at the Site were volatile organic compounds. The presence of these types of compounds which were alleged to have been spilled, leaked and/or dumped on the ground at the Site gave rise to two considerations for the installation of groundwater monitoring wells at and around the Site. The first consideration was the potential for personnel exposure to organic vapors during drilling operations and the second consideration was the opportunity to evaluate the distribution of contaminants in the soil and groundwater as the wells were being installed. The following sections describe the approach to air monitoring respiratory protection and soil/groundwater analyses carried out at the Site during the monitoring well installation.

AIR MONITORING/RESPIRATORY PROTECTION

Background Information

Except in an area of the Site where drums remain all other areas on the Site where wells were installed were free of any visible sources of organic vapors. All of the on-site area is open and flat, precluding conditions which could lead to an accumulation of potentially dangerous levels of organic vapors.

The proposed locations of on-site monitoring wells were at areas of the Site where it was highly probable that large amounts of contaminants had been leaked, spilled or dumped onto the ground (Figure 1). Therefore, penetration into contaminant saturated soil and groundwater by drilling equipment could lead to the possibility of releasing organic vapors to the ground surface. Personnel working in the direct vicinity of the well hole would then be subject to an organic vapor respiratory hazard.

In addition, the locations of six of the wells were down gradient in the Site's groundwater flow and although it was not anticipated that highly contaminated soil would be encountered during drilling, consideration had to be given to the possibility of personnel exposure to organic vapors during the processes of well development and sampling which involve bringing groundwater to the surface.

Air Monitoring

A Century Systems Model 128 Portable Organic Vapor Analyzer (OVA) was used in the total survey mode to continually monitor organic vapor concentrations in the

air in the immediate vicinity of each well hole on-site and down gradient. In the total survey mode, air is drawn into the instrument through a probe and sampling line to a flame ionization detector (FID). The instrument used is calibrated to methane so that the concentrations read out from the FID response are methane-equivalent, i.e., the total organic vapor concentration (expressed in ppm) is relative to the concentration of methane.

Prior to drilling at each location, total organic vapor concentrations were within the Site's normal ambient range of 3-4 ppm. As drilling commenced, the air in the immediate vicinity of the well hole was monitored. Also, each time drilling was stopped to allow a new section of hollow stem auger or casing to be added, the probe of the OVA was placed directly at the top of the well hole. Although personnel would not be breathing air directly from that point, the intent was to anticipate high levels of vapors which might emanate from the hole and possibly be inhaled by personnel.

Results

All personnel at on-site locations wore full-face air purifying respirators to start drilling operations. At the locations of two on-site wells, total organic vapor concentrations intermittently approached 1000 ppm, measured at the top of the well hole. Although concentrations were still in the range of ambient background (3-4 ppm) in the breathing range of personnel and favorable weather conditions existed (low temperature and strong, steady winds) all personnel utilized Self Contained Breathing Apparatus (SCBA) to complete well drilling at these two locations. Additionally, SCBA was used during the withdrawal of the drilling auger sections, as highly contaminated soil was brought to the surface during this operation.

At the other on-site locations, concentrations above ambient levels were not detected at the top of the well hole or in the breathing range of personnel who wore air purifying respirators throughout the installation procedures. At the locations downgradient from the site, concentrations above ambient levels were not detected and personnel were able to complete these installations without donning respirators.

FIELD ANALYSIS OF SOIL SAMPLES

Soil samples were collected during drilling using a 2 in. O.D. split-spoon sampler every 5 ft or at each change in geological stratum. Soil samples taken over the entire length of the bore hole were then analyzed for total volatile organics. The concept of the approach was suggested by Spittler.[1]

Field Analytical Instrument

The instrument used for field analysis for volatile organic compounds was a Century Systems Model 128 Portable Organic Vapor Analyzer (OVA) with Gas Chromatograph (GC) capability. The instrument may be used in a total survey mode as described in the previous section on Air Monitoring Respiratory Protection and may also be used as a GC by introducing a sample to a GC column and recording a chromatogram on a portable strip chart recorder. The strip chart recorder used in this instance was a Rustrak Model 288 with a high and low gain setting and two chart speeds attained by changing gear assemblies inside the recorder.

The Century OVA utilizes a flame ionization detector (FID) which consists of a diffusion flame of pure hydrogen mixed with air. This type of detector is commonly used in laboratory GC applications. The same hydrogen supply is also used as the carrier gas in the GC column. The sensitivity of the instrument when used in the GC mode increases over that possible when used in the total survey mode. By increasing the size of the sample aliquot injected and setting the strip chart recorder on high gain, it is possible to detect volatile organic compounds in concentrations as low as 30 ppb.

Upon retrieving the split-spoon at each sampling interval, a clean, stainless steel spatula was used to place a small quantity of soil from the core into a clean 40 ml vial fitted with a Teflon-backed septum. The depth over which the sample was collected was recorded by the supervising geologist and entered on the field analytical record.

The soil samples were allowed to thermally equilibrate in the interior of the field laboratory for several minutes prior to analysis. Each sample was then screened for total volatile organic compounds and, if present, the sample was analyzed for individual volatile constituents.

The GC column chosen for the initial analyses of soil samples was a type T-6 (1%TCEP on Chromosorb W, HP, 60/80 mesh). Although this column is short in length and may present separation problems at higher ambient temperatures, it was selected for field use because of the fairly low ambient temperatures encountered and the need to reduce the time between analyses so that the information obtained could be used to make expedient decisions about well installation and placement.

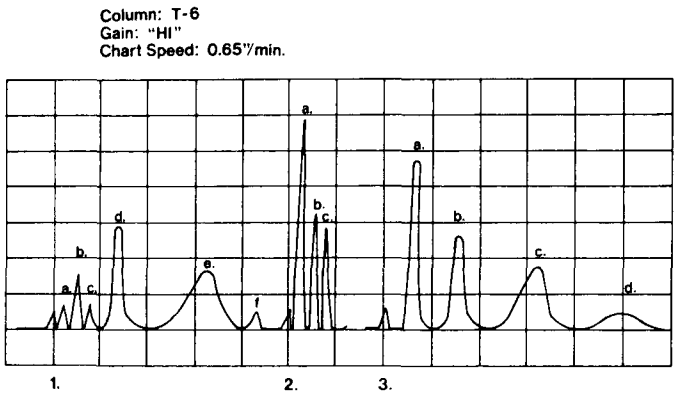
The procedure for analysis was to withdraw by syringe an aliquot of soil sample headspace vapor and inject this into the GC column with the backflush valve up and strip chart recorder running. The size of the aliquot injected was based upon the response shown during the initial total volatile analysis, but was typically 250 µl for off-site down gradient wells and 25-50 µl for on-site wells. The chromatogram was allowed to run for 5-10 min., at which time the backflush valve was depressed reversing flow in the column and the presence of any heavy constituents noted.

Aliquots of headspace vapor from aqueous mixtures of known volatile compounds were then chromatogrammed in order to establish retention times. The resulting chromatograms were compared with those of the samples to determine whether there were any retention time matches. Where matches were apparent, repeat injections of the samples and knowns were made. Two other columns were then used to further establish retention time matches. A schematic representation of a typical soil sample chromatogram and of subsequent injections of headspace vapor from known aqueous mixtures is shown in Figure 3.

RESULTS

A summary of the results of the soil sample analyses is given in Table I. Concentrations are expressed on a relative basis and no attempt was made at precise quantitation. The field analysis of the soil samples benefitted the well installation in the following ways:

- It could be confirmed that well placement based upon previously existing geophysical and hydrological data was intercepting the groundwater contamination plume.
- The vertical distribution of contaminants at each well location could be integrated with geological data to assist personnel in selecting optimum depths for well screen placement during well installation, thereby eliminating unnecessary well drilling or well screen placement which would save on the overall costs of the monitoring well program.
- The need to install wells at different depths at the same location could be confirmed or eliminated.
- The need for drilling equipment to be decontaminated in between wells could be confirmed or eliminated.



The above schematic representation is of chromatograms obtained by injecting headspace vapor from a soil sample (1) and from dilute aqueous mixtures of known volatile organic compounds (2) and (3). Chromatograms of the samples and knowns were also run on different columns to confirm retention time matches.

1. 150 µl Injection: (Small spike marks injection)
   a. 1, 1, 1 Trichloroethane
   b. Trichloroethylene
   c. Tetrachloroethylene
   d. Toluene
   e. Ethylbenzene
   f. Air peak due to backflush valve activation
2. 100 µl Injection: (Small spike marks injection)
   a. 1, 1, 1 Trichloroethane
   b. Trichloroethylene
   c. Tetrachloroethylene
3. 100 µl Injection: (Small spike marks injection)
   a. Benzene
   b. Toluene
   c. Ethylbenzene
   d. O-xylene

Figure 3.
Typical Soil Sample Chromatogram

Table I.
Summary of Soil Sample Analyses During Well Installation

Well Location	Depths of Volatile Detection	Compounds Identified
1. Up-gradient	None Detected	———
2. Up-gradient	None Detected	———
3. Up-gradient	None Detected	———
4. Up-gradient	None Detected	———
5. On-site	5.5-15 ft Total Well Depth 20 ft	1,1,1-Trichloroethane, Trichloroethylene, Tetrachloroethylene, Toluene, Ethylbenzene
6. On-site	10-23 ft Total Well Depth 23 ft	Tetrachloroethylene, Toluene, Ethylbenzene
7. On-site	7-22 ft Total Well Depth 25 ft	Trichloroethylene, Tetrachloroethylene
8. On-site	1-16 ft Total Well Depth 17 ft	1,1,1-Trichloroethane, Trichloroethylene, Toluene, Ethylbenzene
9. Down-gradient (Well Cluster A)	None Detected Total Well Depth 18 ft	———
10. Down-gradient (Well Cluster A)	20-25 ft Total Well Depth 25 ft	1,1,1-Trichloroethane, Trichloroethylene, Tetrachloroethylene, Toluene, Ethylbenzene
11. Down-gradient (Well Cluster B)	None Detected Total Well Depth 13 ft	———
12. Down-gradient (Well Cluster B)	15-21 ft Total Well Depth 22 ft	Ethylbenzene, Toluene
13. Down-gradient	12-28 ft Total Well Depth 30 ft	1,1,1-Trichloroethane Trichloroethylene, Toluene, Ethylbenzene
14. Down-gradient	10-29 ft Total Well Depth 32 ft	Tetrachloroethylene Toluene, Ethylbenzene

INITIAL SAMPLING AND ANALYSIS OF GROUNDWATER

Immediately following the development of the wells by pumping, a groundwater sample was obtained for preliminary analysis on the portable GC. Samples were analyzed using the headspace vapor technique.[1, 2] The results of this initial field analysis are compared, in Table II, to subsequent laboratory analysis by gas chromatograph/mass spectrometer analyses obtained several weeks later.

The advantages afforded by the initial field analysis of the groundwater samples included the following:

(1) The data generated by the previous analysis of soil samples during well installation could be confirmed.
(2) Those wells yielding samples with very high concentrations of contaminants could be identified so that the necessary special arrangements for handling and analyzing those samples could be made.
(3) The data obtained by analyzing samples from the newly installed wells could be evaluated for public health implications.
(4) The field analyses provided an additional quality control element for the subsequent laboratory analysis of samples.

Table II.
Comparison of Field Analysis of Groundwater Samples with Laboratory Analysis(1)

Well Location	1,1,1-Trichloroethane	Trichloroethylene	Tetrachloroethylene	Toluene	Ethylbenzene
Up-gradient	ND (ND)	ND (ND)	ND (ND)	ND (ND)	ND (ND)
Up-gradient	ND (ND)	ND (ND)	ND (ND)	ND (ND)	ND (ND)
Up-gradient	ND (ND)	ND (ND)	ND (ND)	ND (ND)	ND (ND)
Up-gradient	ND (ND)	ND (ND)	ND (ND)	ND (ND)	ND (ND)
On-site	High (2300)	High (8500)	Moderate (1300)	High (8600)	High (2200)
On-site	ND (11)	ND (ND)	Low (20)	Moderate (1000)	Low (200)
On-site	ND (ND)	Low (15)	Low (60)	Low (15)	ND (ND)
On-site	Low (80)	Low (300)	High (3600)	High (4000)	High (1200)
Down-gradient	ND (ND)	ND (ND)	ND (ND)	ND (ND)	ND (ND)
Down-gradient	Low (80)	Moderate (1700)	High (3500)	High (9500)	High (3600)
Down-gradient	ND (ND)	ND (ND)	ND (ND)	ND (ND)	ND (ND)
Down-gradient	Low (80)	ND (ND)	ND (ND)	Moderate (1000)	Moderate (400)
Down-gradient	Moderate (390)	Low (35)	ND (ND)	High (2500)	Moderate (400)
Down-gradient	Low (100)	Low (60)	Moderate (1175)	High (18,000)	High (1800)

ND = Not Detected

1. Field Analysis Performed with portable GC; concentrations given are relative estimated
   Laboratory analysis performed by GC/MS; concentrations in ppb in parentheses.

Groundwater Sampling Results

All the newly installed groundwater monitoring wells were sampled for EPA priority pollutant analysis. Specific analytical results cannot be presented in this paper, however the general trends can be discussed.

The results indicate that there is no groundwater contamination to the north, west or southwest of the Site. There is, however, contamination on-site and to the southeast and east of the Site.

These general observations confirm the conclusions drawn from the Site hydrogeology as briefly discussed in this paper. In summary, groundwater upgradient of the Site is uncontaminated and after entering the Site picks up contaminants and flows southeasterly toward the river.

Contaminants with different chemical properties will exhibit different characteristics in groundwater. The results of the priority pollutant analysis indicated that not all volatile organics followed similar on-site/off-site contamination distribution patterns. However, all conformed to the basic hydrogeologic description of the Site.

Analysis of the contaminant data from the wells screened at different depths indicate that a large fraction of the total contamination in the down-gradient area is confined in ice-contact deposits overlain by less permeable soil deposits.

CONCLUSION

The extent and concentration of contaminants in the groundwater monitoring wells follows the pattern developed from analysis of the Site performed before the monitoring wells were installed and sampled. This close agreement supports the engineering approach and field analytical methods used by E & E to develop the site hydrogeologic model.

The actual levels of volatile organics also closely correlate with the results of preliminary soil and groundwater testing performed by E & E personnel using the Century Systems 128 OVA on-site during installation of the well. The agreement between the E & E on-site field analysis and the actual contaminant concentration data supports E & E's use of the OVA during groundwater investigations.

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2. Dietz, E.A. and Singley, K.E., "Determination of Chlorinated Hydrocarbons in Water by Headspace Gas Chromatography", *Analytical Chemistry, 51*, September, 1979.

LOCATION AND PRIORITIZING OF ABANDONED DUMP SITES FOR FUTURE INVESTIGATIONS

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INTRODUCTION

The methodology described in this paper to locate and classify abandoned dump sites was developed in Monroe County, New York in response to a 1978 county legislature request to locate potential "Love Canal" type problems and a 1979 New York State law requiring counties to identify abandoned sites. The system is designed to evaluate and prioritize a large number of sites for more detailed investigation. While not all points will be applicable in every part of the country, the general approach will allow government agencies to focus limited resources on those sites that pose the greatest potential impact on human health.

This paper is a brief description of a methodology that will be fully described in a final report to EPA to be completed in 1982.

RATIONALE AND APPROACH

The highest priority for the Monroe County study was to locate sites where potentially hazardous substances in high concentrations might be present in areas occupied by large numbers of people. There are many other situations where hazardous materials might have a potential long-term effect on humans or the environment that were excluded from the highest priority category in the design of the study, i.e.: the slow, long-term release of toxic substances into streams and lakes through ground water might be of great concern in other circumstances. However, the immediate effect of these low concentrations on areas where large numbers of people live or work might be negligible. Furthermore, detection of low concentrations of hazardous substances in water bodies used for drinking water or recreation is an area of current concern for health or water quality agencies and should be handled under existing programs. Information bearing on such long-term problems is not ignored in the present study but would be referred to the appropriate agency when encountered.

On the other hand, public or private well water supplies in close proximity to existing or abandoned landfills are placed in the highest priority category because the potential for a more direct contamination pathway is obvious.

An integrated study such as the one undertaken in Monroe County documents a great deal of historic information that could eventually be used for many purposes. It provides comprehensive baseline data that might be unrecoverable in future years. Planning activities and zoning requirements are obvious areas of impact. The information, once collected, could be used by any agency whose efforts or priorities might overlap but differ from the specific goals of the present study.

The key to the successful implementation of this type of program is the careful organization and integration by qualified individuals of all the critical resources that might be overlooked or ineffectively utilized in a less comprehensive effort with more limited time constraints. Involvement of personnel from all affected or peripheral agencies is strongly recommended.

Historic aerial photographic analysis is the best way to confirm actual or potential site boundaries. This, in turn, allows personnel and resources to be focused on those areas where physical documentation of sites is reasonably accurate.

The geologic analysis aids in both the search for and prioritization of potential sites, but the date must be integrated with the information developed by record searches, interviews and the careful development of a comprehensive site activity profile.

Finally, this effort is not meant to replace those technical studies which have dealt with the analysis and prioritization of known hazardous waste sites where a great deal of specific information is available on site history, contents, and hydrogeology. The present study should reduce the need for expensive drilling and testing programs and provide a means for their rational implementation.

SITE IDENTIFICATION

In conducting a general survey of abandoned dump sites, there are many sources of information which must be used in combination to identify and/or verify site locations and to characterize site activity. The Monroe County methodology uses historic aerial photographs in stereographic pairs as the primary resource to develop an information base, but no single source should be depended upon entirely. Aerial photographs are the most reliable resource for identifying site boundaries, periods of operation, site drainage, and pre-existing uses or features such as sand and gravel operations, borrow pits, surface pond-

ing, and access routes. However, it is not always possible to distinguish dumping from "clean" fill or construction activity on photographs. The information must be supplemented by other sources. Reports, maps, records, interviews and information from the general public all provide information that is useful in constructing a site activity profile. These sources, used without air photo information, may be insufficient to locate sites adequately and generally do not provide accurate information on site boundaries. It is the combination of all available resources that is the key to accurate site characterization.

Data Sources

The useful sources of date include:

- Aerial photographs in stereographic pairs for selected years
- Records from local and state health department and conservation agencies
- Environmental atlases
- Government publications on hazardous waste sites
- County soils maps
- Historic resources (newspaper clippings, articles, city directories, fire insurance maps, plat books, industrial surveys)
- Interviews with public officials, agency employees
- Public call-in campaign.

General Survey

The general survey is conducted for one USGS quadrangle sheet at a time. Historic aerial photographs are interpreted for selected years (generally ten year intervals) to identify abandoned dumps. A record of interpretations is made on mylar sheets attached to one photo in each stereo pair. These overlay sheets are retained as important permanent documentation for the study.

Since it is not always possible to distinguish between construction, filling, and dumping on the photographs, sites are initially given one of six site activity designations (Table 1). Sites in the "Possible Dump" and "Unspecified Fill" categories will need supplemental information to determine whether dumping actually occurred. The mixture of types that occurred for one quadrangle in Monroe County is shown in Figure 1.

After the photos are interpreted for each selected year, the information from all years must be combined for each site. A written record of site activity is compiled and recorded on the Site Activity Record (Figure 2). This record is also used to record detailed information subsequently gathered for each site. A maximum site boundary map is prepared using large scale (1":200') maps. Orthophoto maps are best for this purpose if available. Lastly, a general survey map at the scale of 1:24000 is completed for each quadrangle by transferring boundaries from the larger scale maps (Figure 1).

GEOLOGIC ANALYSIS

A general geologic analysis of the entire region under study is essential to the development of a rational approach to site prioritization. Such a broad-based analysis also serves as the frame of reference for site specific studies during the later phases of the project.

The important components of a general geologic analysis are those factors which directly influence the production, containment, attenuation or migration of leachate. These generally involve the groundwater system, the soil or rock permeability, and the structures within the

TABLE 1: Site Activity Categories

D—Identifiable:
Sites where information on dumping activity is known from public records, interviews with government or industry officials, the public call-in campaign, industrial surveys, or where dumping activity is clearly evident on aerial photographs.

P—Possible:
Sites where filling activity is evident but there has been no confirmation as to whether or not dumping has occurred. However, based on the location of the site and peripheral land use, it would appear that dumping could have occurred. Sites located adjacent to industrial or commercial activities, maintenance areas, large construction sites and public facilities such as sewage treatment plants and incinerators should be evaluated as possible dumps.

U—Unspecified:
Sites that are apparent either as recent surface disturbances or topographic changes that were not present on earlier photographs. Sites that are obviously clean fill for construction purposes are not included in this category nor are they annotated. (Such sites may be identified by the relatively rapid completion of activity followed by the appearance of a highway, new building or structure on more recent photographs.)

L—Lagoons:
Potential liquid waste disposal areas that are either suggested by associated activity on the photographs or are known to have existed. Standing water in borrow pits or quarries is not generally placed in this category unless associated with dumping.

J—Auto Junkyards and Salvage Areas:
Such sites may contain significant surface disposal or spills of oil, transmission and hydraulic fluids, or solvents.

S—Suspicious:
Areas where unusual or unidentifiable activity has occurred that is not readily recognizable. Sites are placed in this category pending more complete analysis that will result in one of the above designations or elimination.

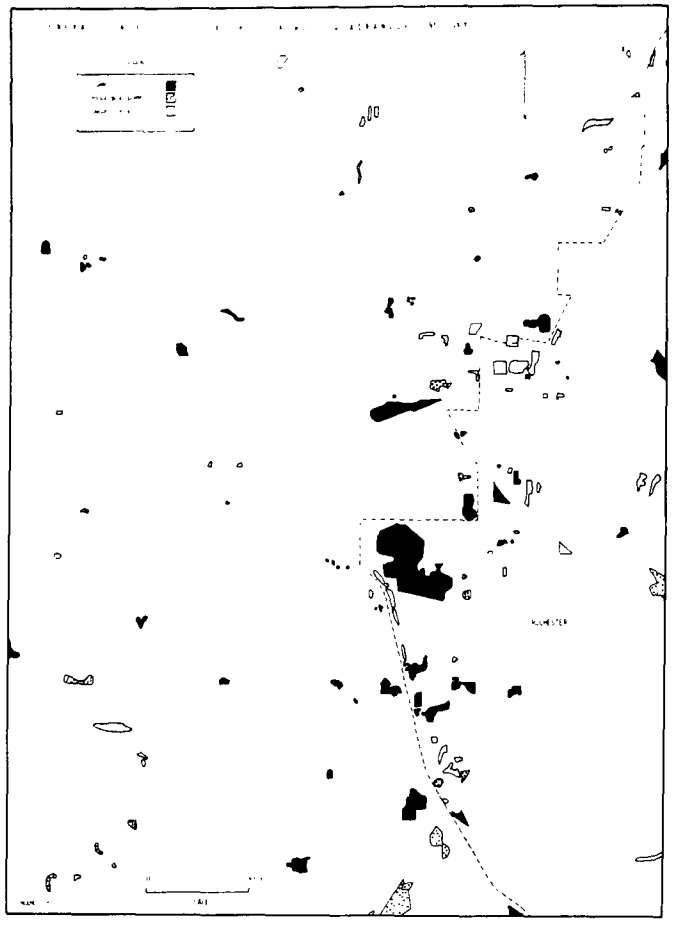


Figure 1
General survey map of sites in the Rochester West quadrangle.

overburden or rock that control either the direction of movement, rate of movement or local concentration of fluids. In most cases, landfills or old dumps are located in unconsolidated soils or overburden but occasionally the character of the local bedrock is also significant. Any geologist working on a project such as this needs to evaluate the critical factors within the particular region under study.

When dealing with abandoned landfills that were started or completed prior to the late 1970's, it should be assumed that wastes were generally placed in natural or man-made depressions without utilization of sophisticated preparation or containment techniques. Thus, the properties and structures of the natural overburden and rock formations should be assumed to control the natural migration of leachate and groundwater adjacent to the site. While the Monroe County study emphasizes the problems encountered in the glacial overburden deposits bordering Lake Ontario, the basic approach should be applicable, with minor modifications, to any regional analysis of hydrogeologic conditions.

The first phase of the general geologic analysis consists of the collection of all readily available published or unpublished data for the construction of regional geologic maps such as those shown in Figures 3, 4 and 5. The collection of additional unpublished data should continue throughout the period of study because useful or unique information can continue to be located. The types of sources commonly used in the development of a geologic data base for both general or site-specific geologic models are:

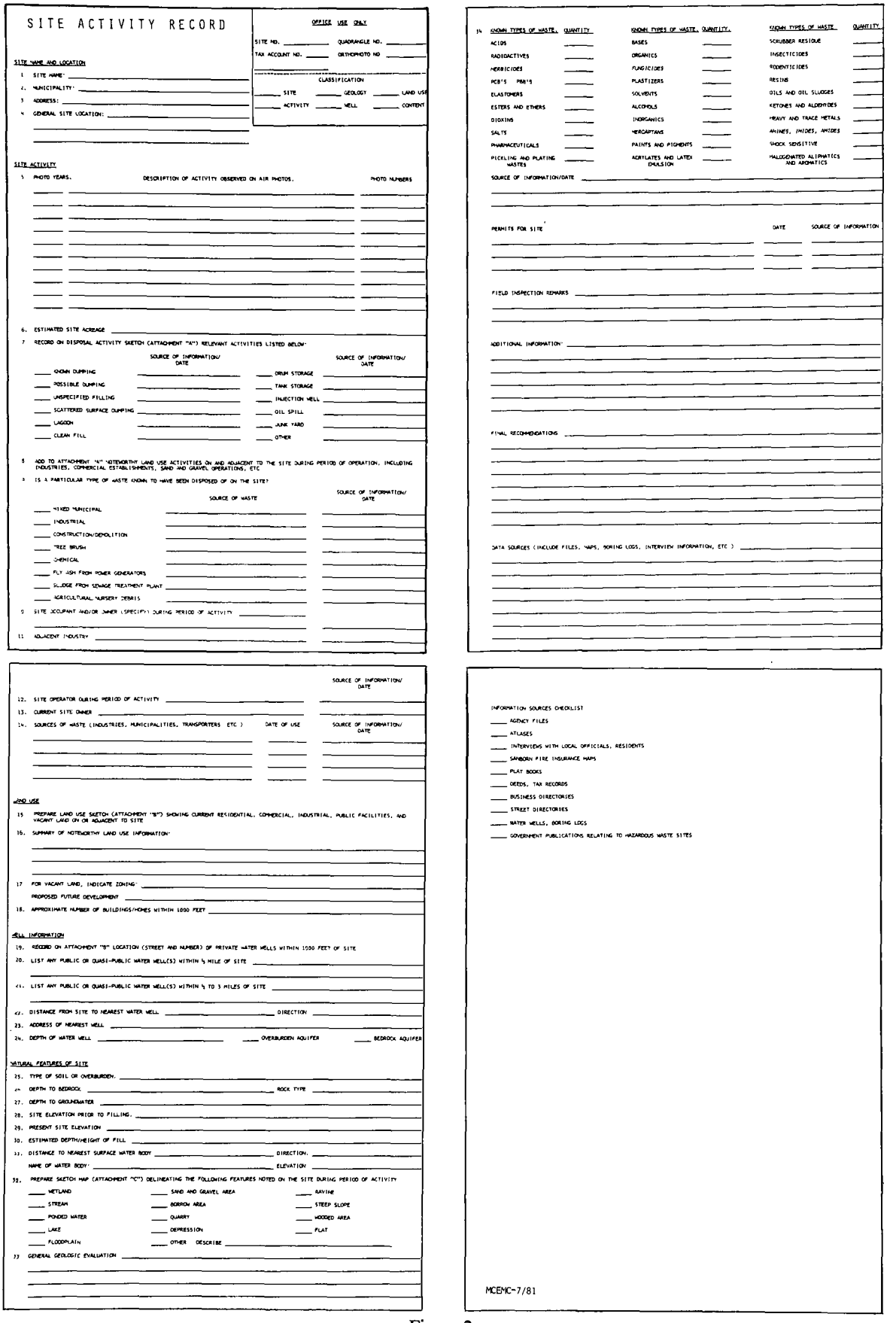
- Geologic maps and reports: published literature and student theses/dissertations; open-file reports of agencies such as United States Geological Survey; government documents.
- County soils maps: old and new versions of United States Department of Agriculture maps describing soil types and locations of dumps or "made land" (good for shallow depth of overburden only).
- Aerial photographs and topographic maps: used for geomorphological analysis of landforms if need to supplement or confirm published data. Compare old and recent prints or maps, if available.
- Engineering data from public or private agencies or firms (especially exploratory boring logs)—
  Highway/bridge plans or surveys
  Town, village or county construction/maintenance projects
  Utilities, railroads, pipeline companies, canals
  Drilling and soil testing from engineering firms
  Architectural firms
  Oil, gas and water well drillers
  Sewer and water district agencies
  Mining, quarrying and tunneling ventures
  Public buildings, airfields and large industrial firms

Geologic Overlay Maps

Using all available sources, maps such as those in Figures 3, 4 and 5 are constructed. It is recommended that a common scale be adopted for all such general survey map products and that they be compiled on transparent overlays so that all types of information can be easily transposed onto or compared with the general survey site maps. Topographic maps with a scale of 1:24,000 are very convenient for this purpose as much geologic data are routinely published on this scale by state and federal agencies.

These maps and the data from which they are generated have the following uses:

- Development and improved understanding of a regional groundwater model that includes depths to the water table and flow directions
- Development of a regional perspective concerning areas where landfill or leachate problems would either be reduced or aggravated by local geologic conditions
- Development of a basis upon which to prioritize or organize the search for sites with potential for significant impact
- Allowing an agency to focus its limited resources in the most critical areas
- Extrapolation of subsurface conditions to sites where no data can be located from similar ones where detailed information exists



SITE ACTIVITY RECORD

OFFICE USE ONLY

SITE NO. _____ QUADRANGLE NO. _____

TAX ACCOUNT NO. _____ ORTHOPHOTO NO. _____

CLASSIFICATION

_____ SITE _____ GEOLOGY _____ LAND USE

_____ ACTIVITY _____ WELL _____ CONTENT

SITE NAME AND LOCATION

1. SITE NAME:
2. MUNICIPALITY:
3. ADDRESS:
4. GENERAL SITE LOCATION:

SITE ACTIVITY

5. PHOTO YEARS. DESCRIPTION OF ACTIVITY OBSERVED ON AIR PHOTOS. PHOTO NUMBERS

6. ESTIMATED SITE ACREAGE

7. RECORD ON DISPOSAL ACTIVITY SKETCH (ATTACHMENT "A") RELEVANT ACTIVITIES LISTED BELOW:

	SOURCE OF INFORMATION/ DATE		SOURCE OF INFORMATION/ DATE
___ KNOWN DUMPING		___ DRUM STORAGE	
___ POSSIBLE DUMPING		___ TANK STORAGE	
___ UNSPECIFIED FILLING		___ INJECTION WELL	
___ SCATTERED SURFACE DUMPING		___ OIL SPILL	
___ LAGOON		___ JUNK YARD	
___ CLEAN FILL		___ OTHER	

8. ADD TO ATTACHMENT "A" NOTEWORTHY LAND USE ACTIVITIES ON AND ADJACENT TO THE SITE DURING PERIOD OF OPERATION, INCLUDING INDUSTRIES, COMMERCIAL ESTABLISHMENTS, SAND AND GRAVEL OPERATIONS, ETC

9. IS A PARTICULAR TYPE OF WASTE KNOWN TO HAVE BEEN DISPOSED OF ON THE SITE?

	SOURCE OF WASTE	SOURCE OF INFORMATION/ DATE
___ MIXED MUNICIPAL		
___ INDUSTRIAL		
___ CONSTRUCTION/DEMOLITION		
___ TREE BRUSH		
___ CHEMICAL		
___ FLY ASH FROM POWER GENERATORS		
___ SLUDGE FROM SEWAGE TREATMENT PLANT		
___ AGRICULTURAL NURSERY DEBRIS		

10. SITE OCCUPANT AND/OR OWNER (SPECIFY) DURING PERIOD OF ACTIVITY

11. ADJACENT INDUSTRY

		SOURCE OF INFORMATION/ DATE
12. SITE OPERATOR DURING PERIOD OF ACTIVITY		
13. CURRENT SITE OWNER		
14. SOURCES OF WASTE (INDUSTRIES, MUNICIPALITIES, TRANSPORTERS ETC.)	DATE OF USE	SOURCE OF INFORMATION/ DATE

LAND USE

15. PREPARE LAND USE SKETCH (ATTACHMENT "B") SHOWING CURRENT RESIDENTIAL, COMMERCIAL, INDUSTRIAL, PUBLIC FACILITIES, AND VACANT LAND ON OR ADJACENT TO SITE

16. SUMMARY OF NOTEWORTHY LAND USE INFORMATION:

17. FOR VACANT LAND, INDICATE ZONING:
PROPOSED FUTURE DEVELOPMENT

18. APPROXIMATE NUMBER OF BUILDINGS/HOMES WITHIN 1000 FEET

WELL INFORMATION

19. RECORD ON ATTACHMENT "B" LOCATION (STREET AND NUMBER) OF PRIVATE WATER WELLS WITHIN 1000 FEET OF SITE

20. LIST ANY PUBLIC OR QUASI-PUBLIC WATER WELL(S) WITHIN ¼ MILE OF SITE

21. LIST ANY PUBLIC OR QUASI-PUBLIC WATER WELL(S) WITHIN ¼ TO 3 MILES OF SITE

22. DISTANCE FROM SITE TO NEAREST WATER WELL DIRECTION

23. ADDRESS OF NEAREST WELL

24. DEPTH OF WATER WELL ___ OVERBURDEN AQUIFER ___ BEDROCK AQUIFER

NATURAL FEATURES OF SITE

25. TYPE OF SOIL OR OVERBURDEN:
26. DEPTH TO BEDROCK ROCK TYPE
27. DEPTH TO GROUNDWATER
28. SITE ELEVATION PRIOR TO FILLING:
29. PRESENT SITE ELEVATION
30. ESTIMATED DEPTH/HEIGHT OF FILL
31. DISTANCE TO NEAREST SURFACE WATER BODY DIRECTION:
NAME OF WATER BODY: ELEVATION

32. PREPARE SKETCH MAP (ATTACHMENT "C") DELINEATING THE FOLLOWING FEATURES NOTED ON THE SITE DURING PERIOD OF ACTIVITY

___ WETLAND	___ SAND AND GRAVEL AREA	___ RAVINE
___ STREAM	___ BORROW AREA	___ STEEP SLOPE
___ PONDED WATER	___ QUARRY	___ WOODED AREA
___ LAKE	___ DEPRESSION	___ FLAT
___ FLOODPLAIN	___ OTHER DESCRIBE	

33. GENERAL GEOLOGIC EVALUATION

34.

KNOWN TYPES OF WASTE	QUANTITY	KNOWN TYPES OF WASTE	QUANTITY	KNOWN TYPES OF WASTE	QUANTITY
ACIDS		BASES		SCRUBBER RESIDUE	
RADIOACTIVES		ORGANICS		INSECTICIDES	
HERBICIDES		FUNGICIDES		RODENTICIDES	
PCB'S PBB'S		PLASTICIZERS		RESINS	
ELASTOMERS		SOLVENTS		OILS AND OIL SLUDGES	
ESTERS AND ETHERS		ALCOHOLS		KETONES AND ALDEHYDES	
DIOXINS		INORGANICS		HEAVY AND TRACE METALS	
SALTS		MERCAPTANS		AMINES, IMIDES, AMIDES	
PHARMACEUTICALS		PAINTS AND PIGMENTS		SHOCK SENSITIVE	
PICKLING AND PLATING WASTES		ACRYLATES AND LATEX EMULSION		HALOGENATED ALIPHATICS AND AROMATICS	

SOURCE OF INFORMATION/DATE

PERMITS FOR SITE DATE SOURCE OF INFORMATION

FIELD INSPECTION REMARKS

ADDITIONAL INFORMATION:

FINAL RECOMMENDATIONS

DATA SOURCES (INCLUDE FILES, MAPS, BORING LOGS, INTERVIEW INFORMATION, ETC.)

INFORMATION SOURCES CHECKLIST

___ AGENCY FILES
___ ATLASES
___ INTERVIEWS WITH LOCAL OFFICIALS, RESIDENTS
___ SANBORN FIRE INSURANCE MAPS
___ PLAT BOOKS
___ DEEDS, TAX RECORDS
___ BUSINESS DIRECTORIES
___ STREET DIRECTORIES
___ WATER WELLS, BORING LOGS
___ GOVERNMENT PUBLICATIONS RELATING TO HAZARDOUS WASTE SITES

MCEMC-7/81

Figure 2.

Site activity record forms used throughout the investigation to develop and maintain an updated profile of historic site activity including information on ownership, natural features, geology, nearby wells and types of waste.

Geologic Ranking Process

Once all the general maps have been prepared and subsurface engineering information compiled, the geologic ranking process can be applied using the Geologic Ranking Sheet (Figure 6). This ranking sheet has been devised for the following reasons:

- To provide a means of organizing the process of site comparison
- To minimize inconsistencies and oversights that could occur when dealing with large amounts of data
- To provide a record for other project personnel that can be updated and will allow discussion or review of site characteristics.

A ranking scheme such as this is basically an information gathering and documentation device that would be especially useful if project personnel changed.

Strict numerical site rankings should be considered only as approximations of site characteristics and geologic expertise should be substituted where appropriate. The system described here requires knowledgeable decisions to be made for each of the "presumed effects" and the ranking process should be done by an individual with hydrogeologic background.

The ranking sheet was designed to divide potential sites into high, intermediate or low priorities based on anticipated geologic conditions governing leachate (groundwater) occurrence, production, migration or accumulation, but it is only one component of an integrated assessment system. Its prime consideration is the potential or inferred effects that leachate contamination would have on people near the sites.

High priority sites are those where hazardous materials might accumulate, move readily at shallow depths, or reappear at the surface in concentrated amounts. Low priority sites are those adjacent to lakes, ravines, or on steep slopes and presumed to have been well drained for an extended period. Any large site with known hazardous contents should be evaluated individually and referred to the appropriate agency regardless of its position in the geologic ranking system.

Intermediate sites are those falling between the extremes described above. They would generally be sites

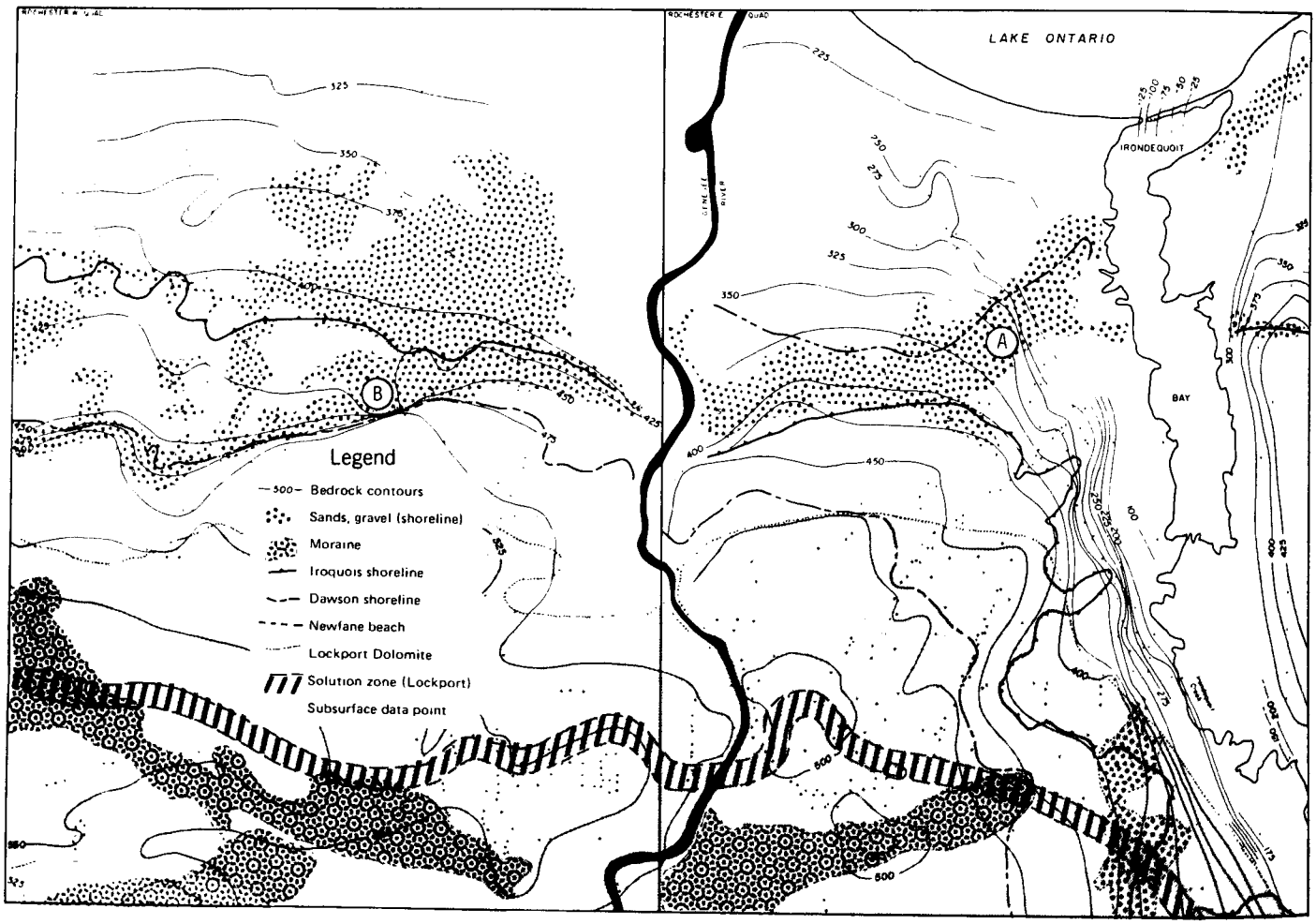


Figure 3.
Subsurface bedrock contour map with selected surface geology for Rochester East and Rochester West 7½ minute topographic quadrangles. Contour interval 25 feet. Horizontal distance across map is 12.6 miles. A: Culver-Ridge Shopping Center Site; B: Weiland Road Site.

where geologic conditions contain and isolate any leachate or partially attenuate its effects.

Potential water well contamination involves geologic considerations but sites near public or private drinking water supplies are treated separately due to the potential direct risks involved.

USE OF THE RANKING SHEET

Each factor on the ranking sheet is analyzed as to whether it increases or decreases the potential risk for a site. Available engineering information and potential interrelations among factors need to be considered. When the sheet subtotal is computed, the "additional factors" are evaluated and a total score computed. It is important that borderline cases be carefully evaluated and a tentative rank assigned if necessary, pending further data collection. Special problems should be noted in the space provided at the bottom of the sheet.

This system is designed to deal with a large number of abandoned sites where information is scarce or difficult to locate. It is not meant to replace the elaborate systems for ranking known hazardous waste sites such as those by LeGrand[1] and Kufs *et al.*[2] The Monroe County study is intended to broadly prioritize sites, rapidly identify potentially high risk sites and allow the most efficient use of funds available for later testing or subsurface investigations.

INTEGRATION OF WATER WELL DATA

Upon completion of the site identification phase, there will be sites categorized as "Possible Dumps" or "Unspecified Fills." Additional information must be obtained in order to clarify which of these sites were actually used as dumps. Information can be obtained from existing agency records, interviews with local officials, waste haulers, industrial employees, historic documents and street and business directories.

Once the site categories are refined, the process outlined in Figure 7 is followed to determine which dump sites could impact private or public water wells. Where private

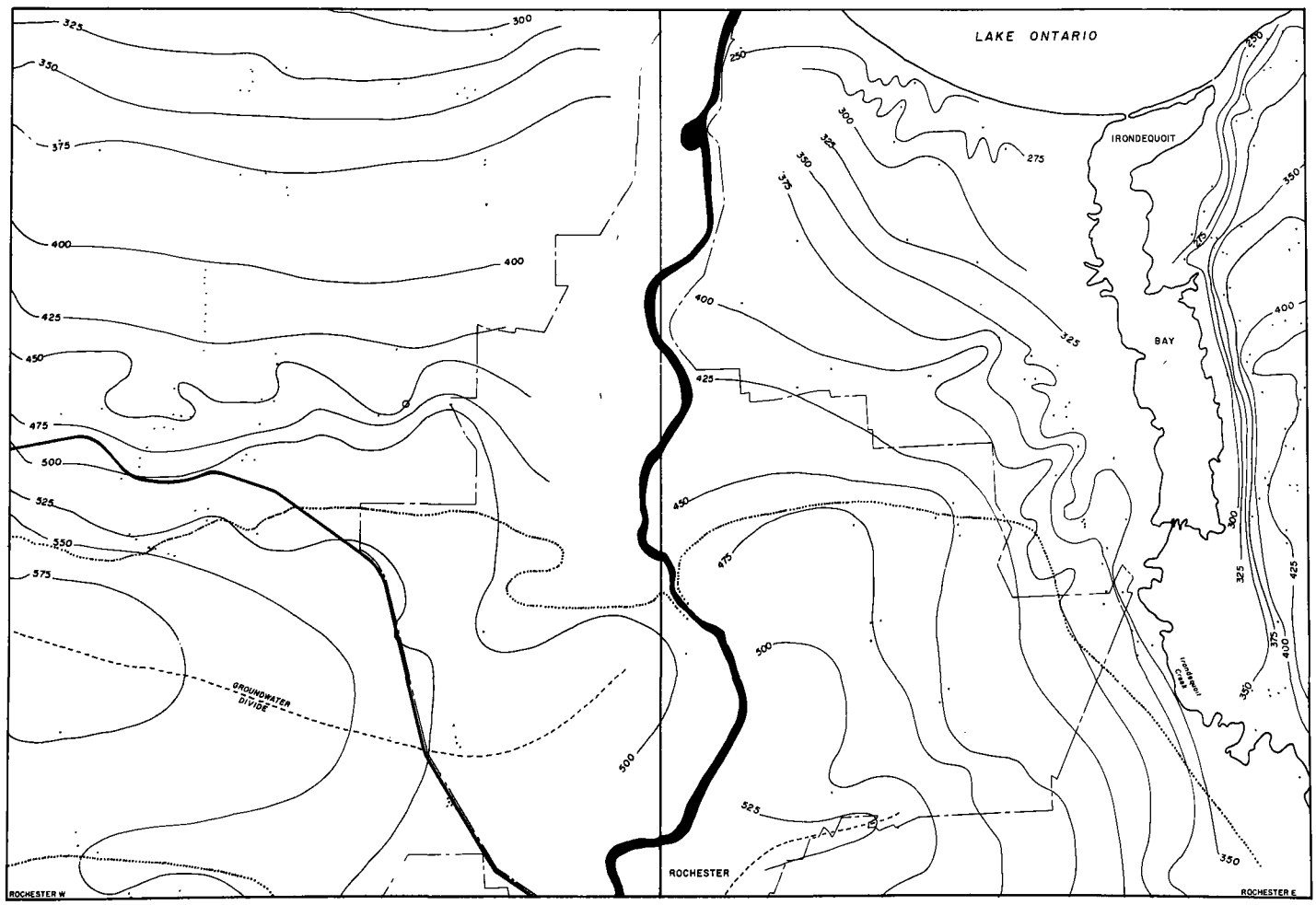


Figure 4.
Generalized groundwater contour map for Rochester East and West topographic quadrangles. Twenty-five foot contour interval shows water elevations in overburden and may reflect some seasonal variations in data or perched water. Same scale as Figure 3.

wells are found within 1000 ft. of a known dump, or public water wells within 0.5 miles, geologic conditions are carefully evaluated to determine if contamination could occur. When this determination is positive, the sites are referred to the appropriate local or state agency for groundwater testing. Sites which do not appear to impact drinking water supplies are then classified and prioritized according to the method described below.

SITE CLASSIFICATION

Site classification takes place throughout the study. Initially, each site is classified as Major or Minor at the time of photo interpretation according to the following criteria:

Major:
- Greater than one acre with measurable depth
- With known chemicals regardless of size
- With drums or containers
- With lagoons, bermed pits

Minor:
- Less than one acre
- Random surface activity greater than one acre with little accumulation
- Low volume activity on steep slopes

Sites are classified according to current land use at the time the boundaries are transferred from the photos to the orthophoto maps. One of six categories is applied. These will eventually need to be verified by field inspection.
- 24-hour occupancy on or within 100 ft. of the site (commercial establishments, industry)
- 24-hour occupancy within 1000 ft. of site
- Part-time occupancy within 1000 ft. of site
- 24-hour occupancy within 1000-2500 ft. of site
- Part-time occupancy within 1000-2500 ft. of site

At the time the geologic analysis is performed, the sites are ranked geologically based on the potential for leachate impact and migration. The geologic ranking system is de-

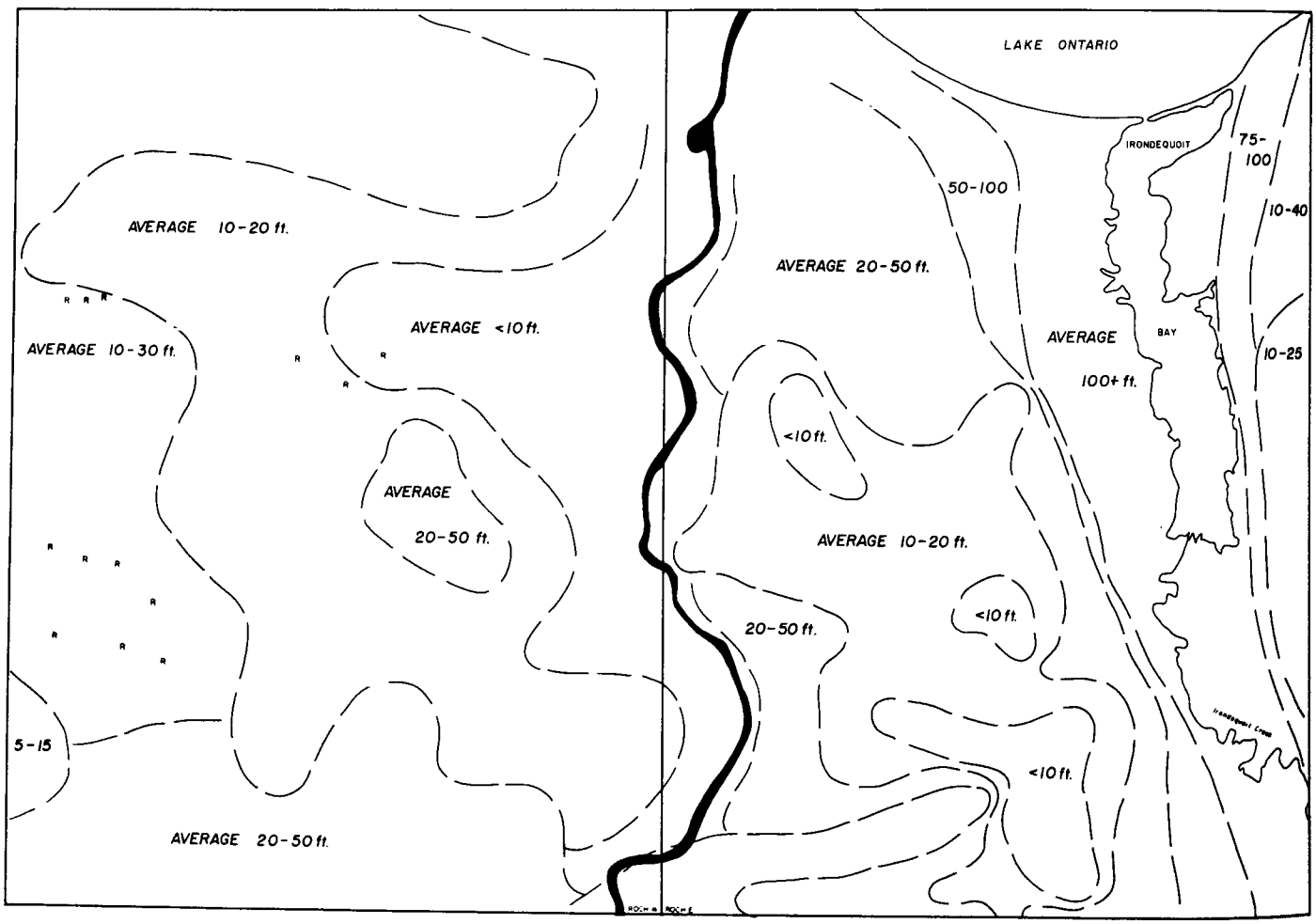


Figure 5.
Overburden thickness map for Rochester East and West topographic quadrangles from same data points as Figure 3. R designates rock outcrops. Same scale as Figures 3 and 4.

a

GEOLOGIC RANKING SHEET
FOR GENERAL COMPARISON OF ABANDONED LANDFILL/DUMP SITES

SITE NAME/NO. _____

PRESUMED EFFECT[1] / FACTORS	OVERBURDEN GEOLOGY[2]	ESTIMATED PERMEABILITY[3]	RELIEF, GEOMORPHOLOGY[4]	DEPTH TO GROUND WATER[5]	GROUNDWATER GRADIENT[6]	BEDROCK CHARACTER[7]	SOIL MINERALOGY TEXTURE[8]	NUMBER OF ENTRIES	MULTIPLIER	ENTRIES x MULTIPLIER
A. INCREASED HAZARD									3	
B. INTERMEDIATE (UNCERTAIN)									2	
C. DECREASED HAZARD									1	

SYMBOLS USED IN COLUMNS ABOVE

x PROBABLE EFFECT
u UNCERTAIN: LIKELY EFFECT
(X) EFFECT OF OVERRIDING SIGNIFICANCE

SUBTOTAL ____
ADDITIONAL FACTORS ____
TOTAL POINTS: SITE RANK ____

SITE RANK (CHECK ONE)

.01 HIGHEST PRIORITY (17-21 PTS)	
.02 INTERMEDIATE PRIORITY (12-16 PTS)	
.03 LOWEST PRIORITY (7-11 PTS)	

___ TENTATIVE ___ FINAL

NOTE: IN CASES WHERE MORE THAN HALF THE CRITICAL FACTORS MUST BE RATED AS UNCERTAIN (u), THE RANK SHOULD BE TENTATIVE.

ADDITIONAL FACTORS (CIRCLE AND ADD ABOVE)

THESE POINTS MAY INCREASE (+1), DECREASE (-1), OR NOT AFFECT (0) SCORE

VERY LARGE SITES (20+ ACRES)	+1
ENGINEERING/GEOLOGIC DATA ON OR NEAR SITE	0,-1,+1
GEOLOGY EXTRAPOLATED CONFIDENTLY FROM NEARBY	0,-1,+1

DESCRIBE IMPORTANT OR OVERRIDING FACTORS BELOW IF APPROPRIATE (DESCRIBE SPECIAL CONDITIONS): _____

b

GEOLOGIC RANKING SHEET: EXPLANATION AND NOTES

This sheet is intended to document the geologic ranking process for abandoned sites using subjective and deductive geologic analysis of the near-surface geohydrology, as well as any preexisting subsurface boring data located on or near the site. It is not intended to deal with site contents, which are generally poorly documented. Each FACTOR must be evaluated separately or, if appropriate, in conjunction with interrelated factors, according to the judgment of a geologist experienced in surficial geology and hydrology. The intent is to permanently record information, standardize the ranking process, and provide a means to update or revise site rankings. This ranking system would be applied prior to other published ranking systems that require more specific contents information.

1. PRESUMED EFFECT: A decision is required as to whether each inferred or documented FACTOR would increase or decrease the hazard relative to leachate production, migration, or attenuation. No simple, uniform guidelines can be set forth that cover all situations or geohydrologic complexities.
2. OVERBURDEN GEOLOGY: From inferred nature of unconsolidated sediments would leachate occurrence be likely to increase or decrease human exposure to pollutants?
3. ESTIMATED PERMEABILITY: Is estimated permeability of unconsolidated materials likely to increase or decrease exposure risks? Include estimated effect of either aquifers or aquicludes or inferred combinations.
4. RELIEF, GEOMORPHOLOGY: Does relief on or adjacent to the site influence the occurrence or migration of leachate so as to increase or decrease the exposure hazard?
5. DEPTH TO GROUNDWATER: Does the estimated depth to the water table imply a high or low risk for contamination or leachate production. Relate to permeability and gradient factors.
6. GROUNDWATER GRADIENT: Gradient is dependent on local relief, estimated permeability, aquifer characteristics and rainfall patterns. Steep or flat gradients by themselves cannot be presumed to have similar effects in each case. Judgment is required on local conditions.
7. BEDROCK CHARACTER: Is local bedrock important factor in local hydrologic system? If so, do textures or structures in bedrock produce asymmetry or enhanced flow of potential leachate plume (flow along bedding, joints, faults, or solution channels, etc.)
8. SOIL PROPERTIES, TEXTURE AND BEHAVIOR: Are there known textural or mineralogical factors that could enhance or diminish leachate migration, such as strong cation exchange or swelling/shrinking clays (cracking)? Are seasonal effects such as rainfall duration, infiltration capacity, freeze-thaw conditions, vegetation cover, etc. of significance?
9. ADDITIONAL FACTORS: These three considerations are meant to allow for an increased distinction between sites where data is only extrapolated (however confidently) and those where subsurface borings have been located. The "additional points" (added or subtracted) formally take into account the natural prejudice likely to be accorded better documented sites. They may raise or lower the priority, or it may be concluded that no clear effect is obvious (+1, -1, 0). One point on a scale of 21 will not unrealistically distort the relative scores in a subjective evaluation. All borderline scores should be reviewed in any event, and a final judgment made as to whether the higher or lower category is more appropriate. Informed or professional judgments should override arbitrary numerical scores, especially where the geohydrology may be complex. In the final analysis not all sites can be accurately evaluated without some subsurface exploration.
10. COMPUTING RANK: After all columns are filled in for A, B, or C, the number of entries is multiplied by the rating factor and added for the subtotal. Additional factors circled are added or subtracted to compute total points for site rank.

Figure 6.

Geologic ranking sheet. This scheme is intended to serve only as a general guide and evaluation record and should not be used as an absolute means of discriminating between sites having numerical differences of only 1 or 2 points.

a. Front of form.

b. Back of form.

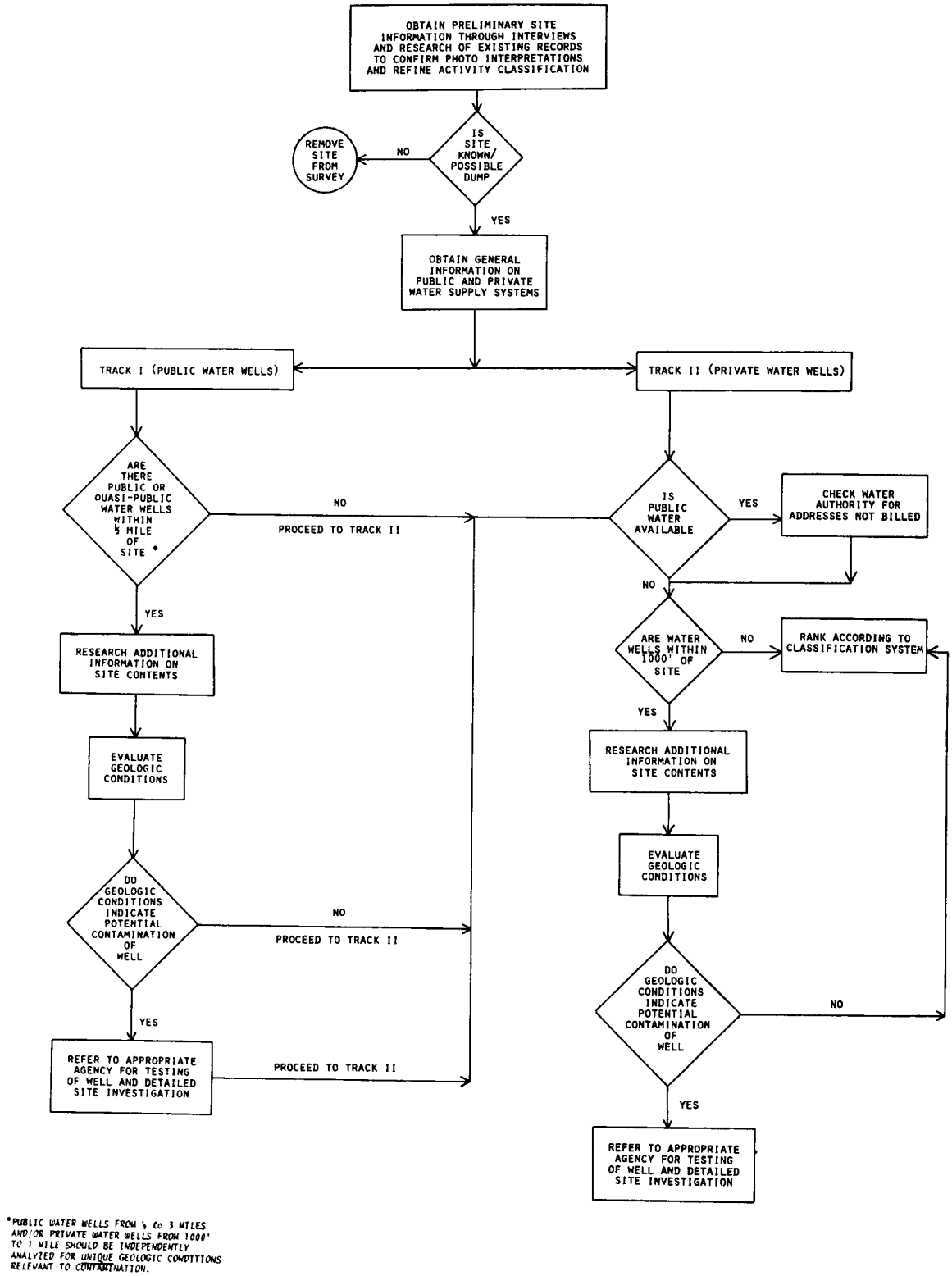


Figure 7.
Flow chart for investigating water wells near potential or documented abandoned dump sites. Distance limits are arbitrary and may be changed to fit circumstances.

scribed under the Geologic Analysis section of this report.

The information on each site is combined into a final classification system, incorporating site identifying information.

Sample Site Code No:

D	10	RO	6	1	1	3	2
A	B	C	D	E	F	G	H

A: Type of site activity (dump, possible dump, unspecified fill, lagoon, junkyard)
B. Quadrangle sheet number (assigned)
C. Municipality: two letter code (assigned)
D. Site number (assigned)
E. Proximity to wells: (private wells within 1000 ft.; public wells within 0.5 miles)
F. Major or minor
G. Land use: 24-hour or part-time occupancy on or adjacent to site
H. Geology: impact of leachate

Sites that could impact nearby wells are immediately referred to local and state health agencies for testing. The remaining sites are prioritized in a matrix that weighs geologic and land use impact, size, and type of activity.

CASE HISTORY

One of the proposed uses of the general geologic analysis and map products is the development of geologic models from available engineering data that can be extrapolated to sites where subsurface information is inadequate. The following example illustrates this approach.

A cross-section through an abandoned landfill located on a former proglacial lake shoreline is shown in Figure 8. This abandoned site, now beneath a paved shopping area, was the subject of studies related to construction of a deep sewer project. Descriptions of former gravel deposits in borrow pits nearby were also located in old geologic publications.

The Weiland Road landfill, partially abandoned and built over, but still used, in part, by a large corporation as a private solid waste disposal site is shown in Figure 9. The Weiland Road site is located on a similar, but higher, abandoned glacial lake shoreline a few miles to the west of the Culver Road site. The approximate location of both areas is shown on Figure 3.

The Monroe County study documented photographically the extent of the Weiland Road site and described the anticipated subsurface geologic conditions using the Culver Road site for comparison. This information was used by state and county agencies to evaluate procedures proposed by the company to upgrade the existing leachate collection system. It was postulated that wave energy in the former glacial lakes would have left more permeable sediments at depth than had been encountered or described in preliminary borings. Borings for a county highway relocation project adjacent to the site strengthened this hypothesis which resulted in the company drilling additional borings in suspected critical areas. Sandy sediments were located at depths of ten feet or more below the existing fill. This new subsurface information con-

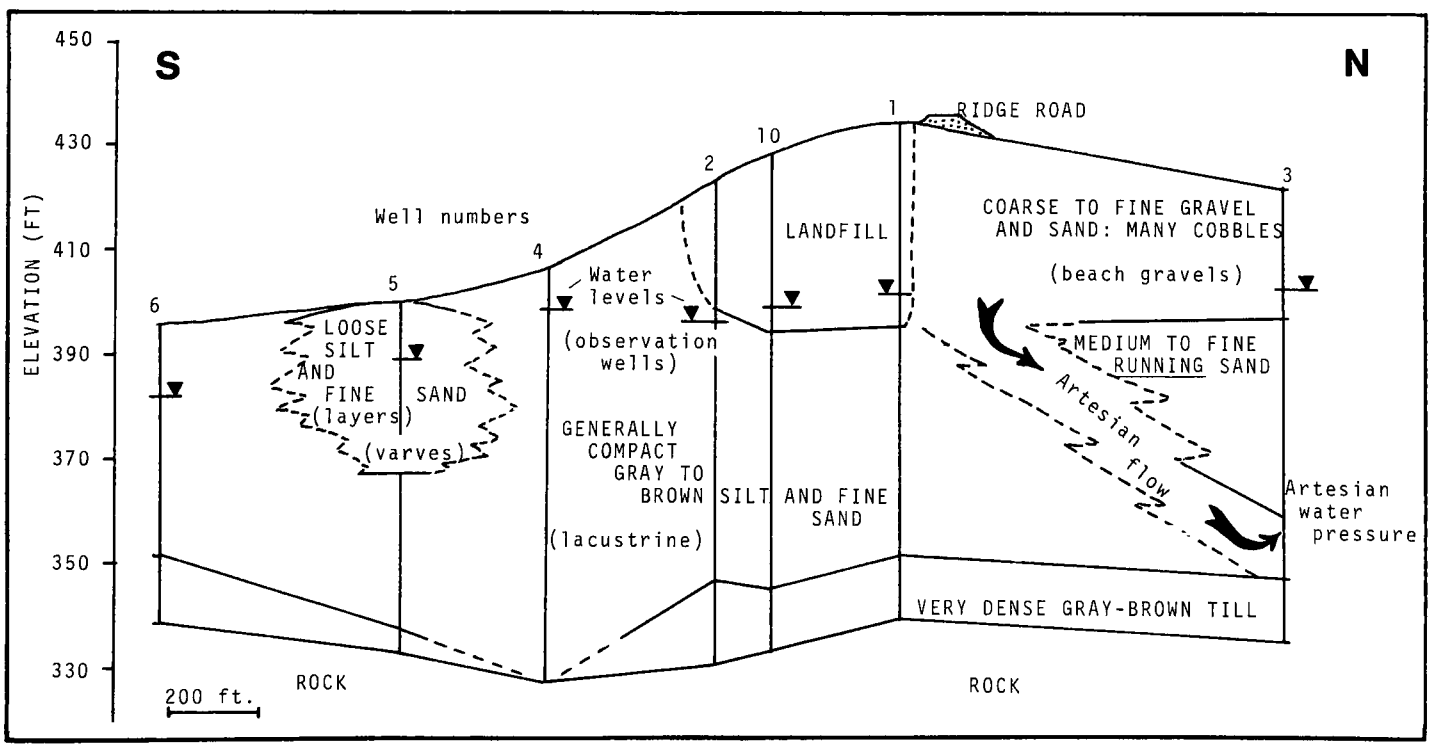


Figure 8.
Hydrogeologic conditions and interpretive geologic cross section of Culver-Ridge Shopping Center site developed from sewer interceptor contract studies. Groundwater monitoring and soil investigation wells indicated by vertical lines. Location A on Figure 3.

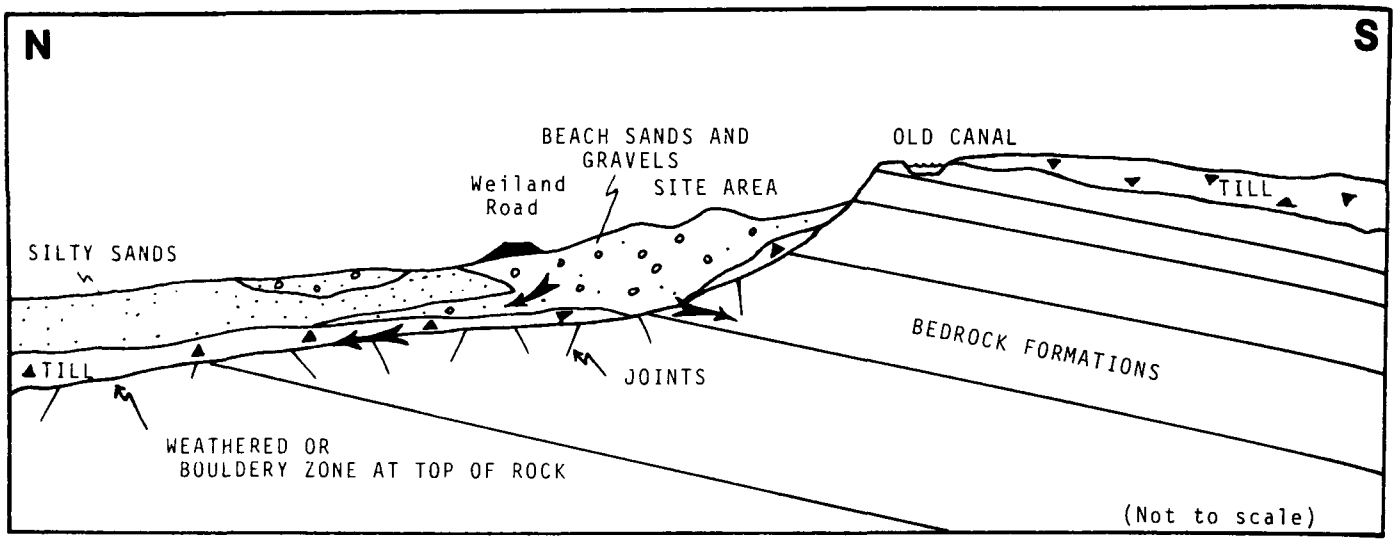


Figure 9.
Diagrammatic geologic cross section of the Weiland Road solid waste disposal site illustrating the inferred relations between groundwater and surficial deposits prior to site development. Arrows denote subsurface groundwater migration. Location B on Figure 3.

firmed the preliminary geologic analysis and permitted an evaluation of the existing leachate collection system.

As a result of the recommendations of a joint committee composed of participating state and county agencies, a more comprehensive groundwater sampling plan was voluntarily developed and implemented by the owner. Further investigations are being considered to evaluate the effects of the landfill on nearby wells in bedrock located near geologic structures striking toward the landfill. This structural zone was unsuspected prior to recent completion of subsurface engineering studies unrelated to the landfill.

SUMMARY AND CONCLUSIONS

In the final analysis, no general program for identifying abandoned dump sites can ever completely determine the location and contents of all hazardous waste disposal areas. The Monroe County approach is designed to provide general information on a large number of previously undocumented sites, as well as a method for local, state and federal agencies to prioritize sites for more detailed site investigation and testing. Application of the procedures will reduce the expense of costly drilling and testing programs by focusing resources on the most critical sites.

ACKNOWLEDGMENTS

This study has been conducted under the direction of the Monroe County Landfill Review Committee, comprised of representatives of the Monroe County Environmental Management Council, the Monroe County Departments of Health and Planning, the New York State Departments of Health and Environmental Conservation, the City of Rochester Department of Community Development and the Industrial Management Council.

The development of the methodology has been made possible through the financial support of the New York State Department of Environmental Conservation in 1979 and 1980, and currently through the United States Environmental Protection Agency's Environmental Monitoring Systems Lab in Las Vegas, Nevada (Contract No. 14043 administered by Lockheed Engineering and Management Services Company, Inc.).

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1. LeGrand, H. E., *A Standardized System for Evaluating Waste Disposal Sites:* A manual to accompany description and rating charts. National Water Well Association, Worthington, Ohio, 1980.
2. Kufs, C., Twedell, D., Paige, S., Wetzel, R., Spooner, P., and Colonna, R., "Rating The Hazard Potential of Waste Disposal Facilities." *Proceedings, U.S. EPA National Conference on Management of Uncontrolled Hazardous Waste Sites,* October 15-17, 1980, Washington, D.C. Hazardous Materials Control Research Institute, Silver Spring, Md. 31-41.

SELECTION OF MONITORING WELL LOCATIONS IN EAST AND NORTH WOBURN, MASSACHUSETTS

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Ecology and Environment, Inc.
Woburn, Massachusetts

INTRODUCTION

Potentially hazardous materials have been generated, stored, used and disposed of in East and North Woburn, Massachusetts and portions of the surrounding towns (Figure 1) for over 120 years.

Of particular interest is the Industri-plex site situated in North Woburn which has a long history of chemical manufacturing activity. In 1853, Robert B. Eaton's Chemical Works began to produce chemicals for the textile, leather and paper industries of New England. In 1863, the property was purchased by Merrimac Chemical Company which, by 1929, grew to be one of the largest chemical manufacturers in the country. Products of this complex included lead-arsenic pesticides, acids, TNT and various heavy metal compounds.

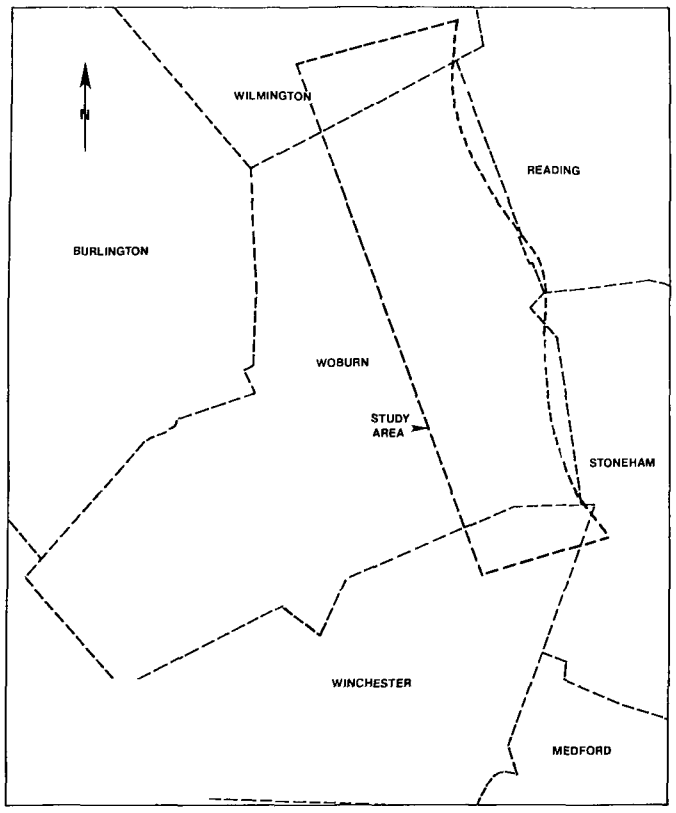

Figure 1.
Site Location
(Scale: 1:48,000)

Between 1934 and 1968, ownership of the property changed hands several times, and the production of animal glue and grease became the primary activity.

Present industries within the defined study area (Figure 2) include three chemical manufacturers, a tannery, a tallow manufacturer, three drum reclaiming operations, a waste oil company, several auto junkyards, a truck washing operation and the City of Woburn sanitary landfill. In addition, several suspected illegal hazardous waste dump sites have been identified within the study area.

As a result of present and past industrial and illegal dumping activities, a very productive aquifer tapped by approximately 200 industrial, private and municipal wells has been contaminated. Two of Woburn's municipal drinking water wells were closed in late 1979 when significant amounts of chlorinated organic solvents were detected in the water.

As a result of the detection of groundwater contamination in Woburn, Ecology and Environment, Inc. (E & E) was authorized by EPA (Contract # 68-01-6056) to investigate the sites of fifteen existing industries to determine if they were sources of the contamination. No direct sources of the previously detected contamination were discovered during the site inspections. Because of the complex industrial history of the area, it is very likely that the detected contamination was introduced at some time in the past from a source no longer in existence.

E & E was then asked by the EPA to evaluate groundwater quality in the entire East and North Woburn area. It was decided that a complete hydrogeologic investigation of the area would be necessary to identify past or present sources of contamination and to recommend appropriate remedial action. The purpose of this paper is to outline the approach developed by E & E for this investigation, especially the siting of additional groundwater quality monitoring wells.

BACKGROUND INFORMATION GATHERING

The study area (Figure 2) of approximately ten square miles is a very large area for a complete hydrogeologic investigation. Route 128 divides the area into North Woburn and East Woburn. The Industri-plex area as well as the

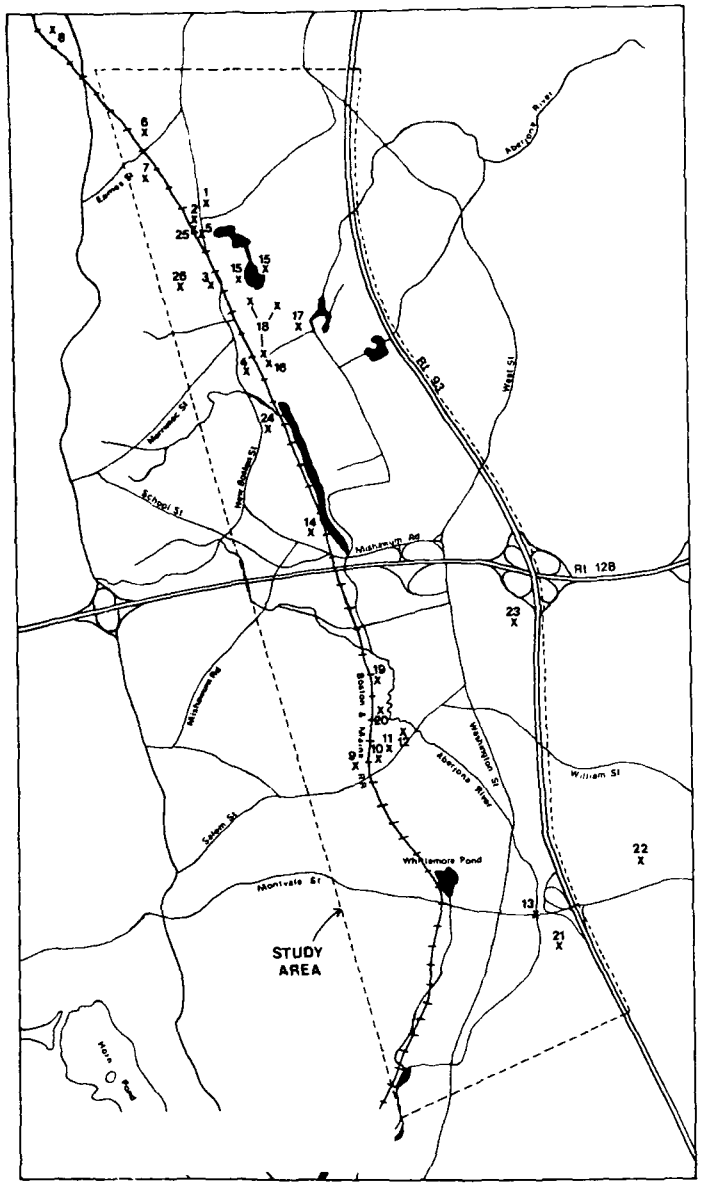

Figure 2.
Sites includes in the groundwater investigation of East and North Woburn, MA.

Key for Figure 2
Sites Included in the Groundwater Investigation East and North Woburn, Massachusetts

1. Truck washing operation
2. Drum reconditioning plant
3. Chemical warehouse
4. Drum reconditioning plant
5. Septage receiving station
6. Paint and lacquer thinner plant
7. Chemical manufacturer
8. Chemical manufacturer
9. Tannery
10. Waste oil company
11. Drum reconditioning plant
12. Used auto parts
13. Degreasing plant
14. Former City of Woburn sanitary landfill
15. Present location of hide piles
16. Chromium lagoon
17. Former location of hide piles
18. Arsenic pits
19. Arsenic trioxide drums (now removed)
20. Unlabelled barrels and drums along unpaved road
21. Food processing plant
22. Stoneham—Sweetwater Brook
23. Tallow company
24. Drum burial site
25. Drum storage area
26. Present location of Woburn sanitary landfill

majority of industrial sites are located north of Route 128, and this area was once considered to be the largest industrial complex in the world. South of Route 128 is primarily residential, and it is within this area that an elevated level of childhood leukemia has raised suspicions regarding the quality of the city's drinking water. The Aberjona River passes from north to south through the industrial complex and the residential area and empties into the Mystic Lakes which are used extensively for recreational purposes.

To determine the need for and locations of monitoring wells in an area as large as Woburn, a detailed background investigation was performed. All chemicals which might be encountered during preliminary sampling of existing wells were identified during a process evaluation of existing and historical industrial activities. A toxicological evaluation of the identified chemicals was then performed to ensure the safety of all individuals involved in the sampling of existing wells and installation of additional monitoring wells.

All available information regarding the geology and hydrology of the area was assembled. Included were topographic maps, aerial photographs from 1938 to 1980, a bedrock outcrop map, numerous well logs, USGS hydrologic data reports, groundwater quality analyses and literature on the bedrock geology. To fill in the gaps in the literature, a field survey was performed to investigate the nature and competency of all bedrock outcrops and gather additional data regarding the unconsolidated glacial deposits overlying the bedrock.

Although drillers logs for 123 wells within the study area were located, most wells were found to be screened in the glacial materials and very little depth to bedrock data was available. Previous experience regarding the investigation of organic solvent contamination of groundwater has shown that the solvents tend to migrate downward through the aquifer to the bedrock/overburden interface and into the bedrock if it is highly fractured. Because of this, an accurate picture of the bedrock surface configuration is essential to an evaluation of contaminant migration.

A seismic survey was performed to gather the necessary depth to bedrock information. The performance of this survey was hampered by thick deposits (up to 50 feet) of peat along the Aberjona River and in the area formerly occupied by Lake Mishawum in North Woburn. The presence of heavy traffic and various utilities also increased the challenge of locating appropriate sites for

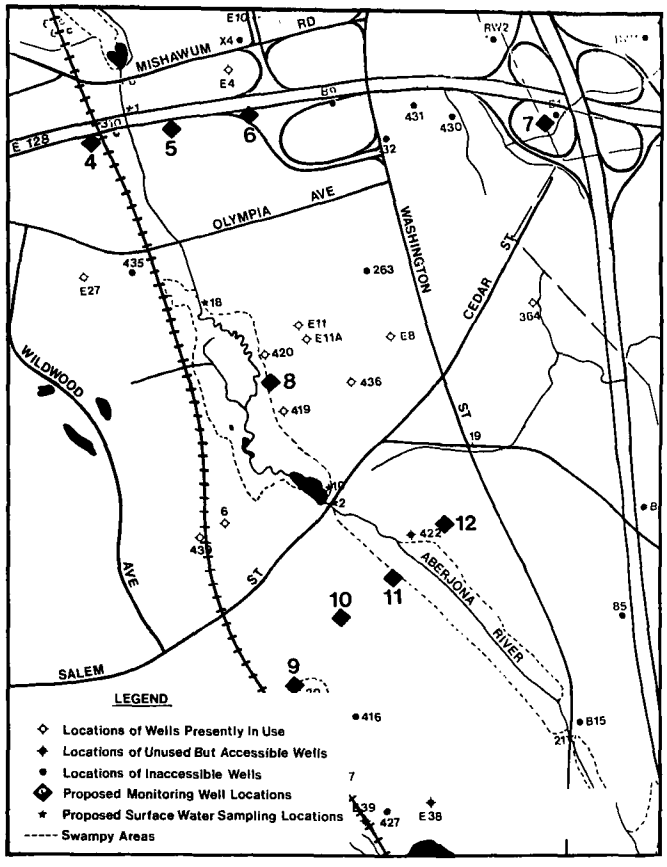

Figure 3.
A portion of the base map of the Woburn, MA. study area

seismic lines. However, appropriate data were recorded and later supplemented by existing well and bedrock outcrop data to produce a bedrock surface elevation contour map. The seismic survey also provided data regarding the water table depth within the study area.

The locations of all 123 inventoried wells were inspected to determine which of the wells could be sampled. Of these, 32 wells were found to be accessible and a sample from each was taken following approved EPA procedures. Due to the complex industrial history of the site, each sample received a complete priority pollutant analysis at an EPA approved laboratory. Preliminary screening of all samples was performed on site by E & E using a portable organic vapor analyzer. This procedure ensured the identification of highly volatile organics which might be lost if a delay of the complete analyses occurred.

SELECTION OF MONITORING WELL LOCATIONS

Using the assembled background information, a series of maps was generated to aid in the selection of appropriate sites for groundwater quality monitoring wells and to develop the appropriate specifications for the installation of these wells.

Using color stereo aerial photographs taken on November 6, 1980, a base map of major roads and railroads having a scale of 1:9600 was prepared. The locations of all inventoried wells were plotted on this map. In addition, the surface drainage of the area was plotted on the base map using the stereo imagery. A portion of the base map is shown in Figure 3 to illustrate the types of information contained in it.

A uniform set of well logs was constructed from the existing data to facilitate correlations between logs and the construction of geologic cross-sections. Because of the large area of the site, twelve cross-sections were required to adequately characterize the area. Figure 4 is an index map of the prepared cross-sections and Figure 5 shows a portion of one of the sections. The sections were prepared with a horizontal scale of 1:9600 so that they could be used in conjunction with the base map and all maps derived from it.

The geologic map presented in Figure 6 was prepared from the literature and field survey of all outcrops within the study area performed by E & E personnel.

Using the 1:9600 scale base map, a ground elevation contour map, water table contour map and bedrock surface contour map were prepared. United States Geological Survey topographic sheets were used to prepare the ground elevation contour map. Water table elevation measurements taken by E & E personnel were supplemented by

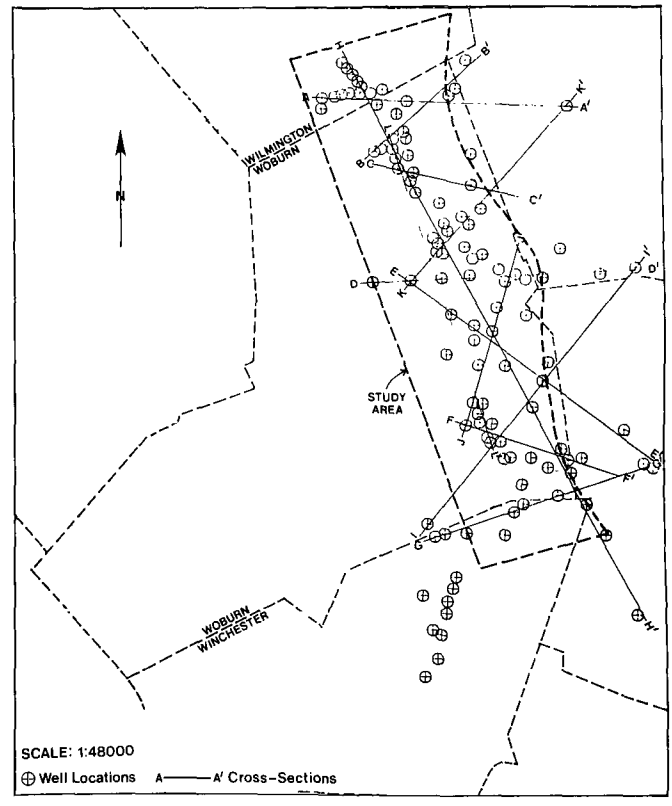

Figure 4.
Cross-section locations
(Scale: 1:48,000)

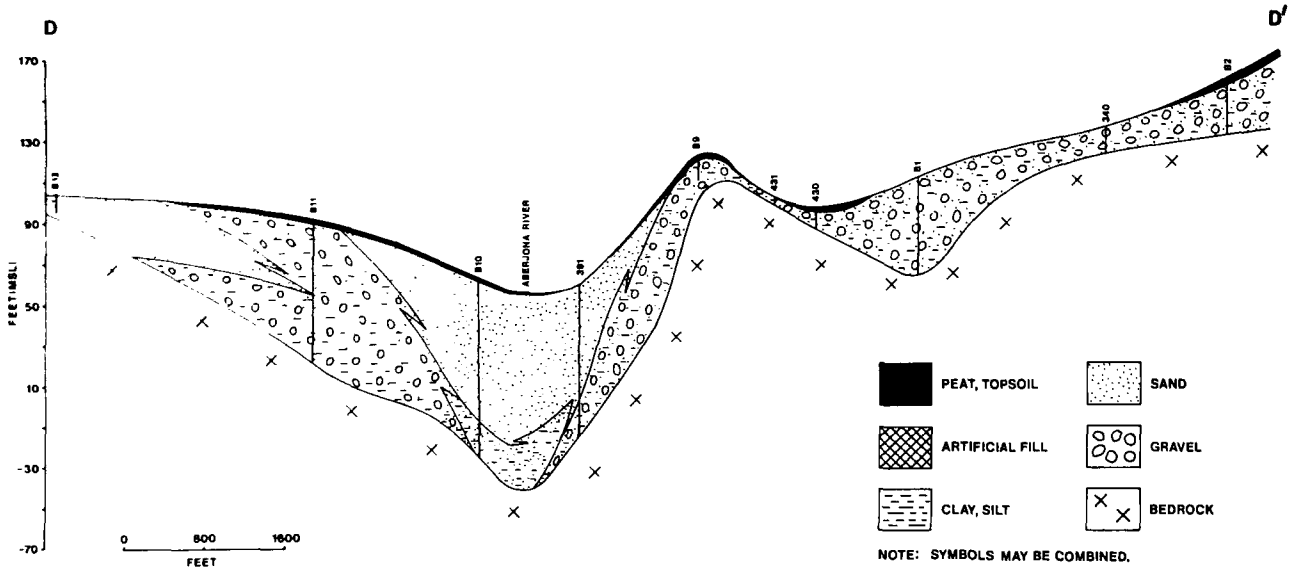

Figure 5.
Cross-section D-D′

data from the available literature logs and the seismic survey to produce the water table contour map.

The surficial deposits are controlled to some extent by the bedrock topography, the most prominent feature of which is a fault-controlled valley. This valley was probably widened and deepened during Pleistocene glaciation. Locally, the valley has very steep walls, but throughout most of the study area, it has gently sloping walls.

The areas adjacent to the valley are mantled with glacial till consisting of poorly sorted sand, silts, clays and cobbles. The bedrock valley contains glacial deposits up to 160 feet thick overlain by modern alluvial deposits. The glacial material in the valley consists of outwash deposits of fine- to coarse-grained sands and gravel interbedded with fine sand, silt, clay and till. Well log data indicate that the sediments generally become coarser with depth. Upper and central portions of the valley contain finer sands, silts and clays, while the coarser sands, gravels and till are located at the bottom and long the walls of the valley. Much of the finer materials was deposited by meltwater streams which sorted and reworked the valley material.

Modern alluvium associated with the Aberjona River System consists of peat deposits and bogs located along the current course of the river and its tributaries. Topsoil and artificial fill make up the top five to ten feet of the surface deposits except in North Woburn where extensive reworking of the sediments by man has severely disrupted the surficial deposits.

Bedrock Surface Topography

The northern one-quarter of the study area is characterized by four shallow bedrock troughs which meet to form one deep north-south trending trench. The four troughs slope toward the deep trench from the general

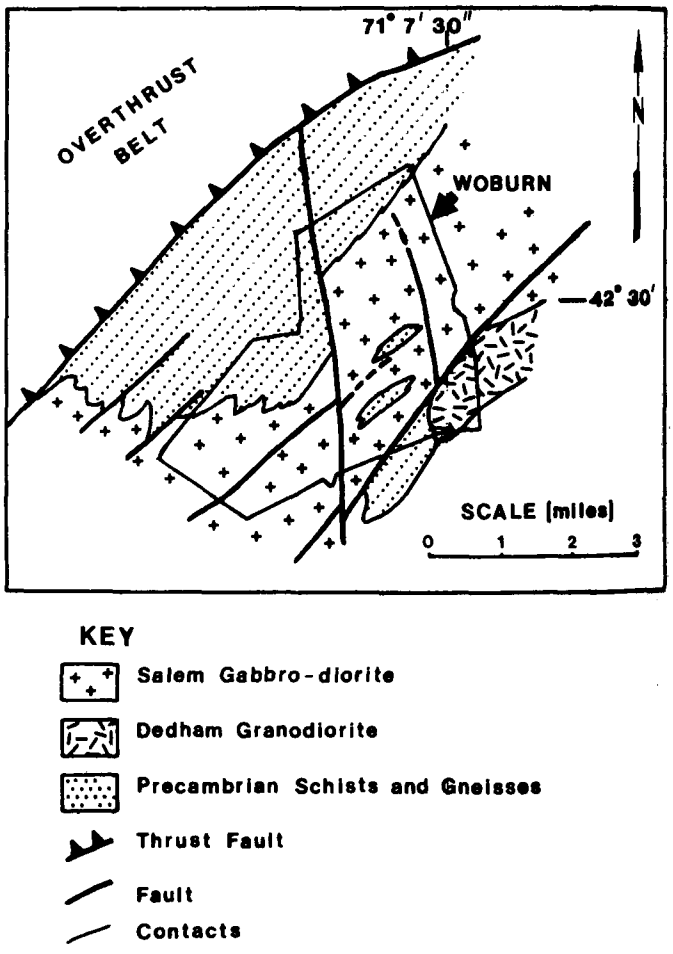

Figure 6.
Geologic map of Woburn, MA

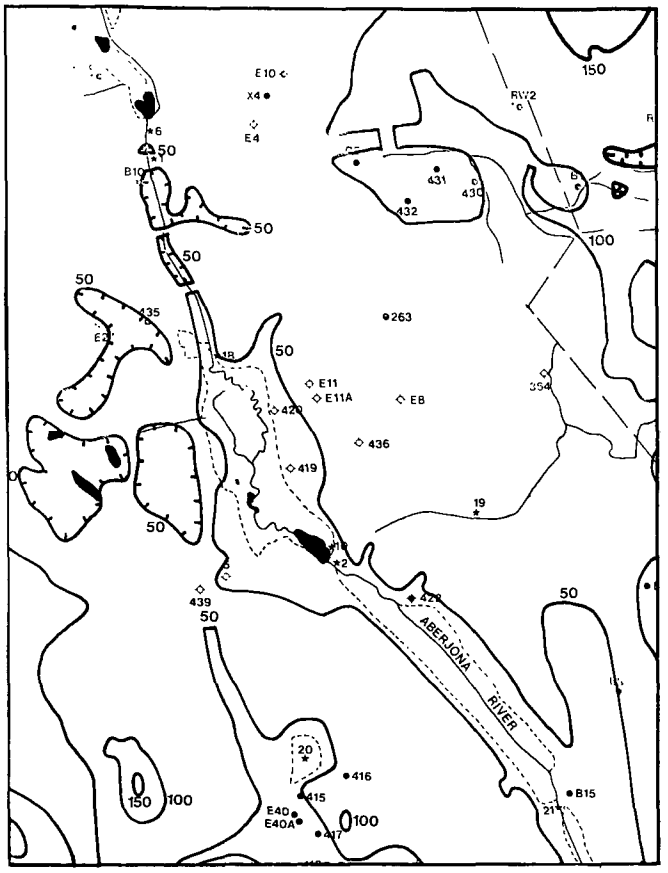

Figure 7.
A portion of the ground elevation contour map of the Woburn, MA. study area

areas of the two branches of the Aberjona River to the northeast, the East Drainage Ditch to the north and the Woburn Sanitary Landfill to the northwest. The deep trench is approximately two miles long and reaches a depth of approximately 100 feet below the ground surface providing a possible trap for groundwater contamination.

The southern portion of the area is characterized by a deep trench sloping from the Stoneham/Woburn boundary to Whittemore Pond and into Winchester with depth increasing to 150 feet below the ground surface at the Woburn/Winchester boundary. A shallower trench under the Sweetwater Brook enters the deep trench approximately 1200 feet southeast of Whittemore Pond.

Between the two deep bedrock trenches in the study area is a bedrock high. All of the bedrock troughs and trenches in the study area are most likely fault-controlled as the regional geology indicates faults trending parallel to them. In general, the groundwater and surface water within the study area flow parallel to the fault shear zones and are presumably controlled by them.

At the east and west borders of the study area, the bedrock surface rises sharply, and many bedrock outcrops are present along Route 93 and west of the Boston & Maine Railroad tracks.

Bedrock Geology

The Woburn Study Area is situated within the Appalachian Mountain orogenic belt which extends from Georgia to Newfoundland. The belt is comprised of a series of plutonic, sedimentary and volcanic rocks, Precambrian through Permian in age, most of which have undergone multiple deformation and intense metamorphism. The Northern Appalachians (New England and the Maritime Provinces) are divided by Zen[1] into several broad linear structural features or zones. The Woburn Study Area is located in the easternmost zone called the Eastern Avalonian Platform.

The Eastern Avalonian Platform is characterized by Late Precambrian metavolcanic rocks intruded by a series of Late Precambrian granitic plutons. The age of these plutons has been radiometrically set at approximately 630 million years by Naylor.[2] Unconformably overlying these Precambrian rocks are fossil-bearing lower Cambrian strata composed of shales and carbonates. Superimposed on the Platform are several down-faulted blocks or basins; the Boston Basin being nearest to the Woburn area. A large thrust belt of Precambrian metavolcanic and metasedimentary rocks lies at the western edge of the platform. The Woburn Study Area (Figure 1) lies between the thrust belt and the Boston Basin.

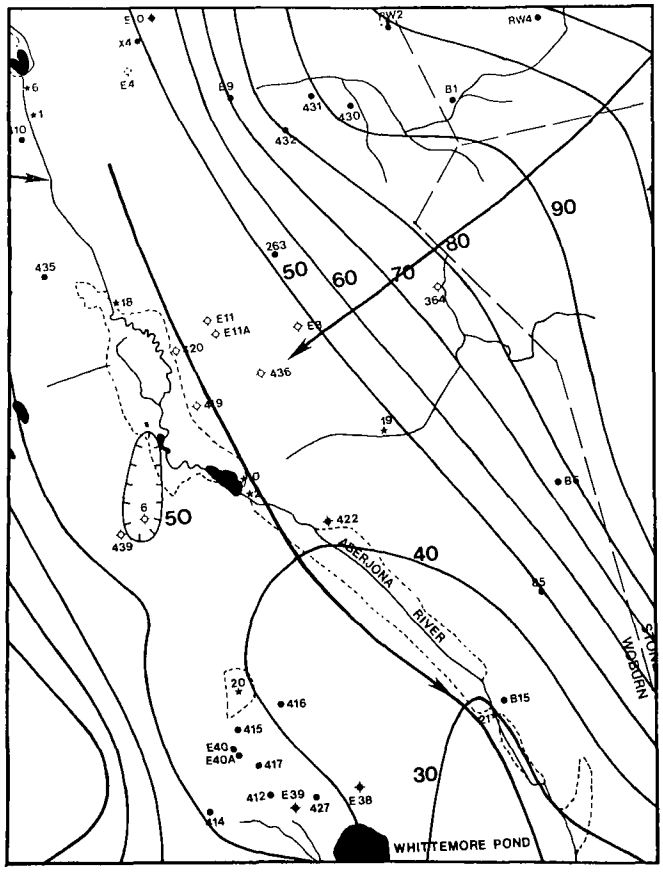

Figure 8.
A portion of the water table contour map of the Woburn, MA study area

Relationships between the units described above are difficult to determine in the field because extensive glacial material overlies the bedrock resulting in widely spaced outcrops. In addition, faults have dissected the region into slices and small blocks, extensively distorting the regional geology. As a result, the geology of the study area is not well known, having been mapped in reconnaissance fashion only, by Emerson,[3] LaForge,[4] Bell and Alvord, [5] and Barosh. *et al.*[6]

Where faulting occurs, the original character of the rock is severely altered to produce a finer-grained, highly-foliated rock that is very susceptible to weathering. In time, weathering of the faulted materials will produce topographic lows or valleys within the bedrock surface. Glacial plucking is more easily accomplished in the faulted material than in the non-faulted rocks. Within the Woburn area, several faults exist, some paralleling the regional trend of the rocks (northeast-southwest) and some perpendicular to the regional trend. The bedrock lows associated with fault zones appear to control a significant amount of the groundwater and surface waters in the Woburn area.

Groundwater Flow Direction

Groundwater flow closely parallels surface water flow throughout the study area. Groundwater from the west,

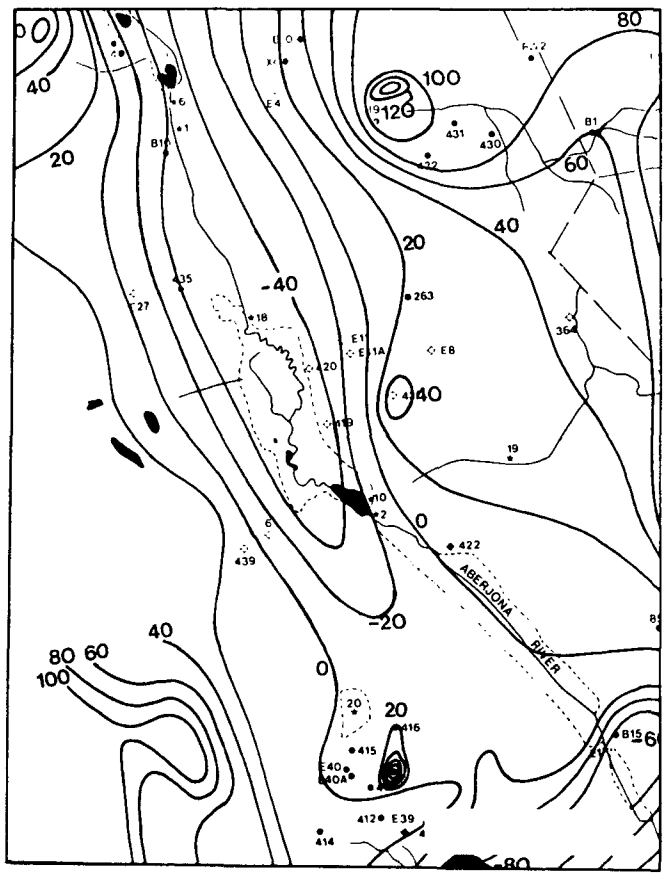

Figure 9.
A portion of the bedrock elevation contour map of the Woburn, MA. study area

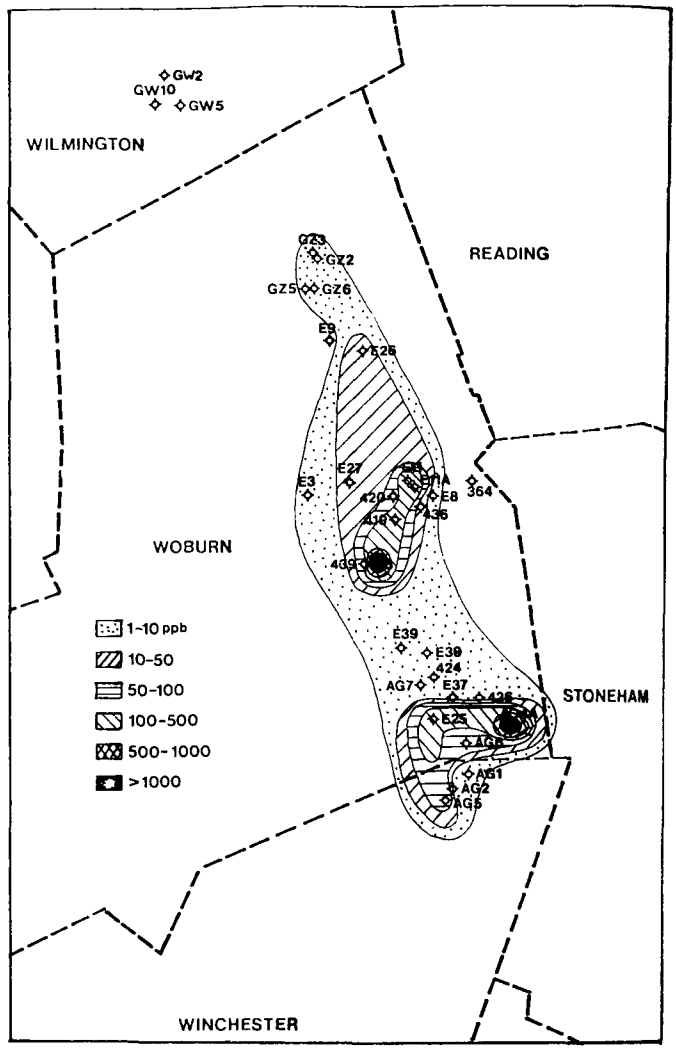

Figure 10.
Areal distribution of trichloroethylene East and North Woburn, MA

north and east moves toward the center of the area and then south into Winchester. Contours in the Sweetwater Brook area are close together indicating a strong gradient from Stoneham into South Woburn. Groundwater depressions near the center of the area and in the southern portion of the area represent the drawdowns resulting from the pumping of industrial wells.

SELECTION OF ADDITIONAL MONITORING WELLS

All of the data gathered during the procedure described earlier in this paper were used to select sites that will provide the maximum amount of reliable information. Of primary concern during the selection of the sites were the locations of bedrock depressions and fault zones, areas with confirmed high levels of groundwater contamination, areas down gradient from suspected sources of contamination and areas where there are no existing accessible wells. The locations chosen are shown in Figure 11. An accurate assessment of groundwater con-

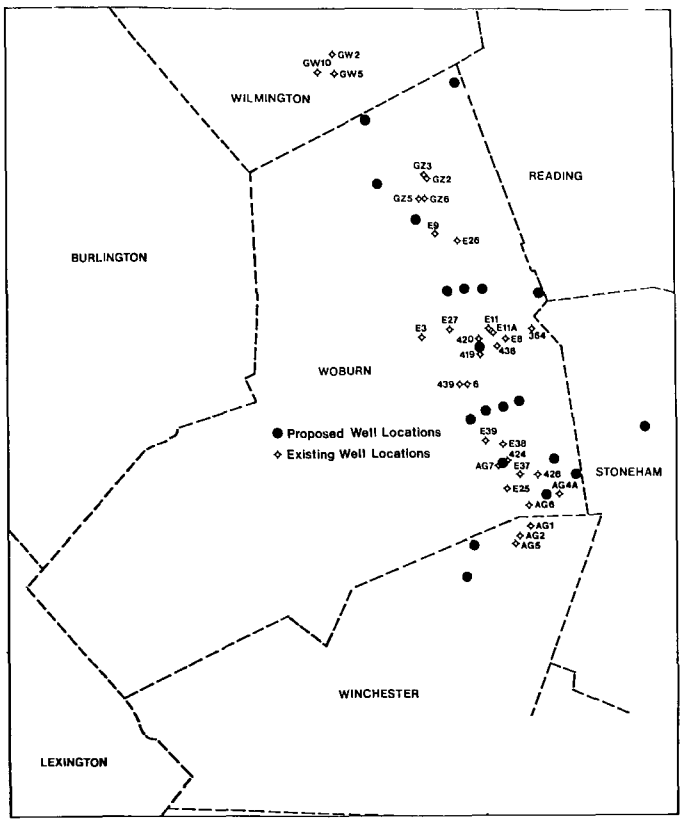

Figure 11.
Locations of proposed monitoring wells

tamination within, entering and leaving the study area will be possible using the existing and proposed monitoring wells. From this information, recommendations for appropriate remedial actions may be formulated.

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CHARACTERIZATION, IMPACT ASSESSMENT, AND CLOSURE REQUIREMENTS FOR A COPPER RESIDUE DISPOSAL SITE

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INTRODUCTION

An 11 acre disposal site located in the southeastern United States was utilized for 50 years for the disposal of copper-laden sludges and a number of other materials from the production of rayon. This paper summarizes the results of a preliminary engineering/hydrogeological study which included characterization of the materials in the waste fill, an assessment of the impact of the site on surface and groundwater and development of closure plans for the site so that a light industrial park could be developed on land adjacent to and possibly on the closure area.

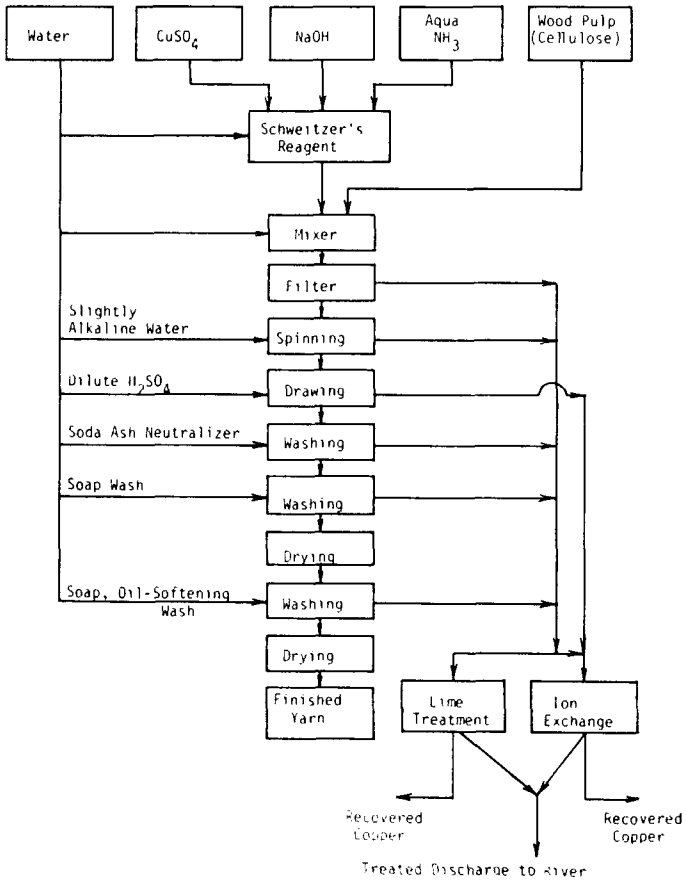

Figure 1.
Process Flow Diagram—Cuprammonium Rayon Production

The textile mill adjacent to the site was utilized for the production of rayon fiber between 1927 and 1977. The northern portion of the property includes a filled disposal area, whose size is estimated to be approximately 11 acres. The disposal area lies just south of a moderate size river. Adjacent to the site is a lagoon with a surface area of approximately 3.8 acres, which was utilized for controlled release of treated liquid process wastes while the mill was in production. There is also a much smaller depression on the site, which is dry and contains a sludge residue.

Field reconnaissance indicates that during the years of operation of the textile facility, virtually all types of solid wastes generated at the mill were disposed of in this site, including rayon and paper waste, construction debris, laboratory wastes, scrap equipment and some process sludge residues. These residues likely resulted from the spent copper ammonium sulfate spinning solutions used in the rayon production. Based upon existing topography at this site, the disposal area ranges from 1 to 15 ft above original ground elevations, varying with location.

The state environmental regulatory agency had expressed concern about the disposal area as it presently exists and about the potential for contamination of surface and groundwaters. The owners were interested in reclamation of the site for use as a portion of an industrial park that could be developed on the mill property. The goal of the evaluations described herein was to conduct a preliminary engineering evaluation for site closure that will be acceptable to the state agency and also is environmentally sound and in conformance with the appropriate regulatory requirements.

SITE HISTORY

Rayon manufacturing activities commenced at the mill site in 1927 and continued until December, 1969, when the plant was sold. The plant reopened in August, 1971, but in 1977, production again ceased and the company declared bankruptcy. There have been no rayon manufacturing activities conducted at the site since 1977.

Rayon was manufactured at this mill via the cuprammonium process which involved mixing cellulose (wood pulp) with an ammoniacal copper hydroxide solution (Schweitzer's Reagent). The copper solution was prepared by adding caustic to a copper sulfate solution, filtering and dissolving the precipitate in aqua ammonia. The cel-

lulose solution was then diluted with water, filtered and forced through a spinneret into a coagulating bath of caustic. Coagulated cellulose was decoppered with sulfuric acid, and subjected to a series of washing and drying steps. Both lime precipitation and ion exchange were employed for copper recovery and wastewater treatment. A manufacturing process flow diagram is presented in Figure 1. Principal chemical reactions were as follows:

$$\underset{\text{cellulose}}{(C_6H_{10}O_5)} + \underset{\text{Schweitzer's Reagent}}{Cu(OH)_2} + NH_3 + H_2O \quad \text{solution of cellulose}$$

$$\text{Cellulose solution} + NaOh\ (5\%) \longrightarrow \text{partly coagulated cellulose}$$

$$\text{Partly coagulated cellulose} + H_2SO_4(1\tfrac{1}{2}\%) \quad (C_6H_{10}O_5)\ x$$

Cuprammonium rayon

PROJECT SCOPE

The initial activity on this project was a preliminary site reconnaissance conducted with the client and representatives of State and Federal agencies. A detailed plan of study was then prepared which outlined major work tasks, the extent of field activities, and a project schedule; this plan of study was submitted to the client and agencies for review and comment. The project's scope (Table I) of work included:

(1) Review of information pertaining to the manufacturing process that generated the copper residuals
(2) Review of agency file information (historical correspondence, flood plain maps, meteorological data)
(3) Topographical survey of the site and examination of original topographic maps for the area
(4) Acquisition and review of all available soils, geologic and hydrologic information
(5) Residue and soil sampling and characterization
(6) Groundwater monitoring well installation, sampling and analysis of groundwater samples
(7) Detailed field reconnaissance and surface drainage evaluations
(8) Assessment of site environmental impacts
(9) Preparation of a conceptual closure plan and engineering report.

Table I.
Work Task Outline
Preliminary Engineering for Closure of Disposal Site

TASK	TITLE
1.0	Project Management
2.0	Plan of Study
3.0	Background Information
4.0	Topographical and Boundary Survey
5.0	Hydrogeologic Evaluation
5.1	Available Data Base
5.2	Field Investigations
5.3	Sample Analysis and Data Evaluation
6.0	Field Reconnaissance, Surface Draining Evaluation, Sampling and Analysis
7.0	Regulatory Agency Liaison
8.0	Conceptual Plan for Site Closure
9.0	Engineering Report

SITE CONDITIONS AND EVALUATIONS

Topography

The disposal site topography (Figure 2) is fairly irregular, with existing ground surfaces ranging from elevations 1,525 ft to 1,496 ft. Portions of the site are thinly wooded and vegetated, while the bulk of the surface area consists of solids and waste materials. In general, ground surfaces slope to the north and northwest, toward the river.

Surficial Waste Materials

A detailed site reconnaissance was conducted to classify and quantify surficial debris. There are five categories of waste products, as follows:

Waste Produce	Approximate Exposed Surface Area (Acres)
Ash and Cinders	2.2
Refuse (trash, lumber, pallets)	1.7
Construction Material (bricks, concrete)	1.0
Rayon	
Spools	0.2
Barrels (Fiberboard)	0.3
Copper Sludge	1.0
	6.4

The total landfill area is about 11 acres

Waste Chemistry

Copper was utilized in the rayon manufacturing process as copper sulfate and ammoniacal copper hydroxide. Wastewaters from the manufacturing process were treated for copper recovery by ion exchange and lime precipitation. Waste products (copper sludges) from these two treatment facilities were disposed in the landfill. Contaminants in these sludges include copper, ammonia, nitrate and sulfate. Copper compounds in the sludges are unknown, but solubilities for the most probably compounds are as follows:

Compound	Solubility in Water
copper sulfate	decomposes; soluble in concentrated acid
copper hydroxide	insoluble; soluble in acid
copper sulfate, ammoniated or copper ammonium sulfate	18 g/100 g water at 21 °C

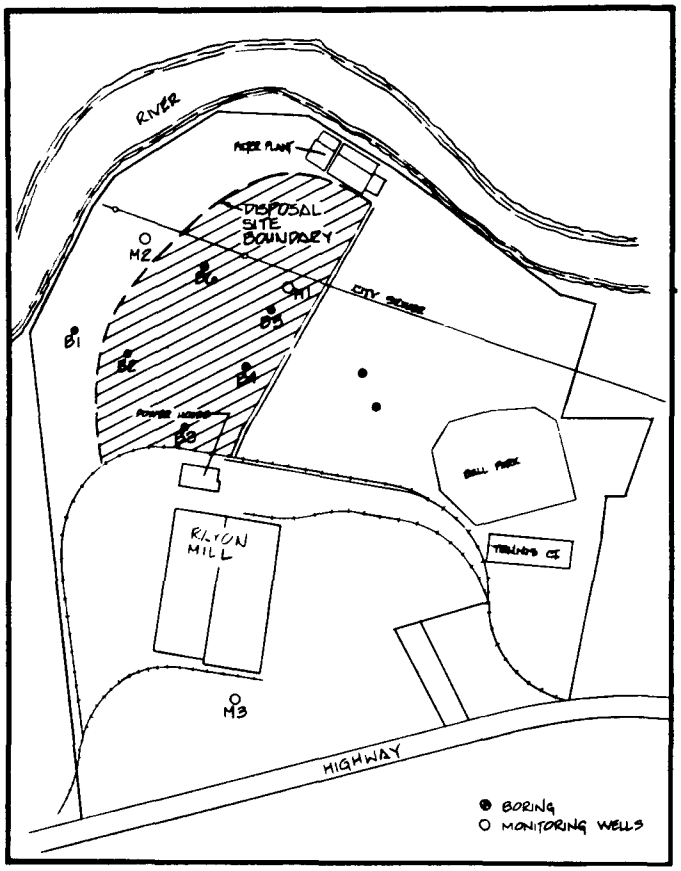

Figure 2.
Site Plan

The solubility of the copper sludges would also be influenced by natural physical and biological forces in the landfill.

Copper concentrations in two samples collected from the sludge pond were 34,000 and 100,000 mg/kg. The concentration in one sediment sample collected from the lagoon was 15,000 mg/kg. The concentrations in the sludges of the two ponds are similar to the concentration expected from the solubility of copper ammonia sulfate in water—which is 47,000 mg/l. Similar copper concentrations were present in soil samples obtained near the sludge pond.

Geology

The waste disposal site is underlain by alluvial deposits of Quaternary age and the Honaker dolomite of Cambrian age. The Quaternary alluvial deposits which immediately underlie the waste disposal site are comprised of a heterogeneous mixture of gravel, sand, silt and clay deposited by the river. Typically these alluvial deposits consist primarily of silty clay with varying amounts of silt and minor amounts of gravel and cobbles. Distinct, continuous lithologies were not apparent based upon the logs of these wells. The thickness of alluvial deposits beneath the site ranged from approximately 20 ft to greater than 35 ft.

Underlying the surficial alluvial deposits is the Honaker dolomite of Middle Cambrian age. The Honaker consists of light to dark, fine-to-coarse-grained shaley and massive dolomite. Interbedded limestone is also common within the formation with shale becoming dominant in the lower part of the formation. Structurally, the Honaker dolomite in the general area of the site has been folded into a southerly plunging, northeast trending anticline. The dip of the underlying bedrock is expected to be to the northwest. The thickness of the Honaker dolomite ranges up to about 1,300 ft in this region; however, the actual thickness at the site is undetermined.

Soils

The original soils underlying the waste disposal site were primarily Congaree and Masada type soils. The Congaree soils are present in the northern half of the site and are classified as fine sandy loam. This soil type is an alluvial soil containing mica and minor amounts of gravel and cobbles. The Congaree soils are well drained and moderately permeable. These soils have a low shrink-swell potential and a low to medium plasticity index. The Masada soils are predominantly in the southern half of the disposal area and are classified as silt loam and gravelly silt loam. These soils are also alluvial in origin and contain some gravel zones and cobbles. The Masada soils are well drained and moderately permeable. The shrink-swell potential as well as the plasticity index is low for these soils.

As part of the site investigation, two shallow borings were made on the small knoll located just east of the waste disposal site. These borings were conducted to make a preliminary determination of the type of soil materials present in the immediate vicinity of the disposal site which might be suitable for cover material. Each boring was approximately three ft deep. A composite grab sample was collected from each boring with a sieve analysis and plasticity index determination being made for each sample. The results of this limited testing indicated a sandy silty clay to clayey sand being present in the area of the borings. The clayey sand was nonplastic, whereas the sandy silty clay had a plasticity index of only 11. Additional soil samples from shallow (0.5-1.0 ft) excavations in the eastern section of the plant property have been collected by client personnel. A single composite sample was made from six separate sampling locations for laboratory determination of grain size distribution, plasticity index, and permeability. The results from this single composite sample indicate that the material is essentially a clay soil (CH) with a relatively high plasticity index of 25. A falling head permeability test performed on the composite sample revealed an extremely low permeability of 8.43×10^{-9} cm/sec.

Subsurface Investigation

In order to evaluate the distribution of potential contaminants in the soil profile beneatn the waste disposal site, six boreholes were drilled at the site. These boreholes were also intended to provide information on the characteristics and depth of waste materials across the site.

The location of each borehole is depicted in Figure 2. The six boreholes ranged in depth from 4 to 18 ft with refusal being encountered in boreholes AM-B-1, AM-B-4, AM-B-5 and AM-B-6 at depths of 4, 11, 6.5 and 5 ft, respectively. Waste materials were encountered in boreholes AM-B-2, AM-B-3, AM-B-4 and AM-B-5 to depths of 4, 11, 5 and 2 ft, respectively. The total fill material added to this area is estimated to be about 140,000 cu yd, based upon comparisons of original (1927) and existing (1980) site topography. Soil borings indicate that most of this material is ash and cinders.

Twelve grab samples were collected from six boreholes for determination of copper concentration and pH. Each sample was placed in a plastic jar with Saran Wrap® over the mouth (moisture barrier) before capping and returned to AWARE's Laboratory in Nashville for chemical analysis. The results of this sampling program are summarized in Table II.

High concentrations of copper were found in the samples from boreholes AM-B-2, AM-B-3 and AM-B-4. As expected, the highest concentrations are found in the waste materials with concentrations ranging from 26,000 mg/kg in AM-B-4 to 75,000 mg/kg in AM-B-2. The concentration of copper decreases drastically in the underlying soil in each borehole. For example, the concentration in AM-B-2 decreases from 75,000 mg/kg to 3,200 mg/kg in only a 5-ft interval; and in AM-B-4 from 26,000 mg/kg to 570 mg/kg in an interval of 7 ft. This sharp decrease in the concentration of copper with depth is to be expected since copper is one of the least mobile trace elements.

At this site, the copper is apparently readily absorbed by the silt and clay particles in the underlying soil. There appears to be no direct correlation between concentrations of copper and soil pH, which ranged from 4.5 to 9.2 This soil data, in conjunction with the groundwater quality data generated during this investigation, appear to substantiate the low mobility of copper through soils.

The three boreholes with the highest copper concentrations are all located immediately adjacent to the primary disposal area for the copper ammonium sulfate solution. The other three boreholes (AM-B-1, AM-B-5 and AM-B-6) located in the northern and western sections of the site had relatively low copper concentrations with very low values being detected at a depth of 5 ft in each of these boreholes. Therefore, the vast majority of the copper-bearing wastes are expected to be located in the southern section of the disposal site within the confines of boreholes AM-B-2, AM-B-3 and AM-B-4.

Table II.
Analytical Results of Soil and Waste Samples from Boreholes at the Disposal Site

Borehole Sample	Depth	Soil Material	pH	Copper Concentration (mg/kg)
AM-B-1	4-5'	silt	4.8	190
AM-B-2-1	4-5'	fill material & loam	6.0	75,000
AM-B-2-2	9-10'	clay	4.5	3,200
AM-B-3-1	7-8'	fill material (cinder)	8.4	50,000
AM-B-3-2	11-12'	sandy clay	9.2	5,400
AM-B-3-3	14-15'	silty clay	8.1	2,800
AM-B-4-1	1-2'	fill material	6.6	26,000
AM-B-4-2	8-9'	silty clay	9.2	570
AM-B-5-1	2-3'	sandy clay	7.7	1,100
AM-B-5-2	4-5'	sandy clay	5.8	840
AM-B-6-1	2-3'	clay	7.5	8,300
AM-B-6-2	4-5'	clay	7.4	140

Groundwater Conditions

Groundwater at the waste disposal site occurs in both the surficial, unconsolidated alluvial deposits and the underlying Honaker dolomite. Due to the heterogeneous and discontinuous nature of the unconsolidated alluvial deposits, these materials do not typically represent significant sources of groundwater. However, small yields can be obtained from the sand and gravel zones which commonly occur within these deposits. The Honaker dolomite represents a significant source of groundwater in this area with groundwater movement occurring through joints, fractures and bedding planes in the bedrock. Yields of wells completed into the Honaker dolomite in this area are reported to be in the range of 500 to 2,500 gal/min.

Several wells are present on and in the immediate vicinity of the plant site. There are three wells at the plant; however, only one well is currently being utilized. The well currently in use is located a few hundred feet southeast of the waste disposal area. The plant wells are all completed into the Honaker dolomite to depths of 305 ft, 600 ft and 700 ft with each well having a reported yield of 2,500 gal/min.

At lease nine wells have been installed at another plant just west of the rayon mill. Each of these wells is completed into the Honaker dolomite to depths of between 70 and 602 ft. Yields of these wells range from about 100 to 1,500 gal/min. Additional industrial, domestic and municipal wells are not known to be present in the immediate vicinity of the disposal site.

The depth to groundwater at the disposal site during September and October 1980 ranged from about 13 ft to 17 ft in the northern section of the site at wells AM-1 and AM-2 to about 24 ft to 28 ft in the southern section of the plant site at well AM-3 (Table III). The elevation of the water table beneath the disposal site at the time of water level measurements in September and October ranged from about Elevation +1481.9 to Elevation +1485.5. These elevations were approximately 12 to 19 ft below the base of any waste materials at the site. Fluctuations in groundwater levels would be expected to be in the range of 5 to 10 ft annually. Therefore, the base of the waste materials at the site would not be expected to come in contact with the underlying groundwater.

Based upon the general hydrogeologic setting of the waste disposal site, the direction of groundwater flow would be expected to be toward the river, a natural groundwater sink. The three groundwater monitoring wells installed as part of this investigation verified a hydraulic gradient to the north/northwest toward the river. Localized variations in the direction of groundwater flow commonly occur in carbonate bedrock such as the Ho-

naker dolomite since flow is controlled by the orientation of secondary openings such as joints, fractures and bedding planes. However, these flow variations would be relatively local in nature with the regional groundwater flow pattern being toward natural groundwater sinks such as the river.

Table III.
Groundwater Level Data for the Site

Monitoring Well	Date	Depth of Groundwater from Top of Casing (ft)	Elevation (ft)
AM-1	9/25/80	17.0	1480.2
	10/20/80	14.4	1483.5
AM-2	9/25/80	19.0	1479.3
	10/20/80	14.8	1483.5
AM-3	9/25/80	30.0	1481.9
	10/20/80	26.6	1485.5

The rate of groundwater movement in the vicinity of the waste disposal site is controlled by the materials through which flow is occurring. The unconsolidated alluvial deposits at the site would be expected to have moderate to moderately low permeabilities in the range of 10^{-3} to 10^{-5} cm/sec. The rate of groundwater flow through these deposits would be expected to be on the order of 100 to 200 ft/yr. However, the underlying carbonate bedrock would have a considerably greater permeability where secondary openings are present. Flow through these secondary openings in the bedrock would be analogous to flow through pipes with relatively high velocities in the range of a foot per day to several feet per day being common. The exact rates of groundwater flow at the disposal site were not determined; however, the above values would be expected to be representative.

In order to make preliminary determinations of the present extent and distribution of potential contaminants at the site, three groundwater monitoring wells were installed in the vicinity of the waste disposal site. Information was sought on the groundwater quality and water level data to be used as a basis for preliminary determination of potential impacts and the closure requirements for the disposal site. Two monitoring wells were located hydraulically downgradient of the waste disposal site and one monitoring well was located hydraulically upgradient of the site. The two downgradient wells are located within 200 ft of the northern boundary of the waste materials in order to provide information on the potential migration of contaminants from the site via the groundwater flow system. These two downgradient monitoring wells were deemed a sufficient number of downgradient sampling stations based upon the relatively small size of the disposal site, the characteristics of the waste materials, and the scope and intent of the project.

The upgradient monitoring well is located in the southwest section of the mill site at the southwest corner of the plant parking area. This monitoring well was installed in order to obtain groundwater quality data representative of background conditions. The upgradient well was located as far as practicable from the waste disposal site and from other past plant operations that might interfere with the wells' intended use.

Each of the groundwater monitoring wells was completed into the upper part of the uppermost aquifier beneath the site. Monitoring well AM-1 was installed approximately seven ft into the water table, whereas wells AM-2 and AM-3 were installed about 18 and 12 ft, respectively, into the water table. Since the downgradient monitoring wells are within 200 ft of the waste disposal site and the disposal site is situated in a groundwater discharge zone, completion of the monitoring wells into this uppermost zone allowed the interception of the contaminants potentially migrating from the site.

Each monitoring well installed as part of the groundwater monitoring program was constructed of 4-in., schedule 40 PVC pipe. PVC pipe was utilized since organic contaminants were not expected to be associated with the dump site in any significant quantities. It was expected that copper and inorganic parameters such as sulfates and nitrates would be of most concern at this site. Each monitoring well is equipped with a 10-ft section of perforated PVC screen. The annular space around and above the well screen was gravel-packed with the remaining annular space being backfilled with cement grout to the ground surface. A 3- to 5-ft section of 6-in. steel casing was utilized as a protective casing above ground surface. The protective steel casing is equipped with a lockable steel cap.

Following the installation of the three groundwater monitoring wells at the site, samples were collected for analysis of the following parameters:

pH	Sulfate
Copper	Chloride
Ammonia-Nitrogen	Total Organic Carbon
Nitrate-Nitrogen	

Each of the groundwater monitoring wells was bailed to remove three to five well volumes prior to sample collection. Samples were collected in appropriate containers, labeled and packed in ice for shipment to the laboratory. The pH of each sample was determined in the field. All samples were delivered to the laboratory within 24 hr of collection.

In addition to the samples collected from the three groundwater monitoring wells, samples were collected from the on-site plant well that is still being utilized and the river, both upstream and downstream of the site. Each of these samples was handled in the same manner as the groundwater samples and was analyzed for the same parameters. The analytical results for all of the water samples collected at the site are found in Table IV.

The samples from the downgradient monitoring wells, AM-1 and AM-2, have higher concentrations of most chemicals than the upgradient monitoring well, AM-3, and the existing plant well. Those parameters found to be significantly higher in the two downgradient wells included sulfate, nitrate and ammonia. Each of these chemicals would logically be present since one of the primary waste materials disposed at the disposal site was

Table IV.
Analytical Results of Water Samples from the Plant Site

Sampling Station	pH	Chloride	Nitrate	Ammonia	TOC	Sulfate	Copper
AM-1	7.9	15	35	32	5	650	0.08
AM-2	7.3	7	22	2.0	9	310	0.05
AM-3	6.4	7	0.77	0.17	5	87	0.22
Plant Well	7.4	2	0.35	<0.1	< 5	26	0.40
River/upstream	8.0	2	0.40	0.17	< 5	9	< .02
River/upstream	7.9	2	0.42	0.25	< 5	6	< .02

Note: All values, except pH, are in mg/l.

spent copper ammonium sulfate solution used in the production of rayon. The nitrate and ammonia detected in the groundwater are the result of oxidation of the ammonium compounds in the wastes.

Of particular significance are the lower concentrations of copper in the two downgradient wells as compared to higher levels in the upgradient monitoring well and the plant well. Concentrations of only 0.08 and 0.05 mg/l were detected in wells AM-1 and AM-2, whereas AM-3 contained 0.22 mg/l and the plant well contained 0.40 mg/l of copper. The reason for this concentration difference is not clearly understood; however, it might be related to the difference in pH in the upgradient and downgradient wells since copper is less soluble at higher pH values. Another possibility is that reducing conditions exist beneath the waste disposal site. The solubility of copper is generally lower in reducing environments, especially is reduced sulfur species are present.

The high copper concentration detected in the plant well is most likely attributable to the pump, pipe and fixtures of the water distribution system. Based upon the soils and groundwater quality data, it is not believed that the waste disposal site is responsible for the high copper concentration detected in this well. Due to the relatively low concentrations of all parameters in the upstream and downstream samples from the river, no discernible impact attributable to the waste disposal site can be determined.

In summary, the uppermost part of the underlying groundwater flow system immediately downgradient of the waste disposal site has been impacted to some extent. The primary contaminants are sulfate, nitrate and ammonia; copper in the waste materials at the site appears to be relatively immobile. In addition, no discernible impact can be seen in the deeper groundwater system tapped by the plant well or in the river. Since the direction of groundwater flow at the site is toward the river, contaminants leaching from the site would be expected to discharge to the river and not migrate offsite.

Surface Waters

The USGS maintains a continuous recording gauge (river stage) approximately 0.8 miles upstream from the mill site. The USGS reports the following information for the gauge site:

(1) Flows at the gauge are partly regulated by a lake located 10.8 miles upstream from the gauge
(2) Low flows are regulated by a lake located 8.1 miles upstream from the gauge
(3) Average discharge (48 years of record) at the gauge is 1,092 ft^3/sec.
(4) Minimum daily discharge of record is 85 ft^3/sec (December 3, 1953) and the instantaneous minimum of record is 42 ft^3/sec (September 20, 1932)
(5) Maximum discharge of record since closure of an upstream dam (December 1, 1948) is 14,500 ft^3/sec (March 12, 1963). The corresponding stage at the gauge for this flow is Elevation 1496.93 ft (from National Geodetic Vertical Datum of 1929)
(6) Drainage area at the gauge is 692 mi^2
(7) The river flows into a reservoir about 25 miles downstream from the mill site and backwaters of the reservoir arm begin about six to eight miles downstream from the site.

TVA reports that the river stage for the 100 year flood at the site is Elevation 1492. The river at this location is also at one of its steepest slopes. The lowest fill elevation present in the site is about 1496 ft. Therefore, the site would not be inundated by the floods of 100 year frequency.

Water samples collected from the ponds had copper concentrations of 24 mg/l (sludge pond) and 0.17 mg/l (lagoon). The copper concentrations (5,000 to 100,000 mg/kg) in the sludges of the two ponds are similar to the

concentration of 47,000 mg/l expected from the solubility of copper ammonia sulfate in water. Similar copper concentrations were present in soil samples obtained near the sludge pond. The lower concentrations of copper (24 and 0.17 mg/l) in the surface waters of the two ponds indicate that the physical attraction of the copper to soils may be greater than its potential to solubilize in water.

The site soils, both sands and clays, appear to have a high affinity for the copper. This is evidence from the high concentrations in the sludge and the significant reduction in concentrations with depth in the soil borings.

The concentrations of both ammonia and sulfate were high (140 and 460 mg/l, respectively) in the waters of the sludge pond. No significant nitrification of the ammonia in the surface waters of the two ponds was apparent from the water quality data.

No significant difference in water quality between the upstream and downstream samples was evident (see Table IV). The major pathway for contaminants to reach the river is through surface water runoff. Groundwater inflow from the disposal site is an insignificant portion of stream flow as can be seen from the following simplified example in which the theoretical downstream concentration is calculated.

Avg. stream flow = 1,092 ft^3/sec

Approx. drainage area = 692 mi^2

Assume 1.58 $ft^3/sec/mi^2$ groundwater inflow (avg.)

(1,092 ft^3/sec/692 mi^2

Ten acres of landfill = 0.016 mi^2

Assume 650 mg/l SO_4 in groundwaters (max. SO_4 conc.)

Assume 9 mg/l SO_4 in river (upstream conc.)

$$\text{Downstream sulfate concentration} = \frac{(1{,}092\ ft^3/sec\ (9\ mg/l) + (0.016\ mi^2\ (1.58\ ft^3/sec/mi^3\ (650\ mg/l)}{1{,}092\ ft^3/sec + 0.03\ ft^3/sec}$$

$$= 9.01\ mg/l\ SO_4$$

During storm events, contaminants can enter the river through runoff. Copper that might enter the stream during storms would most likely be attached to colloidal soil particles and would eventually settle to the stream bottom. No estimates can be made of what percentage or quantities of material this may represent but it is not believed to be significant compared to total streamflow and sediment volumes.

DISPOSAL SITE CLOSURE

Surface water runoff is anticipated to be the major mode of contaminant transport from the disposal area. The disposal site closure plan described below is basically designed to limit the amount of water running across or percolating into the waste material. The following steps are contemplated in the closure plan:

- Control-burn the combustible material on the landfill
- Eliminate standing water areas by appropriate site grading
- Minimize the distance incident stormwater runoff crosses the landfill
- Minimize run-on (overland flow from other areas) to the landfill
- Place an impermeable cap on the landfill to minimize infiltration into the groundwater
- Establish surveillance and maintenance plan for closed site

A conceptual drawing of the site closure plan is given in Figure 3, while a generalized cross-section is shown as Figure 4.

Disposition of Surficial Debris

Much of the surficial waste consists of combustible materials that could be control-burned during one period (with appropriate county and state approvals). Estimates of the combustible material present are:

Waste Material	Estimated Volume (yd^3)
Paper, Pallets, Lumber	9,000
Rayon	
Spools	1,000
Barrels (cardboard)	1,500

Specific permits for the control burn will have to be obtained from the city/county Fire Marshal and possibly the state air pollution agency. Local foresty officials should also be contacted. The local fire department should be requested to oversee the burning.

Bricks, concrete and other construction material are located in the north fill area and cover about one acre. The bricks should be salvaged if possible.

Site Grading

Based upon existing site topography, it is recommended that the site be graded to a 3 to 4 percent grade as shown in Figure 4. Low spots such as the 0.8 acre sludge pond should be filled in with soil fill. The entire site soils and materials should be compacted in order to decrease the chances of subsequent soil settlement.

Capping and Ground Cover

Once the final grade is achieved, a compacted two-foot thick clay cap should be placed on the fill and graded to conform to the 3 to 4 percent grade. A potential borrow area is present on-site from an area with soils classified as clay (CH). It will be necessary to obtain soil samples for permeability, compaction and porosity determinations from several borings in the prospective borrow area prior to final decision. An estimated 40,000 cu yds of clay material is needed for the clay cap and potential fill material.

Next, six inches of top soil should be placed on top of the clay cap and seeded with a hardy grass cover (e.g., fescue). The final site grade should conform to the 3 to 4 percent slope and no low spots or potential ponded areas should remain. About 10,000 cu yds of topsoil are needed for the topsoil cover.

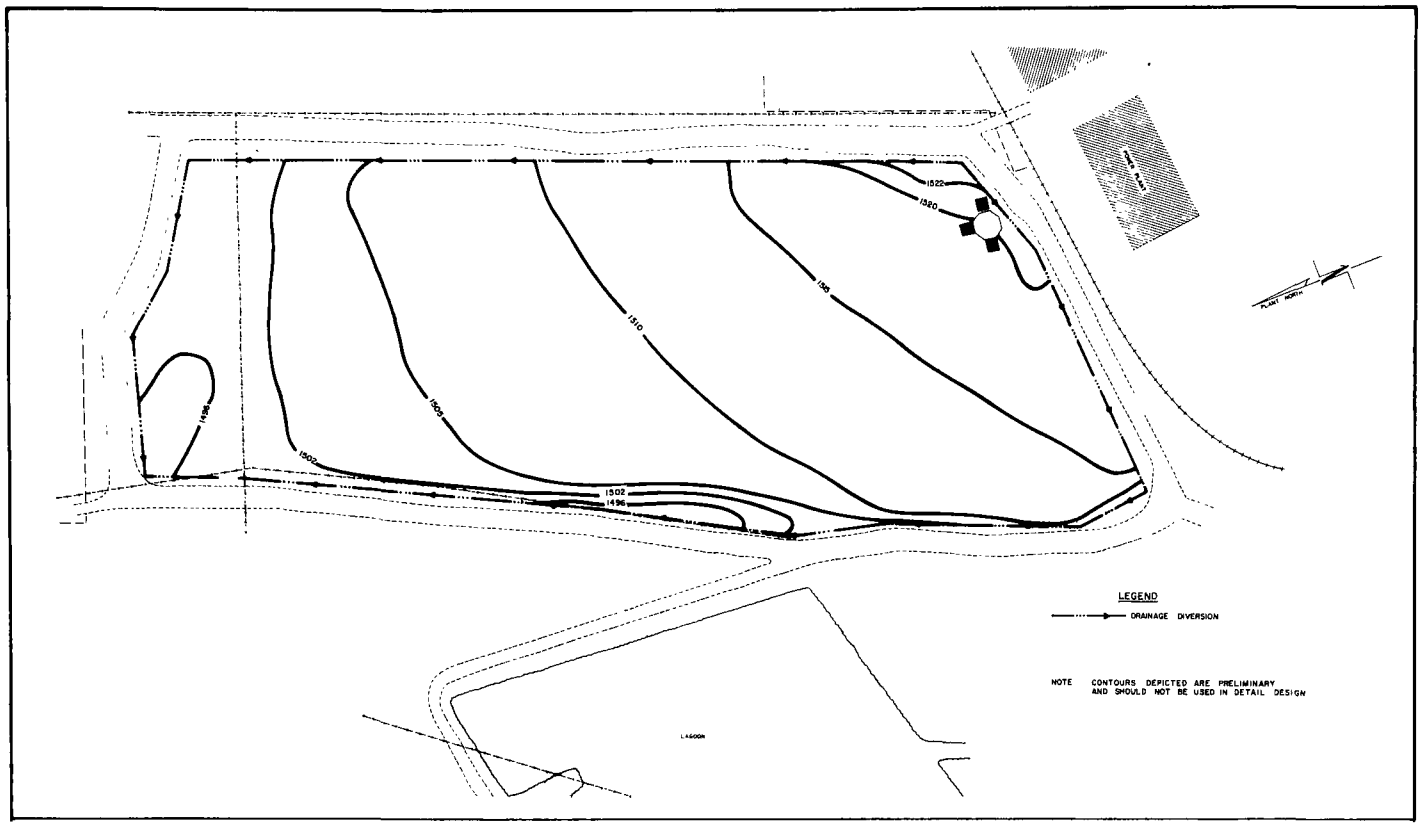

Figure 3.
Conceptual Plan for Disposal Site Closure

Table V.
Future Groundwater Monitoring Program

Parameter	Frequency	LOCATION			
		Observation Wells (c)	Drinking Water Well	River Upstream	River Downstream
Disch (a) or water elev	M	X	X	X	X
pH	Q	X	X	X	X
Cond.	Q	X	X	X	X
Cu (b)	Q	X	X	X	X
So_4 (b)	Q	X	X	X	X
NH_3-N (b)	Q	X	X	X	X
NO_3-N (b)	Q	X	X	X	X

a. Discharge available from USGS gauge
b. Analysis on soluble portion of water sample
c. Observation wells AM-1, AM-2, AM-3
d. M = Monthly Q = Quarterly

Groundwater Monitoring Program

Groundwater monitoring should be done quarterly for at least one year following closure of the landfill. Parameters and sampling frequency for the groundwater monitoring program are given in Table V. River water samples should be obtained upstream and downstream from the site along with the groundwater samples. At the end of the first year, the data from the monitoring program should be reviewed and a continue, curtail or cease monitoring program decision should be made.

CONCLUSIONS

The following conclusions were derived from this study:

- The disposal site covers about 11 surface acres and contains an estimated 140,000 yd^3 of material
- There are approximately 12,000 yd^3 of combustible material on the surface of the disposal site.
- A total of about one surface acre of copper sludges has been placed on the site.
- The groundwater table is 13 ft to 17 ft below the base of the fill material.
- The disposal site is above the 100 year flood plain of the river.
- Copper was at or below background concentrations in groundwaters downgradient from the disposal site. Ammonia, nitrate and sulfate significantly above background concentrations were present in the downgradient wells.
- Surface water runoff is believed to be the major transport pathway for copper. Percolation of surface waters and rainfall to the underlying groundwaters is resulting in degradation of water quality in downgradient wells by ammonia, nitrate and sulfate.
- Water contact with fill materials can be minimized by proper grading, capping with a compacted clay and topsoil layer, and seeding with grass.

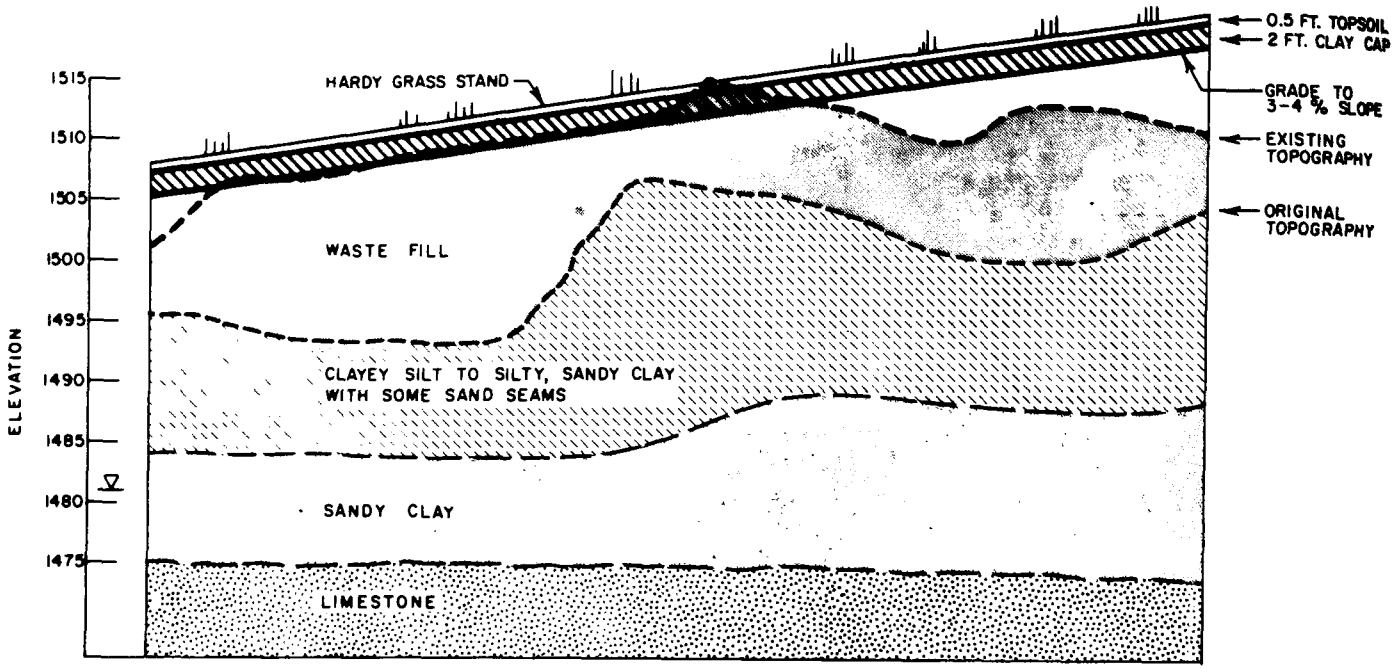

Figure 4.
Conceptual Plan for Disposal Site Closure
General Cross-Section

•Proper closure of the site should prevent any significant future contamination to ground or surface waters. Closure of the disposal site can be accomplished in such a way as to allow certain commercial and/or industrial uses of the site. However, additional evaluations and determinations would be required to ensure that any future development is compatible with the closure plans described herein.

NEW ASSESSMENT METHODS TO AID SITE RESTORATION

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INTRODUCTION

With passage of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, financial and regulatory incentives have accelerated activity in the area of site restoration. The Federal Government now has both clear authority and resources which will allow it to systematically evaluate and, where necessary, apply remedial action to sites burdened with chemical contaminants. In turn, industry is motivated to review areas where former activities may have left residuals and apply appropriate restoration measures to insure against subsequent impacts on public health and the environment.

Historically, when such measures have been undertaken, they have involved a number of activities which were loosely termed environmental assessment. In general, these activities related to the collection of baseline information and the prediction of future impacts. They were typically directed to the preparation of products such as an Environmental Report and ultimately an Environmental Impact Statement.

In the early years, environmental impact assessment was more art than science. Recent developments have changed both the image and the nature of assessment activities. New methods have made the process more quantitative and formalized. They have encouraged the expansion of the assessment role from a relatively passive one to a very active one wherein all phases of problem resolution are designed, monitored and concluded through input from successive levels of evaluation. Assessment methods for site restoration are undergoing much the same evaluation. This paper addresses how new methods can be used to enhance the hazardous waste site restoration process.

THE SITE RESTORATION PROCESS

The site restoration process can be conceptualized as a composite consisting of three discreet elements: (1) site characterization, (2) site assessment and (3) site remediation. (Monitoring is viewed as a form of characterization occurring during and after implementation of remedial action.) It is misleading, however, if this order of presentation is taken to connote sequencing of the four elements. Experience suggests that the elements are interactive and connected by a series of feedback loops which sponsor optimization as one progresses through the restoration process. The substance of the control mechanisms which allow optimization is a suite of assessment methods which function first to determine the adequacy of the previous step and then to design the most cost effective approach to the succeeding step. This process is illustrated in Figure 1.

Site Characterization

Work performed during site characterization is directed to the description of the source term and the surrounding environment. The objective is to enumerate and quantify to the extent possible the physical, chemical, and biological factors which will affect fate and migration of contaminants. For maximum efficiency, characterization is performed in an integrated manner with assessment such that only necessary data are collected.

The first element of characterization, the preliminary survey, is focused on gathering all existing data on a site and the potential contaminants of concern. Reports, maps, monitoring data and related materials are collected for conduct of a preliminary assessment. If data are sufficient, no new characterization efforts are required. If the preliminary assessment reveals data gaps which must be closed before a final assessment can be made, then final characterization is implemented. Hence, the preliminary assessment is designed to determine the adequacy of existing data and the optimum design for any subsequent data collection activities. In particular, the initial assessment should provide details on the location and type of data required from the site and the nature of chemical properties information which should be sought or generated.

When active site characterization is necessary, it is divided among a number of field activities. Geophysical survey techniques can be employed to map deposits. Output details the location of buried objects or the boundaries between significant strata such as the phreatic surface and major impermeable layers. These efforts are complimented by field geohydrologic investigations which determine the nature and extent of geologic and hydrologic features which will affect the movement of contaminants. Finally, sampling and analysis is performed to detail the disposition of contaminants in the environment and the physical/chemical properties of geologic media which would attenuate movement.

All characterization activities may not be required at every site. Further chemical characterization may include in depth literature searches or in situ and laboratory experimentation to generate empirical data. As noted previously, the type and extent of activities should be identified during the preliminary assessment.

Post-closure characterization can actually be thought of as two distinct activities: (1) surveillance of remedial action implementation and (2) post-construction monitoring. The first of these is directed toward assuring safe performance of work and conduct of that work in the manner prescribed in the final plan. The second activity looks to confirm the effectiveness of the remedial action on a continous basis and, in so doing, to provide a warning in the event of failure.

Post-closure characterization plans are dictated by the remedial action approach selected and designed through conduct of a post-closure assessment. Once again, the assessment is directed to determining the optimum location and frequency of sampling activities. This is done by determining the likely location and timing of failures and then placing sample locations to intercept resultant contaminant plumes.

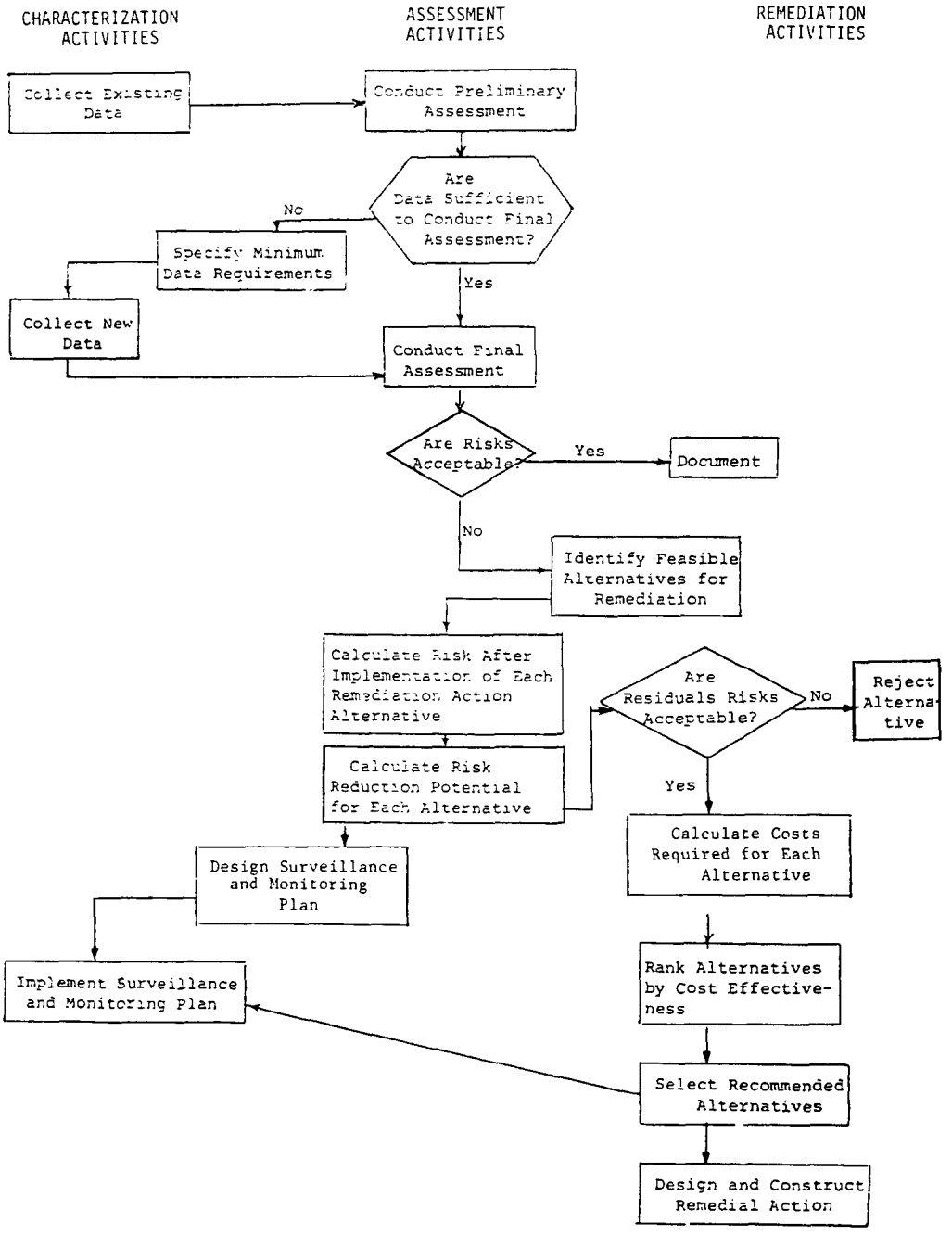

Figure 1.
The Integrated Site Restoration Process

Site Assessment

Activities conducted in an assessment mode are designed to determine the implications of the available data. In this context, they are interpretative in nature. The first level of assessment, preliminary assessment, is conducted using available data to determine if sufficient information is on hand to characterize a site and quantify the risk posed by that site. Two levels of output are possible. The first is a determination that current data are insufficient. In this case, the assessment identifies the minimum necessary data that should be collected to allow conduct of a final assessment. The second possible output is the result of a final assessment itself.

The final assessment is conducted only after sufficient data are in hand. Narrowly defined, the product of a final assessment is the description of the time frames, durations and concentrations of contaminants in each segment of the environment (i.e., surface water, groundwater, atmospheric and soil). In this context, the assessment product is a prediction of what continuous monitors would record if the situation is allowed to remain in its current state. When coupled with data on dose-response functions for the contaminants of concern, the assessment output is converted to an estimate of the risk posed by the site. When it is determined that remediation is required and conceptual approaches are identified, assessment is again conducted to predict the effectiveness of proposed alternatives and to identify the most cost effective postclosure monitoring plan.

Assessment is performed through the use of models which predict the fate and migration of contaminants. Models employed may be as simple as an equation or algorithm describing the partitioning of a contaminant between two phases, or as complicated as a three-dimensional mathematical model. Battelle has found that the best approach to assessment is to have available a suite of models covering each pertinent pathway in successive levels of complexity. The appropriate model is selected at the time of use on the basis of the amount of data available and the level of resolution required. Cost-effectiveness considerations dictate use of the simplest possible model that can provide the level of output required. Only those pathways of major significance are modeled. The key to good assessment is a thorough understanding of environmental pathways and the ability to conceptualize the site under study prior to modeling.

Site Remediation

Remediation activities are the major end-product of site restoration work. They are initiated whenever a final assessment concludes that risks posed by a site are unacceptable. At that time, the preliminary work is begun to identify all feasible alternatives.

After a cursory screening, the most promising alternatives are described in a conceptual framework and input to the post-closure assessment where estimates are made of the effectiveness of each alternative. Output from the post-closure assessment is compared to output from the final site assessment to determine the level of risk reduction offered by each alternative. Alternatives not capable of reducing risks to acceptable levels are discarded. Remaining candidates are ranked according to cost. The ratio of risk reduction to cost is then employed to select the most cost-effective approach.

The selected alternative is then taken into final design and construction. Post-closure characterization is conducted to assure that construction is performed in accordance with final designs and to detect any releases or activities which pose a hazard to the public as a result of remediation.

The need to select the most cost-effective means of remediation dictates knowledge of the latest technology as well as a strong interaction with regulatory agencies to insure that recommendations can meet permit application requirements. Site restoration is an area of rapid technical change. Considerable work is presently ongoing to develop new approaches to remediation. At the same time, there are no formal standards for defining clean-up thresholds.

EXPOSURE-RESPONSE ANALYSIS IN SITE RESTORATION

As suggested previously, one means of tying all elements of site restoration together is to reduce assessments to quantitative results where possible. One of the most effective ways of doing that is to couch results in terms of risk. Risk is a common unit between the elements of the restoration process. At the samed time, it lies at the heart of the motivation for restoration efforts in the first place, i.e., site restoration is necessitated because extant contamination poses unacceptable risks and similarly, restoration is deemed complete when risks are reduced to acceptable levels. Given this background, it is now possible to discuss the nature of risk assessment in site restoration.

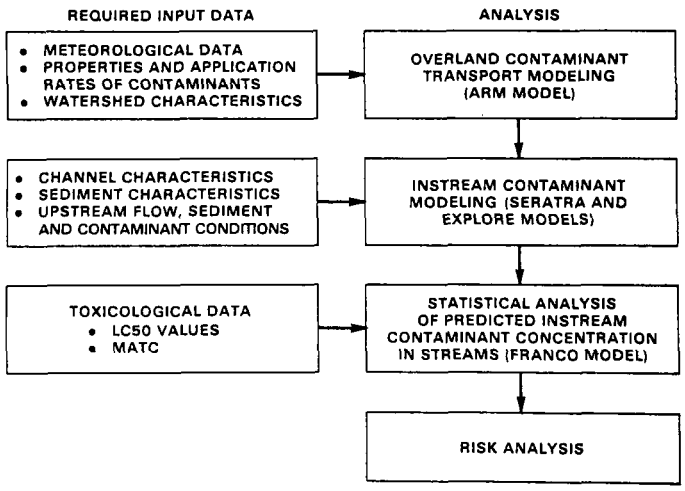

Figure 2.
Chemical Migration and Risk Assessment (CRMA) Methodology

By the classical definition, risk is considered the product of the probability of an occurrence and the consequences of that occurrence. Hence, if one in every 1,000,000 airplane landings results in an accident, and 200 people died in the last 100 accidents (150 in one, 50 in one and 0 in all others) the risk of death during airplane landings is 1 in 5,000 or 2×10^{-4}.

When the activity being evaluated involves contaminant migration, the data are not available in such simple formats. Hence, the definition is altered slightly to accommodate the nature of the inputs. Exposure-response analysis is performed through the integration of results from an exposure assessment and a hazard assessment. For these purposes, an exposure assessment is a quantitative estimation of the timing, concentration and duration of contamination exposure at a specified location. This assessment is typically performed through use of mathematical models that predict the transport, transformation and fate of chemicals in the environment.

A hazard assessment is the estimation of the effects a receptor population will evidence if exposed to specified concentrations of contaminant for given periods of time. This is usually done by constructing a time-dose relation chart for the contaminant of interest.

As the result of a recent EPA funded development effort, [1] a methodology has been devised to integrate the results of the exposure and hazard assessments. The Chemical Migration Risk Assessment (CMRA) Methodology couples a number of computerized codes to accomplish the integration as illustrated in Figure 2. A statistical code, FRANCO (Frequency Analysis of Concentrations), reduces the results obtained from transport models to a time-concentration format consistent with the time-dose relation output from a hazard assessment. Hence, when the two are overlayed, one gets a numerical estimate of the percent of time concentrations exceed specified hazard levels. The segmentation of the time-dose universe into hazard ones is illustrated in Figure 3.

This method has been applied to the pesticide Toxaphene in the Four Mile Creek watershed in Iowa[1] and the Yazoo River Basin in Mississippi.[2] Example results are provided in Figure 4. The numbers in each segment of the time-dose universe indicate the percent of the time that conditions at a downstream site would fall in each hazard zone. A similar approach can be employed to look at human health effects employing available data on acute and chronic dose levels and drinking water limits.

There are two key issues to be addressed by the application of exposure-response analysis to the site restoration problem set:

- Which sites require remediation?
- How clean is clean enough?

The first of these concerns questions both the degree of risk posed and the timing of the risks. Ideally, after conduct of the exposure-response analysis, one will be able to categorize sites into one of three groupings:

- Sites which do not require remediation
- Sites which pose a long-term risk
- Sites which pose a short term risk

The first refers to sites where risks fall below some maximum acceptable level, i.e., risks are comparable to those accepted by people on a routine basis. The second group would include sites where risks may reach unacceptable levels, but the impacts will not occur for a number of years.

Generally speaking, time and resource considerations will dictate addressing the third group only at the present time. There is no sense in using today's monies to avoid a problem far in the future at the expense of other sites which will have immediate effects. Caution is necessary here, however. For some sites, waiting to implement re-

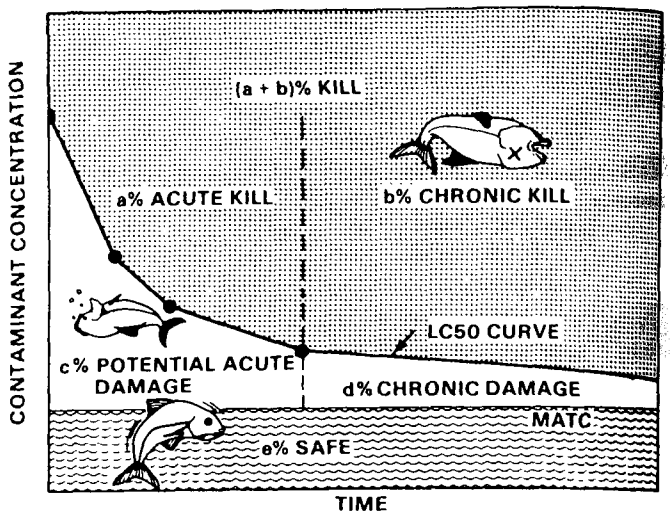

Figure 3.
Time-Dose Universe Employed for Exposure Response Analysis

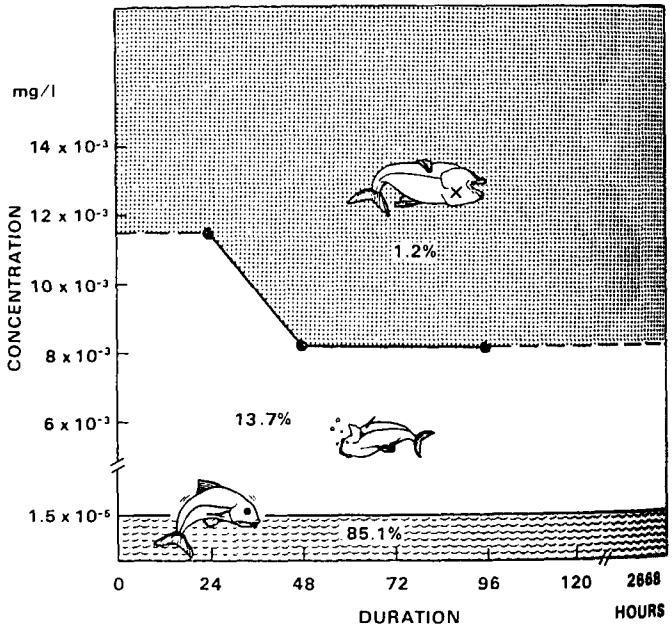

Figure 4.
Toxaphene Exposure-Response Analysis Results for Rainbow Trout

medial action will result in disproportionately large costs because of the nature of the contaminant's migration. As an example, a contaminant plume in the unsaturated zone could be much less expensive to exhume than that same plume once it is allowed to enter the aquifer. Therefore, a part of the separation into short and long term risk should cover the concomitant cost differential.

The issue of "How clean is clean enough?" is at the heart of the selection of a remedial action alternative. Before a preferred approach can be designated, a target level of contamination must be established such that areas with residuals at higher concentrations will be addressed while those at lower concentrations are left untouched. Specifically, cleanup criteria need to be established so one can determine how extensive restoration should be and which alternatives are capable of meeting the goals.

No soil criteria presently exists for most toxic chemicals. For nearly all contaminants, there are no threshold limits defining when hazardous effects will begin to be evidenced. In part, this reflects the fact that there are no simple standard tests to which a contaminated soil can be subjected for designation as hazardous or nonhazardous.

Fortunately, there is still a relatively straightforward approach available for establishing criteria. For most contaminants, soil residuals are of concern because of their ultimate ability to contaminate the atmosphere (through volatilization or resuspension) and the hydrosphere (through leaching and runoff). Hence, hazardous chemical levels in soil can be defined as those which will sponsor hazardous levels in air or water.

Criteria and guidelines for ambient air and water have been suggested for a number of chemicals. By working backwards with minimal data on dilution potential and distribution coefficients, criteria can be established. Given these, one can determine the subset of alternatives which can meet objectives and the extent of restoration required.

Viable remedial action alternatives are evaluated for effectiveness using the same models employed in the exposure assessment. Predicted levels of removal on barriers to migration are input to the models and output reviewed to determine the impact on risk levels. Once these values are available, alternatives can be compared as indicated in Figure 5. Eachf alternative is compared on the basis of cost and risk reduction potential. Selection of the optimum approach proceeds in a two-step fashion:

- Which alternatives meet acceptable risk thresholds?
- Which of the above alternative offers the most risk reduction per unit of cost?

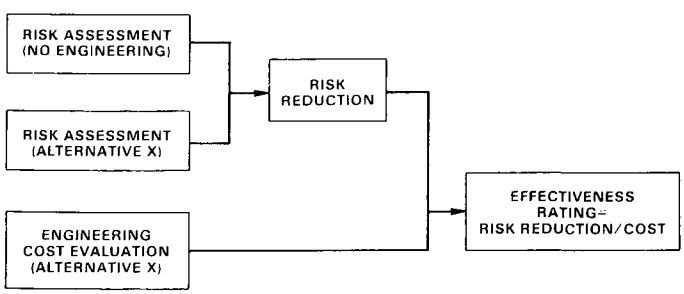

Figure 5.
Approach to Selection of Remedial Action Alternatives

Having performed the analyses, one can conclude site restoration. Assessment has allowed design of each step of work in a cost-effective manner identifying only the necessary and sufficient data to proceed to subsequent steps. Reduction of data to risk values maintains output in a currency that can be communicated with decision makers and employed directly in environmental impact statements, permit applications and other documents associated with the approval process.

STATUS

Environmental-response analysis is currently available for application to site restoration. The exposure assessment elements of the process are particularly well developed. Validated models are available off-the-shelf for predicting migration in the atmosphere, groundwater and surface waters. The major area of uncertainty rests in the ability to describe chemical interactions with soil and other attenuation mechanisms. Knowledge is particularly lacking with respect to organic contaminants.

Hazard assessment is much less developed. This is largely true because of the paucity of data on effects of chronic exposure to most contaminants. Hence, it is impossible to construct accurate time-dose universes for most contaminants. At present, a few data points (largely acute in nature) can be entered. This does not invalidate the process or diminish its ability. It merely points to the significant efforts that must still be undertaken.

In the interim, exposure assessments can be employed as the basis for decision making. When hazard data exist, a complete exposure-response analysis can be made. When hazard data do not exist, judgment can be employed as to the acceptability of projected exposure levels. In either event, decision makers are afforded all available data and a formal process for utilizing that data.

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MINIMIZING COST AND RISK IN HAZARDOUS WASTE SITE INVESTIGATIONS USING GEOPHYSICS

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INTRODUCTION

Hazardous waste sites require the very highest levels of quality and confidence in site evaluations. All site assessment projects require good information at minimal cost.

Commonly, drilling monitoring wells and a sampling program are recommended to define subsurface conditions at these sites. This approach often yields an incomplete and/or erroneous evaluation. Errors arise due to the small volume of subsurface space sampled by a monitor well. This small volume often is not representative of the site conditions. An accurate analysis of site conditions requires that the number of sample sites be substantially greater than are normally used. Conversely, increased drilling activity increases risk of fumes, fire, explosion and release of hazardous materials into groundwater or the environment.

Discrete well sampling programs should be designed with prior knowledge obtained from preliminary surveys using remote sensing geophysical methods. This systems approach will clearly minimize risk and cost, while synergistically improving the understanding of site conditions. In investigating conditions at such hazardous waste sites, three types of problems are commonly confronted:

- Determining the presence and distribution of buried hazardous materials.
- Determining the presence and boundaries of contaminants and leachate plumes.
- Characterizing the natural geohydrologic setting.

Ground-based remote sensing geophysical techniques are very effective in providing information for these purposes and can be rapidly applied to a site. Having obtained this information, a detailed drilling and sampling program can then be designed, ensuring the placement of monitor wells directly in the problem area. This results in much greater confidence in the final data interpretation with fewer wells.

Where site investigations have previously been initiated, the geophysics systems approach also provides significant benefits. The location of existing monitor wells relative to problem areas can be assessed, providing an evaluation of the validity of data previously acquired. If needed, additional well locations can be precisely identified to fill gaps in the overall site coverage.

Depending upon site objectives and conditions, the remote sensing methods utilized will vary significantly. A wide range of methods and variations have already been successfully applied to many hazardous sites throughout the United States.

Successfully applied techniques include:

- photography
- Infrared scanners
- Ground penetrating radar
- Various electromagnetic conductivity measurements
- Metal detection surveys
- Magnetic surveys
- Resistivity surveys
- Seismic refraction surveys

With the exception of resistivity and seismic refraction, all of these remote sensing methods provide continuous measurements along the survey line. These continuous spatial measurements are preferred as they enable site coverage to approach 100%. Continuous spatial measurements have significant benefits when applied to sites which are highly variable, as they avoid incomplete information obtained from station measurements.

In this paper, the authors outline the benefits of geophysical remote sensing assisted programs compared to traditional drilling and sampling methods.

SPATIAL SAMPLING REQUIREMENTS

A critical problem at many hazardous waste sites is the determination of the location of buried materials or plumes. In addition, the investigator often needs to know the amount of material, its boundaries and depth of burial.

The area of a site under investigation is often many times the area of the buried target (Figure 1). Ratios of typical site to target areas (As/At), encountered at hazardous waste sites, range from 10 to 1000. As this ratio increases, the search problem can rapidly become analogous to "looking for a needle in a haystack." The table below illustrates some typical dimensions found for various As/At ratios, assuming a site area (As) of 25 acres.

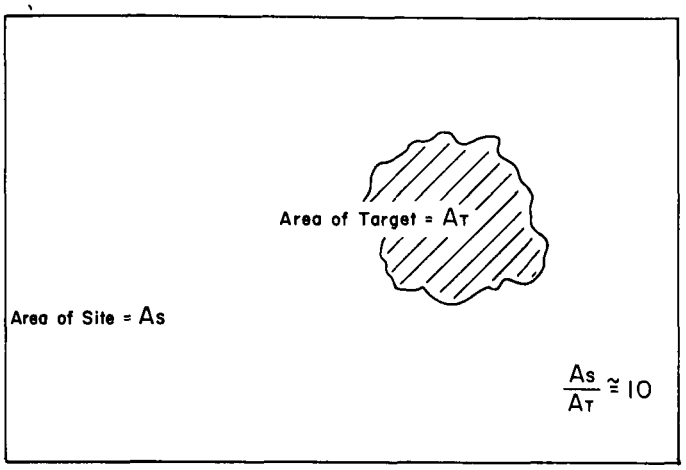


Figure 1.
Site to Target Area Ratios
(Common ranges of As are 10 to 1000)

As/At	Target Area
10	330 ft x 330 ft (2.5 acres)
100	100 ft x 100 ft (0.25 acre)
1000	33 ft x 33 ft (0.025 acre)

Numerous wells may be required to detect the presence of a burial target or plume (Figure 1). A traditional grid search pattern applied to a site-to-target ratio of 10 is shown in Figure 2. More than 16 wells are required to approach a 100% confidence level, just to detect the target. If the target size really is smaller than assumed, the selected drilling program may not detect it. A "miss" will obviously lead to an erroneous assessment of the site. These steps are concerned only with locating a target and not providing any definition of it. Definition of the target's boundaries will require additional wells, and as boundary resolution requirements increase, more wells will be necessary. As an example, using statistical converging methods, a minimum of at least eight to twelve wells would be required to approximately locate four sides of a simply shaped burial site. As many as 20 or more wells may be required to define complex-shaped boundaries. A total of 24 to 36 wells would be necessary to detect, locate and provide approximately spatial boundaries for a complex site with an As/At of 10 to obtain high confidence levels. For the As/At ratio of 100 to 1000, the number of wells and the related costs would be unthinkable.

Often the risk of drilling is significant and the benefit of remote sensing prior to drilling is therefore critically important. Breaching the clay seal of a trench, puncturing a drum, releasing of fumes and gases and possible explosions and fire are all real potential risks when drilling sites with hazardous material present. Although a large number of wells is necessary to detect and define the target (Figure 2), a concurrent, significant increase in risk is incurred (Figure 3).

The discussion of location of buried sites is also applicable to the location and mapping of plumes and defining natural geohydrologic conditions. Limited monitor well installations and sampled collections to define

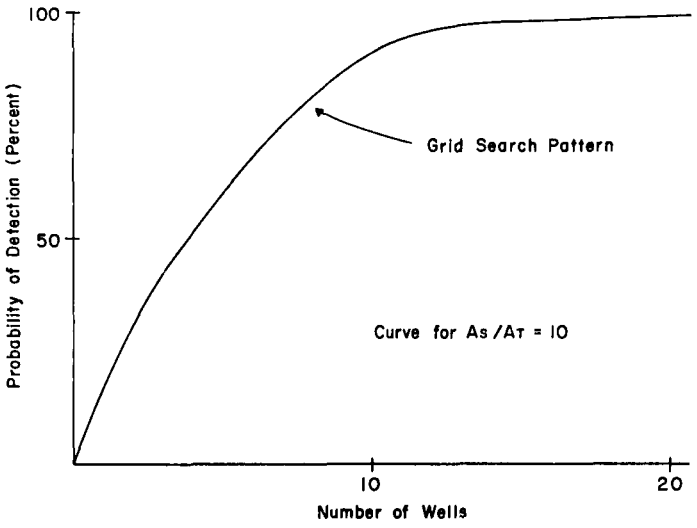


Figure 2.
Detection Probability Vs. Number of Holes

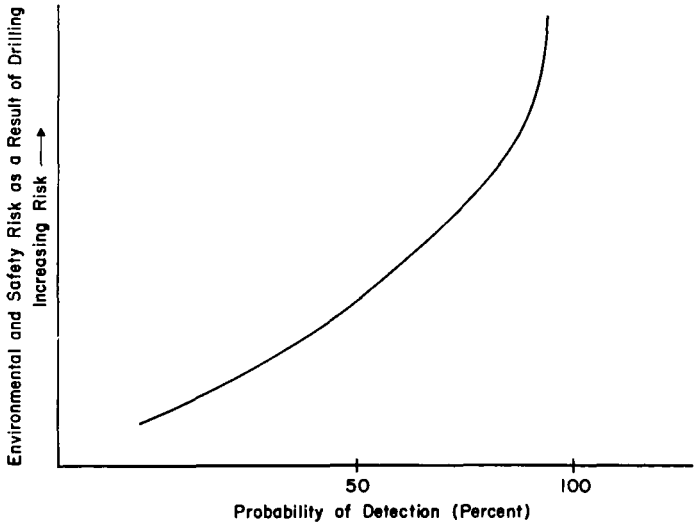


Figure 3.
General Curve of Risk Vs. Probability of
Detection by Drilling

groundwater plumes at hazardous waste sites are often insufficient to adequately define the conditions. Extrapolation beyond and interpolation between data points is necessary when using this approach.

Results, therefore, are highly dependent upon the uniformity of subsurface conditions. Variations in the natural setting as well as interaction with specific contaminants make such estimates highly prone to error.

EXAMPLES OF SITE INVESTIGATIONS USING DRILLING AND ELECTROMAGNETIC METHODS

The following examples are included to illustrate the problems and variations encountered in several hazardous waste site investigations.

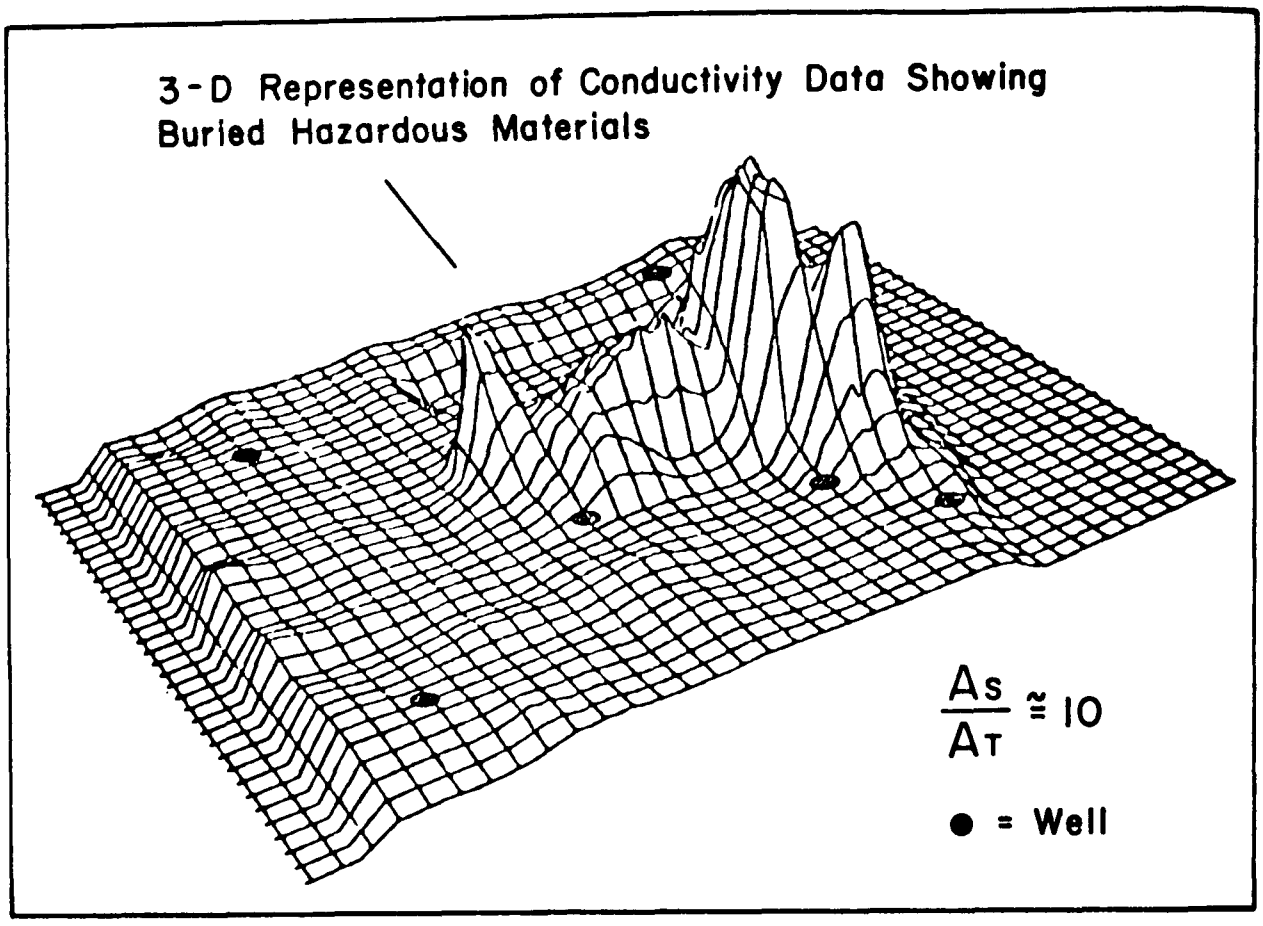


Figure 4.
Six Wells Miss Buried Target

Example 1

Six wells were drilled in a 25-acre site with a site/target area ratio of 10. These wells were placed using the traditional "best guess" approach—one near each corner, one in the center and another at a suspected location (Figure 4). None of the wells located the buried wastes. Two wells showed low levels of contaminants in the groundwater samples. Consequently, investigators knew that a problem existed at the site but still had not located the burial area or had information about the magnitude of the problem.

This result is not surprising as Figure 2 shows that for a site/target area ratio of 10, approximately sixteen wells would be necessary for a high probability of detection at this site.

The site was then mapped using electromagnetic (EM) methods which measure bulk subsurface conductivities. Twenty continuous EM profiles were run across the site in parallel lines spaced 50 ft apart. These results clearly defined an irregular, anomalous zone in one portion of the site (Figure 4). The results of this survey provided the following information:

- Initial location of the target area was made within the first hour of survey
- Approximate boundaries were identified by the end of the first day
- Qualitative EM sounding data indicated that most of the buried wastes were less than 10 feet from the surface
- Magnetometer profiles over the same area indicated that no large concentrations of ferrous materials such as steel drums were present, indicating the contaminants were not buried in drums
- Computer processing of the EM data revealed that contaminants were leaving the burial zone

Based upon these results, two selected wells were drilled to verify and characterize the wastes and to identify the contaminants leaving the site.

The geophysical surveys not only located the burial zone, but resolved the exact boundaries of the burial site as well as location of a contaminant plume. An estimate of contaminant volume and depth was also made from the data. To provide information at this level of detail, drilling costs would have been prohibitive, requiring more than three dozen wells and associated chemical analyses. Well installation time and turn-around time for analysis would have also been an important factor in the overall project schedule. Since hazardous materials were present, the cost of special drilling procedures and the risk factor of drilling this number of holes would have been large.

Geophysical results provided essential information in less than one week and only two to three monitoring

wells were necessary. A high level of confidence at minimal cost and time was achieved.

Example 2

The extent and direction of contaminants seepage and leachate plumes and the evaluation of groundwater flow near hazardous waste sites are major concerns. In ideal homogeneous isotropic soil and rock, textbook approaches using water levels and potentiometric heads may yield predictable and calculable results. The real world, however, is quite often not such a simple system. Local groundwater flow cannot always be equated to regional groundwater flow and permeabilities determined in a laboratory from a few samples do not always represent *in situ* values. Even though water level measurement can yield general flow directions, complex geological settings may create localized variations in this flow. In addition, contaminants denser than water may not follow "flow lines" but may instead be controlled by gravity. Data from the same area, one resulting from observations wells, the other from electromagnetic geophysical surveys, are shown in Figures 5A and 5B.

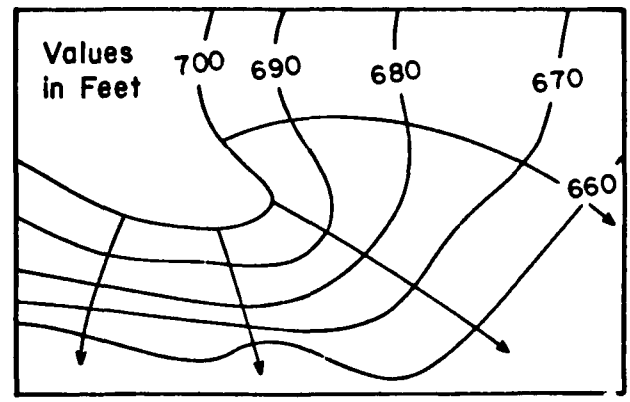
Figure 5A was developed based on data from 16 open hole wells which were also used for water quality sampling. From these data, the generalized groundwater flow and assumed plume direction were determined. The actual plume as measured by EM conductivity is shown in Figure 5B. A much more detailed and accurate definition of the plume is provided by the EM method. Sufficient data were acquired over the site so as to provide nearly total coverage. The plume shown in 5B represents flow of a conductive, conservative contaminant through both the saturated and unsaturated zones. The confidence level of the detailed flow pattern approaches 100% (shown in Figure 5B), while that of the water level measurements provides a considerably lower confidence level (Figure 5A).

To achieve the high resolution results seen in Figure 5B with monitor wells would have required an extensive number of strategically placed wells. The problem occurs in placing the wells in the correct position which is typically accomplished by a "best guess" method. The geophysical systems approach provided not only detailed data on plume flow and concentrations, but also enabled an assessment to be made of contaminant data from existing monitor wells.

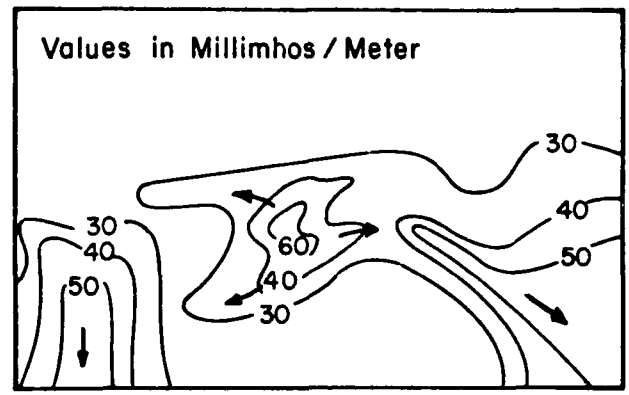
Example 3

Another example of variability in vadose and groundwater flow can be seen in Figure 6. A point source contaminant has flowed through a thin vadose zone into the shallow groundwater. The site was originally considered to be quite homogeneous and isotropic. However, an EM conductivity survey showed the distribution of contaminants within this regime as very complex and changing drastically with time.

An attempt to utilize monitor wells for such mapping could provide highly misleading information on the distribution and degree of contamination. Any conceivable



A) Potentiometric Contours Showing Flow Directions



B) Conductivity Contours Showing Plume Flow

Figure 5.
Difference in Groundwater Flow at the Same Site
Based upon Monitor Wells (A) and Em Measurements (b)

plan to derive similar results using monitor wells would be at a low confidence level.

This example shows that it is possible to measure time variables at a site using geophysical methods. Conducting surveys at periodic intervals, the EM geophysical approach provides an excellent means of monitoring plume development with time as well as providing an excellent early warning system. In addition, the information obtained through mapping plume concentrations and geometries can be used to significantly improve the use of predictive models.

COSTS

The relative costs and benefits of an integrated remote sensing geophysical systems survey combined with selected wells compared to a program consisting of monitor wells only are shown in Figure 7. The curve shows cost versus various site-to-target area ratios. The monitor well costs are based upon a total program cost of $3,000 to $10,000 per well which includes drilling, construction of a

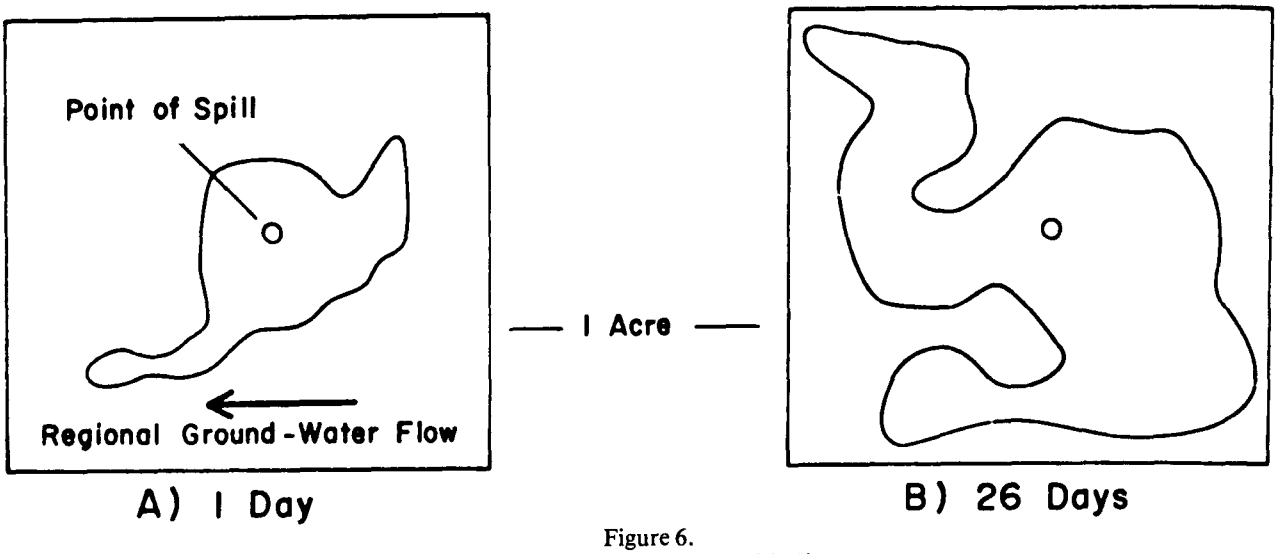


Figure 6.
•Change in Shallow Plume with Time
•Plume Measured by Em Conductivity

quality monitor well, initial sampling and analysis of priority pollutants and a subsequent quarterly sample program over one year, along with supporting interpretation reports and project management. All wells are assumed to be 30 ft deep. The costs used are conservative in that they do not include the increased direct costs of drilling into highly hazardous areas, nor do they include consideration of intangible risk factors.

The geophysical systems costs are based upon a site survey coverage approaching 100% plus three monitor wells as described above and all supporting effort of reports and project management. One well is typically used for background measurement and two placed with high confidence levels to assess spatial distribution of contaminants or attenuation along a plume. The curve shows the geophysical systems approach is more effective for sites of As/At greater than 5.

The geophysicals-assisted approach becomes increasingly more cost-effective than monitor wells when more wells are required. As site complexity, unknowns and risks increase, the advantage of a systems approach becomes even more significant.

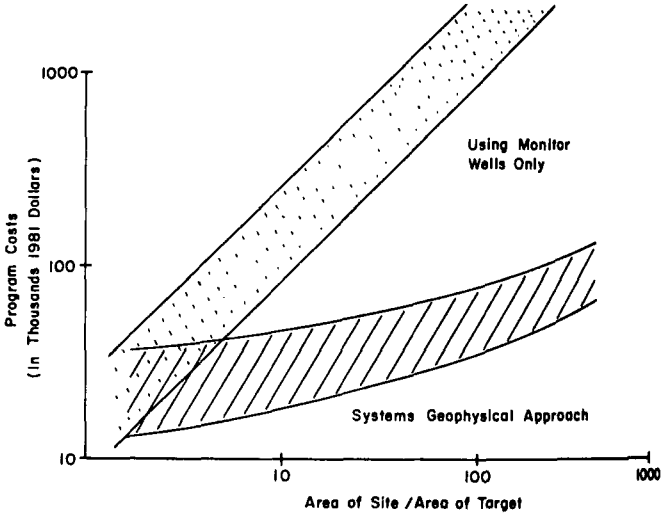


Figure 7.
Cost Comparison of Monitor Wells Vs. Geophysical Approach

SUMMARY

In this paper, the authors have discussed some of the problems, variables, errors and risks encountered in hazardous waste sites evaluations. Some of the trade-offs that may exist in planning and implementing such work are shown in Figures 1, 2 and 3.

The number and placement of monitor wells are often inadequate to describe the natural geohydrologic setting, evaluation of burial sites or contaminant plumes from hazardous waste sites. As a result, significant errors can be made in assessing conditions due to a lack of adequate spatial information.

Alternatives now exist to alleviate problems inherent in direct sampling methods alone. High density or continuous spatial mapping via remote sensing and geophysical methods provides significant benefits. No single method will solve all site problems and geophysical or remote sensing technology is not a panacea in itself. Trained, experienced professionals are required to design and execute surveys and analyze data. Then, an effective monitor well system may be implemented to provide direct sampling and analysis of the contaminants. This integrated systems approach provides synergistic results unattainable by direct sampling methods alone.

As the site-to-target area increases and the complexity, details and hazards increase, the cost/benefit of a geophysics-assisted systems approach becomes more significant. The technologies and benefits are available today to those wanting to optimize hazardous waste site assessments.

INSTALLING GROUNDWATER MONITORING WELLS AT A HAZARDOUS WASTE SITE

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INTRODUCTION

The installation of monitoring wells at a hazardous waste site is important in a groundwater investigation. There is, however, very limited experience using cumbersome safety equipment and following strict safety procedures on hazardous waste sites during well drilling.

Since February 1980, Fred C. Hart Associates, Inc. has provided a Field Investigation Team to assist in the U.S. Environmental Protection Agency's investigations of hazardous waste sites in Region II. During the past year and a half, the Region II Field Investigation Team supervised the installation of 42 groundwater monitoring wells at five hazardous waste sites in New York and New Jersey. Three of these sites are now Superfund sites. Based on this valuable experience, guidance is offered for similar undertakings.

The material presented in this paper is specifically intended to provide a very general overview and serve as a primer for managers, attorneys and other non-hydrogeologists. Non-hydrogeologists working in hazardous waste management should understand the basics of installing monitoring wells. More detailed information can be obtained from the sources provided in the Bibliography at the end of the paper.

The sequence of activities typically required to install groundwater monitoring wells at a hazardous waste site is shown in Figure 1. Each step in the flow chart is discussed.

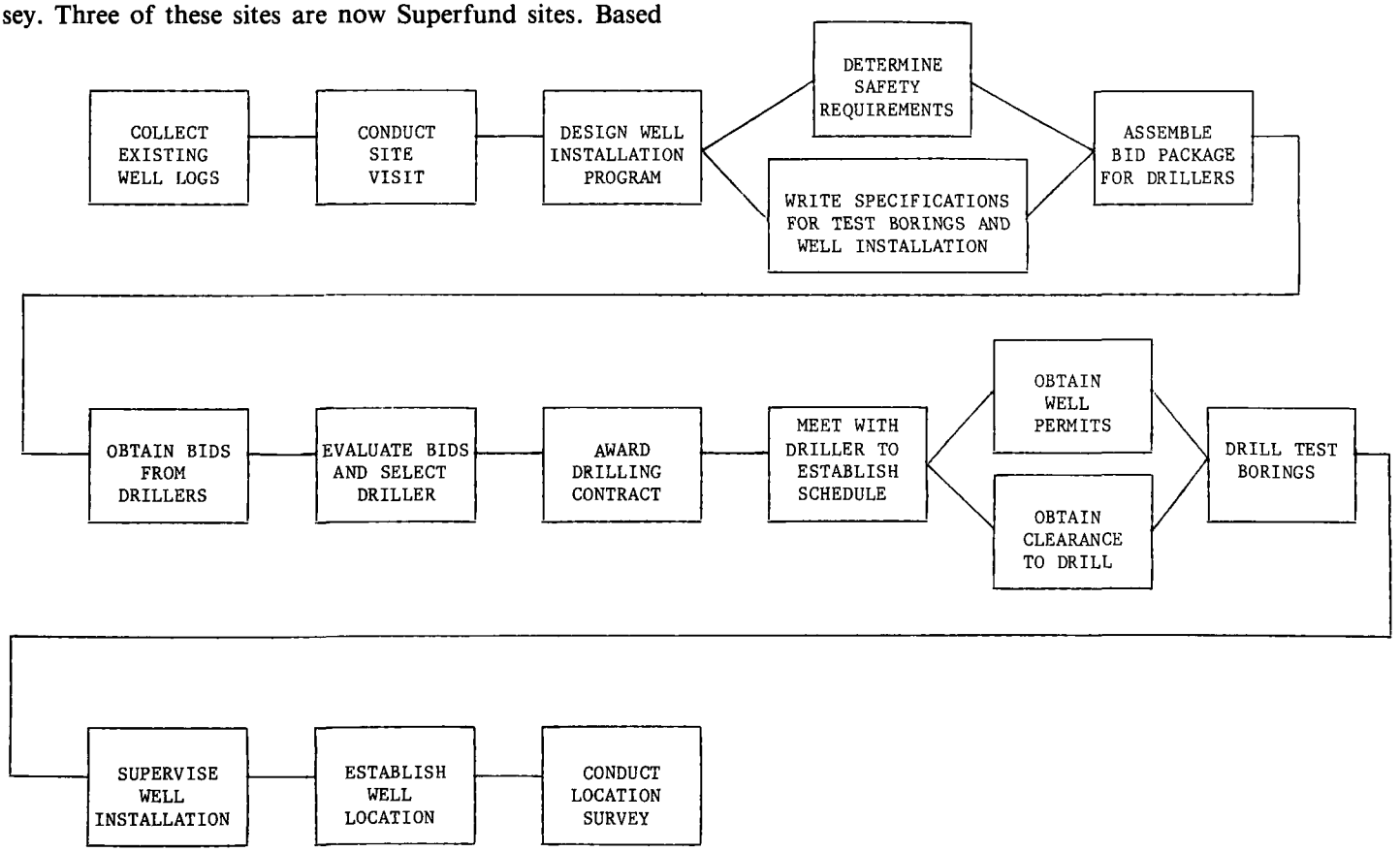

Figure 1.
Block Flow Diagram for Installing Monitoring Wells

PRELIMINARY STEPS

Collect Existing Well Logs

The first step in installing groundwater monitoring wells is to collect existing well logs. A geologic well log provides a detailed record of the lithology of the bore hole containing the well. In addition to geologic well logs, geophysical well logs and laboratory test data such as permeability and grain size analysis should be obtained if available. The purpose of collecting existing well logs is to facilitate well design for the drilling program. Very often, no well log exists for a well, or no one knows who put the well in the ground.

Existing well logs can usually be obtained from the following sources:

- States—
  Some states, such as New Jersey, require that all wells be permitted and that well logs for recently completed wells be filed with the state. In these cases, obtaining existing well logs should be easy.
- U.S. Geological Survey (USGS)—
  The USGS collects well logs in some states. Their regional office may have copies of well logs even if the state collects them.
- Driller—
  In many cases, the driller keeps logs of the wells he drills. The USGS or the state might know who did the drilling.
- Owner—
  The owner of the well often receives a copy of the well log or knows who drilled the well.

Conduct Site Visit

The investigator should conduct a site visit to become familiar with site conditions and identify potential drilling constraints. The site visit should determine the data needed by the investigation such as any site specific features. To facilitate monitoring well design, existing sampling points such as springs, wells, storm sewers and lagoons should be located. Any feature of the proposed drilling site which limits access of the drill equipment should be noted. Typical limiting features include steep grades, forested areas or areas with drums. The investigator should also note any area containing surface contaminants. These must be avoided to protect the safety of the drilling party.

The investigator should proceed with caution during the site visit because at this early point the risks are still relatively unknown. In some cases, a "windshield survey" should first be conducted by driving the perimeter of the site to verify aerial photo information and topographic map data. There should be adequate personnel on hand during the actual site visit to provide assistance in case of an emergency.

DESIGN OF WELL INSTALLATION PROGRAM

After conducting a site visit, the investigator can design the well installation program. The purpose of designing the well installation program is to establish the methods of conducting the groundwater investigation.

First, the investigator must identify the drilling method most compatible with the site geology. He must then determine the number of wells necessary to provide the best spatial coverage of the site with a reasonably high level of confidence. Using information gathered from the site visit and records review, the investigator can identify the aquifer most susceptible to contamination.

Next, fully penetrating wells can be located. In this step, care must be taken to avoid breaching confining layers because this could lead to aquifer cross contamination. The wells should be designed using non-reactive materials such as stainless steel or teflon-coated screens.

If two or more aquifers are potentially subject to contamination, clustered, nested wells are sometimes necessary to define differences and interaquifer leakage. Finally, the investigator should determine if the wells should be gravel packed or naturally developed. If falling head testing is planned on the monitoring wells, gravel packing should be avoided because the test results could be skewed by the higher permeability of the artificial gravel pack. As an alternative, the falling head test can be performed *in situ* before installing the gravel pack, and the well can be completed after testing with the gravel pack in place.

Write Specifications for Test Borings and Well Installation

Specifications must be written for test borings and well installation to define the required scope of work to drillers who bid the drilling contract. The long term needs of the groundwater investigation must be considered along with immediate needs when writing specifications.

The elements of monitoring well installation which must be specified include anticipated lengths of casing, type and length of screen, sampling requirements, development procedures, gravel packing, grouting and final cementing. The method of construction required under each option should be fully described. Options should be included to let the driller select the best drilling method to fit the site characteristics. If use of hydraulic rotary is an option, the driller must be told not to use contaminated water for the drilling operation so the aquifer is not contaminated by drilling. For quality control, samples of the drilling water should be taken and sent to a laboratory for analysis. The proper type of drilling mud should be specified. Organic agents or other items typically used by a driller which have the potential to react with contaminants in the groundwater are not always suitable.

Finally, a plan for properly abandoning unsuccessful well sites should be described. Typical methods include grouting the unsuccessful borehole with an impermeable material such as cement or bentonite. This step is important because an open hole breaching a confining unit increases the potential for cross contamination of the aquifer.

DETERMINATION OF SAFETY REQUIREMENTS

The first step in determining safety requirements is to identify hazards and analyze their potential effect. A

hazard analysis should be based on the following considerations:

- Type of waste (toxicity, explosivity, volatility)
- Quantity of waste
- Site topography
- Weather conditions

Based upon the hazard analysis, a safety plan should be developed and safety equipment requirements should be determined.

When drilling takes place in an area where hazardous materials could be encountered, the driller must be warned. The safety plan should include provisions to reduce the risk of exposure to contaminated soils, water or vapors that could be released during the drilling operation. Safety equipment and safety training to be provided by the driller must be specified so the bidders can include the cost of these requirements in their bids. For example, at one site, monitoring wells had to be installed in a landfill containing polychlorinated biphenyls (PCB's) and other contaminants. At this site, the investigator and drillers had to wear self-contained breathing apparatus and butyl rubber rainsuits for safety.

The safety plan must consider the strenuous effort that well drilling involves. Consideration must be given to the stress and discomfort caused by wearing of safety equipment during extreme hot and cold weather. Stress and discomfort must be balanced against the necessity to limit exposure. The driller must be made aware of all safety requirements and agree to them upon award of the contract.

BIDDING

Assemble Bid Package for Drillers

A drilling bid package must be assembled to give the drilling contractor enough information to reasonably estimate the costs involved in drilling at the site. Local drillers should be consulted to confirm the feasibility of the required drilling.

The drilling bid package should include a map providing the precise location of the site, a site sketch, geologic cross-section sketch, a short description of the geology of the site and the type of conditions the driller may encounter. The bid package should contain a statement advising the driller he is responsible for verifying all site conditions. The driller should be told to visit the site if he needs more information to prepare his bid.

Well construction should be described. Abandoned procedures for unsuccessful borings must be specified to make certain that abandoned wells are sealed to prevent interaquifer contamination.

Unit prices should be requested. One option involves bidding on a footage-plus-time-and-material basis. Another option is a straight time-and-materials basis. The latter method tends to be simpler, but it can be abused by drilling contractors who work slowly. To avoid this problem, time and material cost can be tied to a bonus to be paid for every foot drilled over a specified minimum footage.

The driller should be instructed to obtain any necessary permits. In some states he must prove that he is a duly licensed driller in that state. In these cases, the driller should be asked to submit his license number with his bid.

Materials to be used by the driller, such as casing, screens, bentonite, gravel and cement must be specified. The driller should be told when he will be expected to collect split spoon samples and how to store and label them. He should also be told which development methods will be necessary to insure the wells are adequately open to the formation. The driller must also be told when drilling should begin and end.

Obtain Bids From Drillers

The investigator should develop a list of reliable (and preferably) local bidders. At least three drillers should be sent a bid package and asked to bid. For sites requiring high levels of safety protection, such as self-contained breathing apparatus, bidders may have to be drawn from a wider geographical area.

Drillers usually require at least two weeks to review the drilling specifications and other requirements. After completing their review, the drillers can prepare a cost estimate and determine their time requirements to do the drilling.

Table I.
Driller Selection Factors

Category	Selection Factor
Drilling	•Availability of drilling equipment •Qualifications of personnel
Mobilization	•Mobilization plan •Time required from notice to proceed to on-site drilling
Experience	•Drilling experience in landfills •Drilling experience in hazardous waste sites •Experience with split-spoon sampler
Safety	•Attitude toward safety plan •Availability of personnel trained in safety •Willingness to train personnel in safety •Availability of safety equipment •Prior projects involving safety procedures •Understanding of decontamination responsibility •Experience with decontamination of personnel and equipment
Project Comprehension	•Understands project requirements •Understands project complexity
Liability Insurance	•Amount •Type coverage
Costs	•Realistic breakdown of costs •Cost limitations •Lump sum costs •Hourly rates
References	•Names •Phone numbers

Evaluate Bids and Select Driller

The investigator must identify driller selection factors as a basis for comparing bids. A suggested list of considerations when evaluating drillers' bids is given in Table I.

Although price is important, a driller should never be selected because of a low price alone. References should

always be contacted to insure that the driller's previous work has been done properly.

Award Drilling Contract

After the driller is selected, he should be notified at once. If he accepts the assignment, he should be sent a contract to sign. The drillers who bid but were not selected should be so notified in writing as a courtesy. This simple step will encourage them to bid on similar work in the future.

DRILLING

Meet with Driller to Establish Schedule

After the contract is signed by the driller, the investigator should meet with him to confirm the drilling schedule. This meeting should be held at the site, especially if the driller has not visited the site.

The following factors will determine the drilling schedule:

(1) Accessibility of drilling locations
(2) Drilling methods
(3) Safety equipment required at each drilling location
(4) Weather conditions, especially temperature extremes

The length of time required to drill at a hazardous waste site depends heavily on the safety equipment requirements. Drilling is strenuous work and safety equipment can make the job much more difficult. Wearing safety equipment can double the required length of time to drill, especially during very hot and humid weather.

Obtain Well Permits

Some states such as New Jersey require the registration of all wells drilled by the state. This requirement provides a centralized information source for well locations and their respective logs.

Either the driller or the investigator can assume responsibility for acquiring the necessary permits. The permit should be registered in the name of the investigator's firm to facilitate later inquiries about the well.

After drilling is completed, a copy of the well logs should be submitted to the state agency which issued the permit. This will complete the record concerning the monitor well and make it easier to compile well information in the future.

Obtain Clearance to Drill

Drilling to detect possible contamination may require the wells to be placed either on the site or on privately owned land. For wells which are to be drilled on privately owned land, permission must be obtained from the owner. State-owned land requires obtaining clearance from any public service companies which might have underground transmission lines, electric lines or water mains which could be damaged during the drilling process. The driller is often best qualified to obtain these clearances since he will most likely be more familiar with the local area and would know which utilities have to be contacted. This is a good reason to use local drillers.

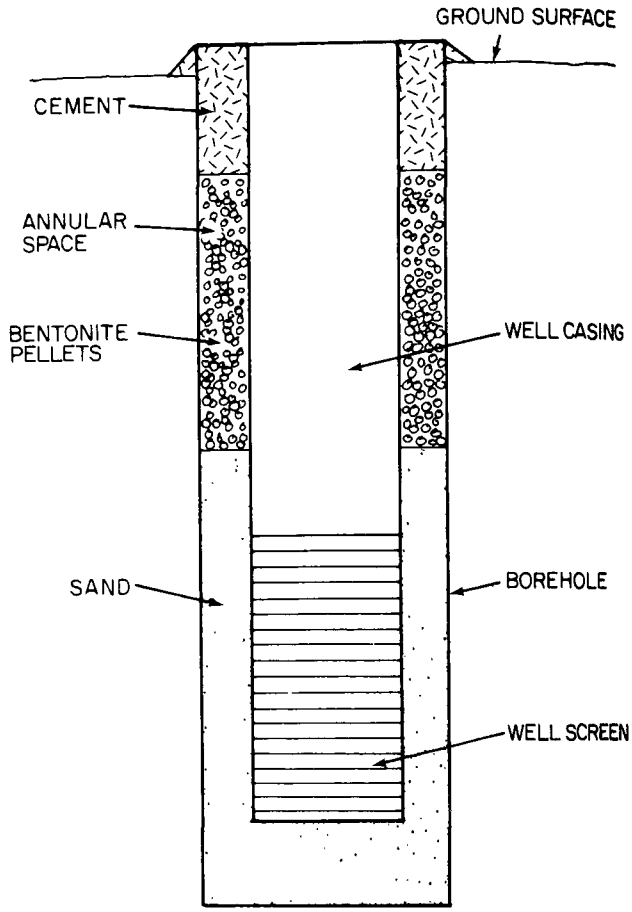

Figure 2.
Simplified Schematic of a Typical Well Installation

Some states have a centralized agency which handles clearance matters for a number of large utilities. Even in these cases, additional information should be obtained from the local municipality to help locate underground lines.

Drill Test Borings

Test borings are drilled to provide information concerning site geology. In turn, this information is used to determine well locations and depths. Test boring information on site geology is obtained by analyzing split-spoon samples taken at various depths, usually every 1.5 m or when lithology changes.

Monitoring wells can be installed in the test bore hole after completing the boring. This method saves a considerable amount of time and money since it eliminates the need of an additional borehole.

WELL INSTALLATION

The investigator must supervise the installation of wells to insure the well design is properly followed. Figure 2 is a simplified (many details have been purposely omitted) schematic of a typical monitoring well installation. The specific well design used in a given situation depends heavily on site geology and the purpose of the well. For

example, a well with a long life requirement should include a lock to prevent tampering.

In many cases, the borehole is drilled, the screen is set, the well is developed and finally the well is completed. Each of these steps must be carefully monitored by the investigator.

A borehole must be drilled to contain the well screen and casing. Materials used in the drilling process must be carefully monitored and accurately recorded to avoid influencing water quality and subsequent chemical analyses. The investigator must carefully monitor what goes into the borehole to prevent any contamination from migrating further due to drilling techniques. For example, the confining layer between a contaminated and "clean" aquifer should not be breached without sealing off the upper part of the aquifer.

A well screen must be set in the zone where groundwater is to be monitored. The ideal screen setting depth is in the zone of highest contamination and highest permeability. Usually, both of these conditions are found in the same zone because contaminants tend to be transported by groundwater.

Figure 3.
Setting up drill rig and connecting to air supply

Figure 4.
Drillers and investigators at drill rig location

When volatile organic contaminants are not present, test boring information must be used to locate the highest permeability zone and establish the well screen setting which can be temporarily set at various depths to obtain groundwater samples. These groundwater samples from various depths can be scanned with an organic vapor analyzer (OVA). This instrument can be used as an on-site, portable gas chromatograph to analyze water samples from various depths. Representative samples of groundwater at a specific depth are obtained by pumping the well at that depth. A representative water sample from each depth is analyzed with the OVA to identify contaminated zones of the aquifer.

The proper depth for the permanent screen setting is determined by scanning the water sample with the OVA to determine the presence of organic contaminants. Split-spoon samples can also be scanned with the OVA to determine proper well screen setting depths.

After the well screen is set in a zone, the well must be developed. In sand and gravel formations, the well can be naturally developed by pumping water through the screen. This will allow the formation to collapse around the screen as fine particles are removed. When clear water begins to be pumped, the development process is complete.

After the well is developed, the well installation must be completed by filling the annular space between the borehole and the well casing. For example, sand can be poured into the space part of the way, then bentonite pellets and finally cement can be poured up to the ground surface to prevent contamination by surface runoff. Sand is often mixed with bentonite to form grout and this mixture can be used to prevent downward flow of water.

The investigator must also monitor safety during the well installation process. This important function can become very difficult when there are very hot outdoor temperatures and the drilling team would prefer to relax safety requirements to avoid bodily harm from heat exhaustion. The investigator should monitor safety using the OVA. He should stop drilling operations if OVA readings of ambient air show high concentrations of volatile organics.

Figure 3 shows a driller setting up his drill rig and connecting to the breathing air supply. In Figure 4, a closer view of the drillers and the investigator wearing protective clothing at the drill rig location is provided. In Figure 5, one can see a driller's helper checking the breathing air connections. Figure 6 shows a close-up view of the chemical resistant suit worn by the driller. The drill auger flight and 150-lb hammer are visible behind the driller.

ESTABLISH WELL LOCATION

Completed monitoring wells must be accurately located horizontally and vertically. Accurate well location is necessary to determine groundwater gradients and to tie groundwater data in with surface water data. In this effort, accurate horizontal well locations are usually less

Figure 5.
Driller's helper checking breathing air connections

critical than are accurate vertical well locations. If accurate large scale maps or controlled aerial photos are available for the site, the horizontal location may be determined by chaining to four existing topographic features such as buildings, culverts or utility poles.

If surveying expertise is available in-house or can be developed, significant savings of time and money can be realized. For example, EPA Region II conducted an in-house training program to enable vertical location surveys to be done without resorting to subcontract.

Because there are significant differences between doing a vertical location survey in-house and doing it by contracting the work out, guidance for either method is provided below.

Conduct Vertical Location Survey In-House

Conducting level surveys typically requires less surveying expertise and experience than do most other ground survey tasks. Vertical surveys can often be conducted in-house using personnel who have been given adequate equipment and training.

The following guidelines are recommended when conducting a vertical survey:

(1) Decide on a fixed elevation reference point on all wells to eliminate confusion. For example, always take the elevation at the northernmost point of the inner casing.
(2) Establish a temporary benchmark near each well or cluster of wells to facilitate rechecking elevations.
(3) If possible, resurvey at the end of long term monitoring campaigns.

For level surveys, all measurements must be part of a complete level circuit, beginning and ending at a properly documented state or federal monumented benchmark.

Conduct Vertical and Horizontal Location Survey by Contract

If in-house surveying expertise is not available, it will be necessary to establish horizontal and vertical well locations using services of a professional land surveyor. Surveyors may not be familiar with groundwater investigations, particularly at hazardous waste sites. Several items must therefore be included in the specifications and bid package to prevent confusion and minimize costs.

Accuracy requirements must be specified for horizontal and vertical location. Typically, absolute vertical accuracy of 0.03 m and horizontal accuracy of 30 m will be adequate for most investigations. Between wells, relative horizontal accuracy standards may be more rigorous.

Required safety equipment and training for survey crews must be specified. Surveyors will generally require training if self-contained breathing apparatus is required. Based on Region II experience, operation of transit or level is possible while wearing full-face respiratory protection. The investigator should serve as Safety Officer on-site and provide technical supervision.

Materials, construction and documentation should be specified to establish temporary benchmarks at each well or cluster of wells. Proper temporary benchmarking will facilitate rechecking well elevations.

Required documentation such as large scale location maps, location sketches and reports should also be speci-

Figure 6.
Driller in chemical-resistant suit

fied. The bidder should also be told if documents on reproducible media such as sepia prints or film (Mylar) are required.

After bids are received, the bid evaluation for selecting a surveyor should be based on his understanding of the special requirements for such surveys, ability to comply with schedule requirements, and cost. Licensed professional land surveyors will have demonstrated necessary technical surveying expertise as part of the state licensing process.

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MANAGEMENT OF ANALYTICAL LABORATORY SUPPORT AT UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

The recently enacted "Superfund" law (PL-96-510: the Comprehensive Environmental Response, Compensation, and Liability Act of 1980) provides significantly broadened legislative authority for response to spills and other discharges of hazardous chemicals. "Superfund" establishes a trust fund for the mitigation of hazardous substances released from all sources including uncontrolled hazardous waste disposal sites. "Superfund" also provides for the amelioration of pollution in groundwaters, surface waters, soils, sediments and the atmosphere. In support of this mandate, EPA Research and Development (ORD) has focused attention on generating new and improved technology for multi-media cleanup, removal and remedial action at spills and hazardous waste dumpsites.[1]

The imminent threat posed by the continuing discovery of abandoned hazardous waste sites necessitated the development of a comprehensive management scheme to coordinate analytical services at such environmental incidents. ORD's Municipal Environmental Research Laboratory (MERL), through a program at its Oil and Hazardous Materials Spills (OHMS) Branch in Edison, New Jersey, has developed a unique interlaboratory management approach to provide broad scope emergency response analysis capabilities. The Chemisty Group at the OHMS Branch serves a dual role: (1) managing research and development projects and (2) providing emergency support in the form of analytical assistance. The R&D and emergency support programs are interrelated within the overall management scheme of the laboratory, which integrates the functions of central, mobile and service laboratory entities, as depicted in Figure 1. Each unit within this matrix may operate on specific or joint tasks with continual input, feedback and integration with other units to yield rapid responses to requests for analytical services.

In this paper, the authors describe a specific approach for providing accurate and timely analytical services during environmental emergencies and include a detailed discussion of the mechanics involved in managing such a concerted analysis effort. The paper portrays one of the essential functions of the OHMS Branch, namely the development of a prototype emergency response analysis capability, consisting of several integral units functioning as a single entity in coordinating sample analyses. The overall objective of integrating the individual units is to establish the capability to respond promptly and efficiently to emergency situations, using the appropriate equipment, facilities and methodology. The paper presents an overview of this prototype response capability.

CENTRAL LABORATORY

The OHMS Branch maintains a highly sophisticated central analytical laboratory that serves as the nucleus or coordination center of the individual laboratory entities. The central laboratory conducts research studies designed to develop, evaluate and refine methods and techniques for the detection, identification and quantitative measurement of oil and hazardous materials in diverse environmental matrices. The central laboratory is also responsible for managing and supervising the practical application of prototypal analytical methodology during emergency response episodes. Interrelation of research and development responsibilities with analytical assistance needs is therefore a key function performed by this laboratory.

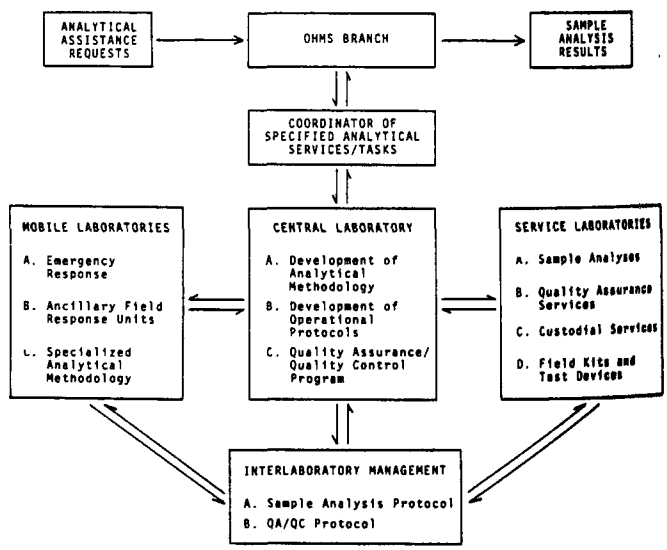

Figure 1.
Overall OHMSB Laboratory Management Scheme for Providing Emergency Response Analytical Services

Analytical Methodology

The primary focus of method development activities involves generating exceptionally rapid and direct methods of chemical analysis for use within the confined work space of mobile laboratories operating in remote field locations. The OHMS Branch has developed a substantial number of analytical methods and techniques for the qualitative and quantitative determination of hazardous chemicals in water, sediments and the contents of abandoned chemical storage tanks and drums. The methodology is in the form of individual instrumental analysis techniques, sample preparation and analysis procedures, and quality assurance/quality control guidelines. These protocols are employed by both the central and mobile laboratories to ensure the acquisition and subsequent dissemination of timely verified data.

The analytical methodology developed by the laboratory utilizes an assemblage of instrumental approaches including gas chromatography and fluorescence and infrared spectroscopy. The chromatographic methods specifically address the analysis of EPA designated priority pollutants[2], a "template" of organic toxicants comprised of pesticides, polychlorinated biphenyls (PCBs), base neutrals, phenolics and purgeable compounds. Organic pollutants analyzed by fluorescence and infrared spectroscopy include aromatic compounds and petroleum oils. An earlier publication describes specific aspects of the analytical and instrumental approaches, citing examples of their application to emergency response analytical assistance situations.[3] The methods exhibit unique capabilities in providing rapid and accurate information regarding oil and hazardous material concentrations in a variety of environmental media.

The majority of the specialized methods incorporate the use of single stage extraction techniques which avoid tedious and time consuming solvent and soxhlet extraction, evaporation and concentration steps. These innovative techniques are applicable to the analysis of virtually all priority pollutant materials. Rapid spinning techniques are employed to extract priority pollutants from aqueous media.[4] Extraction is accomplished by agitating the mixture (i.e. organic solvent(s) and water sample) using a magnetic stir bar and stirring mechanism. Soil and sediment samples are extracted in a single step procedure utilizing a gyratory shaker to ensure complete contact between solvent and sediment. Gas chromatographic analysis of the extracts permits rapid quantification of the priority pollutants.

The development of rapid analytical methods based upon the synchronous excitation fluorescence technique considerably reduces sample preparation and analysis time. Direct *in situ* quantification of hazardous materials in aqueous media enables detection of fluorescing organics at the µg/l level.[5] Rapid quantitative analysis of petroleum oil in water is achieved through addition of an equivalent amount of co-solvent to a portion of aqueous sample. The synchronous excitation fluorescence technique is also applicable to the rapid measurement of hazardous materials[6] and petroleum oils[7] extracted from wet sediments. The extraction procedure incorporates the use of a gyratory shaker which affords a five to ten-fold reduction in analysis time over conventional methods using soxhlet and alcoholic-KOH extraction techniques.

Infrared spectroscopy is almost exclusively employed for the identification and quantitative measurement of petroleum oils extracted from various matrices.[8,9,10] An unusually time efficient method for analyzing petroleum oils in sediments entails extracting the samples with carbon tetrachloride via gyratory agitation. The extracts are then diluted for infrared spectroscopic measurement which provides accurate quantification of petroleum oil in the sediment.

The availability of this unique technology greatly facilitates emergency response analytical laboratory support by providing proven applicable methodology, or furnishing the groundwork for the rapid development of an appropriate method required for a specific response action. The response capabilities of the laboratory have evolved over the last decade according to the operational needs of both hazardous materials spills and uncontrolled hazardous waste dumpsite management. The central laboratory is presently compiling a manual of analytical methods for emergency response to discharges of hazardous chemicals and petroleum oils. This manual is intended for use in support of decisions associated with responses to environmental emergencies.

Operational Protocols

In addition to coordination the development, evaluation and refinement of analytical methods and techniques, the laboratory manages the implementation of specific operational protocols for assuring emergency response readiness. The central laboratory established a column quality control system for maintaining and documenting the use of gas chromatographic columns. Columns entered into the system are performance evaluated in accordance with specified efficiency and resolution criteria. Certification files are established for the individual columns which are assigned inventory control numbers for management purposes. Extensive records are maintained regarding column use and performance, to assure the availability of an adequate supply of validated columns in anticipation of emergency response activations. Effective management of such a laboratory system is of critical importance for providing accurate and timely analytical services during environmental emergencies.

The laboratory also evaluated a large number of column packing materials for broad scope application to the gas chromatographic analysis of priority pollutants. The objective of this research was to establish a "universal" column packing material suitable for the analysis of nearly all priority pollutants. Advantages of employing a single column for general use include simplification of data acquisition and column inventory, and reduction in time and cost. Comprehensive evaluation of commercially available column packing materials resulted in the selection of a mixed phase column consisting of 1.5% SP-2250 and 1.95% SP-2401 coated on 100/120 mesh Supelcoport, for general use. This column yields excellent results for the

analysis of pesticides, PCBs, base neutrals and a limited quantity of phenolic and purgeable compounds.[4]

Quality Assurance/Quality Control

An important function of the central laboratory is assuring interlaboratory compliance with applicable Quality Assurance/Quality Control (QA/QC) requirements. Quality assurance defines the limits of measurements and monitoring data in terms of sensitivity, reproducibility, detection limits and accuracy. QA/QC protocols are necessary to demonstrate the reliability of data generated by the individual laboratory entities. The central laboratory implemented a comprehensive QA/QC program to ensure the acquisition of high quality data in method development and sample analysis activities.

The QA/QC program incorporates a novel technique for defining a suitable quantitative measurement or linear dynamic range for single point analysis.[11] Single point analysis affords significant capabilities in terms of processing large numbers of samples rapidly, and providing analytical results having known accuracy and precision. The procedure of defining the calibration range for single point analysis employs numerous computations that are amenable to computer processing. Computer programs developed by the laboratory include calibration range determinations and quantitative analyses for both spectroscopic and chromatographic instruments.[12] Increased utilization of automated instrumentation and microprocessors facilities management of data acquisition, manipulation and processing in sample report format.

The laboratory employs a method validation procedure in which replicate synthetic samples are prepared in a matrix and at a concentration resembling that of the actual samples. The synthetic samples are used to evaluate the precision and accuracy of the primary analysis methods. Method evaluation is essential to confirm the veracity of analytical results, especially when procedures and data are used in an interlaboratory mode. The method validation techniques are employed extensively during emergency response activations of the mobile laboratory to ensure data integrity.

MOBILE LABORATORIES

As part of a continuing effort to provide prompt analytical support to environmental incidents requiring emergency response, the OHMS Branch developed a mobile laboratory and an ancillary mobile unit for performing requisite analytical services in remote field locations. The primary function of the mobile laboratory[13] is to provide rapid on-site chemical analyses in support of multi-media cleanup activities. The EPA mobile laboratory is equipped with multi-parametric analytical instrumentation, including:

- a computerized gas chromatograph/mass spectrometer
- two computerized gas chromatographs furnished with automatic sample injectors and flame ionization, electron capture and nitrogen-phosphorous detectors
- a computerized atomic absorption spectrometer with a graphite furnace accessory and automatic sampling system
- infrared and fluorescence spectrophotometers
- an emission spectrometer
- a total organic carbon analyzer. The broad range of

The broad range of analytical capabilities aboard the mobile laboratory permits accurate chemical analysis of virtually all organic and inorganic substances potentially encountered at uncontrolled hazardous waste sites.

Emergency Response

The mobile laboratory is readily dispatched for transport to any part of the United States within a few hours of an official request for emergency analytical services. The laboratory is normally stationed within the proximity of the cleanup operation to enable rapid on-site sample analyses. Junior level personnel (i.e. highly trained technicians and cooperative college students) perform the "hands-on" analyses aboard remotely located mobile laboratories, while senior level chemists provide guidance and direction from the central laboratory.

Experience attained over several years of field operations demonstrates that, as a general rule, junior level personnel enthusiastically accept travel and long term assignment to mobile laboratory activations. This operational management scheme avoids the obvious morale problems associated with stationing senior level personnel for prolonged periods of duty in remote field locations.

The staffing of mobile laboratories with junior level personnel prompted the development of a unique management approach for coordinating the on-site analytical laboratory support. Senior level personnel situated at the chemical laboratory manage and direct the sample analyses performed on mobile laboratories, using a multi-faceted communications system. Specific sample analysis procedures and analytical methodology developed at the central laboratory are relayed to the mobile laboratory through use of high speed telefacsimile units. Mobile laboratory transmission of "raw" data, such as sample chromatograms and spectra, supplies the necessary information for senior level chemists to accurately interpret analytical results and implement corrective procedures.

The central laboratory also evaluates the methodology employed and generates validation data concurrently with sample analyses performed aboard the mobile laboratories. The concept of senior level personnel guiding and directing sample analyses on mobile laboratories via a rapid communications system is a unique and effective management technique for integrating analytical services during environmental response efforts.

Ancillary Field Response Units

The experience derived through numerous activations of EPA's mobile laboratory served as a precursor to the novel concept of developing and managing a network of mobile laboratories. The concept involves equipping mobile units with specialized instrumentation for response to specific analytical assistance requests. The concept is em-

ployed when analytical needs are specified in advance, such as requests for establishing the presence of PCBs in abandoned chemical storage tanks and drums. The appropriate instruments and associated support materials are rapidly installed on a mobile unit and dispatched to the site. Communication lines are established for transmitting data to and receiving operational instructions from, the central laboratory. Development of a broad-based management system for coordinagint a network of mobile laboratories provides the OHMS Branch with enhanced emergency response analytical capabilities.

An extention of this approach involves the concept of crating and forwarding specific instruments to particular environmental cleanup operations. Use of this concept is restricted to incidents in which analytical assistance needs are highly specialized. The procedure entails packaging the appropriate analytical instrument in a custom designed crate for shipment. A technician is dispatched from the central laboratory to unpack, install and operate the instrument at facilities established on-site. Communication is maintained with the central laboratory via telefacsimile to permit close coordination of sample analysis activities. Crating of portable field devices such as shoulder borne gas chromatagraphs and redox test kits is often employed to provide additional analytical support. The crating concept is a unique approach for managing analytical services, especially during concurrent emergency response analytical activities.

Specialized Analytical Methodology

The inherent space and time restrictions associated with mobile laboratory operations in the field necessitate the use of exceptionally rapid and direct methods of sample preparation and analysis.[14] Extensive application of the specialized analytical methodology developed by the central laboratory enables rapid processing of numerous samples during field activations. The established methodology is continually refined, and additional procedures and protocols are developed to streamline sample analyses.

Specialized sample preparation techniques are under continual development, in order to maximize the available space and minimize analysis time aboard mobile laboratories. A considerable expenditure of analysis time is required for performing sequential sample and standard dilutions with conventional volumetric pipets. Such sequential dilutions are time consuming, tedious, wasteful of expensive solvents and prone to error magnification with each successive step.

The alternative of using positive displacement micropipets, which afford a "one-step" dilution capability, was evaluated in accordance with established precision and accuracy criteria. The high degree of reproducibility and reliability associated with their use, resulted in the incorporation of positive displacement micropipets into the methodology.[15] Micropipets are used extensively in clinical laboratories, where quantities of body fluids available for analytical tests are at a premium. Application of micropipets to environmental analyses reduces problems associated with waste solvent generation, minimizes personnel exposure to toxic chemicals and conserves costly Primary-Standards and chemical reagents.

The instrumental analysis techniques employed by the mobile laboratories are augmented through the use of computerized gas chromatography/mass spectrometry. This analytical technique enables separation of complex mixtures into their individual constituents for compound identification. Interpretation of mass spectra is accomplished by internal library searching and matching for priority pollutant identification. Files of spectra for numerous compounds are maintained on cassette tapes to facilitate retrieval and storage. Functional GC/MS operation is accomplished by junior level personnel in the field, with minimum supervision from the central laboratory. Computerized interpretation of analytical results is a time efficient managerial approach for acquiring high quality data during emergency response activities.

SERVICE LABORATORIES

Use of commercial service laboratories is an integral part of the interlaboratory analytical emergency response management system. Commercial service laboratories provide emergency response support vis-a-vis sample analyses, quality assurance services, custodial responsibility for hazardous chemicals and reagents and development of field kits and test devices. Primary considerations involved in selecting the appropriate service laboratory for a particular analysis request include: (1) performance history, (2) analytical methods used, (3) analysis cost and time, (4) available instrumentation, (5) internal quality control system, (6) staff and management qualifications and, (7) results of test sample audits.

Sample Analyses

The management system for service laboratories tracks samples from time of receipt until completion of analysis. The initial stage of sample documentation involves scanning the sample(s) for the presence of nuclear radiation. The next stage entails completion of an analytical services request form to execute the following tasks: (1) assign sample log numbers, (2) describe and photograph the samples, (3) establish a contract with a service laboratory, (4) determine methods of analysis, (5) evaluate safety procedures, (6) maintain chain of custody records and, (7) prepare and forward quality assurance samples. This form provides the means for coordinating emergency response sample analyses performed by service laboratories.

Quality Assurance Services

An essential feature of the service laboratory management system is its quality assurance (QA) protocol. QA services are performed by the central laboratory or by a second commercial service laboratory. The protocol necessitates that split samples be retained and analyzed in the central laboratory, while replicate synthetic samples are forwarded to the service laboratory with the actual samples. The QA protocol consists of three states:

(1) a pre-analysis meeting with service laboratory personnel to evaluate the analysis methods and the internal quality control (QC) program

(2) an on-site visit during the course of sample analyses to monitor incoming data
(3) a comprehensive review of the final sample analysis report.

The QA protocol is specifically designed to generate validation data concurrently with sample analysis activities, to provide analytical results of known quality in "real time."

Custodial Services

Commercial service laboratories are also employed to stock and maintain custodial responsibility for specific hazardous chemicals and reagents required by the central and mobile laboratories. This essential service assures the availability of an adequate supply of certified reference standards and chemical reagents during emergency response activation. The service laboratory documents the purity and shelf-life of reference standards, reorders expended materials and prepares stock solutions of chemical reagents upon request.

Field Kits and Test Devices

Contracts are occasionally arranged with service laboratories for the rapid development of emergency response field kits and test devices. These requests are associated with specific emergency response episodes and their ensuing analytical laboratory support requirements. Such a contractual arrangement was recently used for the development of a portable Oxidation-Reduction (REDOX) Potential measurement kit to classify unknown chemicals at an uncontrolled hazardous waste site. This relatively low cost project was completed on an emergency type basis within a two-week period using the service laboratory analytical support mechanism.

INTERLABORATORY MANAGEMENT

The unique interlaboratory management approach developed by the OHMS Branch affords broad scope emergency response analysis capabilities. The central laboratory serves as the coordination center of the analysis effort and functions as a liaison between mobile and service laboratories when the latter support is required (Figure 1). Integration of the analytical services provided by the individual entities is accomplished through the use of specific laboratory management protocols. These protocols are essential for assuring prompt and efficient response to analytical assistance requests.

Sample Analysis Protocol

The central laboratory employs a specialized procedure for coordinating sample analysis activities and preparing final reports. Processing of large numbers of samples is expedited through completion of a Sample Analysis Form (Figure 2). This documentation form provides specific guidelines for directing and performing sample analyses. The central laboratory is responsible for completing the form and managing the overall analysis effort. The Sample Analysis Form incorporates all essential sample documentation and analysis data and is therefore an effective management device for coordinating interlaboratory services during emergency response activities.

The Sample Analysis Form is included in the final report, which contains a comprehensive summary of the analytical results. The report consists of six sections, each of which addresses specific aspects of the analysis activity:

- pertinent sample documentation
- chain of custody records
- the sample analysis results
- methodology used
- QA/QC and method validation
- analysis data, such as sample chromatograms and spectra

Following final review and approval, the sample analysis results are forwarded to the Requestor and the analysis report is archived for future reference and use.

QA/QC Protocols

A complementary series of QA/QC protocols are used by the OHMSB laboratory to monitor the analytical data generated by its individual entities, and to assure the integrity of reported sample analysis results. Management of the interlaboratory QA/QC program is the responsibility of the central laboratory, which coordinates emergency response sample analyses. All sample documentation is performed by the central laboratory prior to forwarding the samples to the service laboratory for an analysis.

A representative portion of sample is separated from the main sample(s) and retained at the central laboratory for QC purposes. Approximately 25% of the retained samples are analyzed at the central laboratory or a second service laboratory. Replicate synthetic samples are prepared in a matrix and at a concentration resembling that of the actual samples to evaluate the accuracy and precision of the analytical methodology employed by the service laboratory.

An abbreviated version of the laboratory QA/QC program is used during emergency response activations of the mobile laboratories. This protocol provides the on-scene coordinator with sample analysis data of known quality for establishing specific QC guidelines. All sample analyses are performed in such a manner as to permit rapid dissemination of analytical results. The central laboratory coordinates the QA aspects of the protocol to ensure that reported results are of known accuracy and precision.

The simultaneous reporting of sample analysis and QA validation data furnishes the Requestor with analytical results in "real time." The Requestor is then in a position to determine the need and practicality of repeated or supplementary analyses. This type of management system permits immediate release of sample analysis results to the on-scene coordinator, who is responsible for implementing appropriate remedial techniques during environmental cleanup operations.

CONCLUSIONS

A comprehensive management system for providing analytical laboratory support to environmental incidents

SAMPLE ANALYSIS FORM

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OIL AND HAZARDOUS MATERIALS SPILLS BRANCH - EDISON, NJ
CHEMISTRY STAFF

1. REQUESTED BY:_____ ORGANIZATION:_____ DATE OF REQUEST: Mo | Day | Yr
   OHMSB LOG #____ # OF SAMPLES:____ SAMPLE ORIGIN (LOCATION):_____
   SAMPLE BACKGROUND:_____
   CHECK ACTIVITY: CENTRAL LAB_____ MOBILE LAB_____ SERVICE LAB_____
2. DESCRIPTION OF SAMPLES (TYPE OF SAMPLES, WEIGHT OR VOLUME, TYPE OF CONTAINER):_____ /ATTACH PHOTOGRAPHS☐
3. ANALYSES REQUESTED:_____
4. METHOD(S) USED (GIVE TITLES):_____
5. SAFETY INFORMATION: *IMPORTANT: DO NOT PROCEED WITH ANALYSES UNTIL THE FOLLOWING INFORMATION HAS BEEN OBTAINED.
   IDENTIFICATION OF:_____ /HANDLING INSTRUCTIONS:
   A. HEALTH HAZARD:_____
   B. FLAMMABILITY:_____
   C. REACTIVITY:_____
   D. RADIOACTIVITY:_____
6. QA/QC:
   A. SERVICE LABORATORY QUALITY ASSURANCE PERFORMED: YES ☐ NO ☐ DESCRIBE:_____
   B. OHMSB (IN-HOUSE/MOBILE LABORATORY) QUALITY CONTROL PERFORMED:
   -CALIBRATION RANGES ESTABLISHED / Ec VALUES OBTAINED:_____
   -COEFFICIENT OF VARIATION (Cv) OF MIDPOINT SOLUTIONS OBTAINED:_____
   -ACCURACY (RECOVERY STUDY) Re VALUES OBTAINED:_____
   -PRECISION (REPLICATE ANALYSES) Cv VALUES OBTAINED:_____
   -CONFIRMATORY ANALYSES OF SPLIT REPRESENTATIVE SAMPLE PORTIONS:_____
   -CALCULATION OF RESULTS CHECKED:_____
7. CHAIN OF CUSTODY RECORD:

RELINQUISHED BY (SIGNATURE)	DATE / TIME	RECEIVED BY (SIGNATURE)	REASON FOR CHANGE OF CUSTODY
RELINQUISHED BY (SIGNATURE)	DATE / TIME	RECEIVED BY (SIGNATURE)	REASON FOR CHANGE OF CUSTODY
RELINQUISHED BY (SIGNATURE)	DATE / TIME	RECEIVED BY (SIGNATURE)	REASON FOR CHANGE OF CUSTODY

8. SUMMARY OF RESULTS (ATTACHMENTS AS REQUIRED):_____
9. REMARKS:_____

Figure 2.
An abbreviated version of the Sample Analysis Form employed by the OHMSB Laboratory for documentation of emergency response sample analyses.

requiring emergency response was developed through effective coordination of a series of interlaboratory services. The system incorporates specific operational protocols for coordinating and integrating the sample analyses performed by central, mobile and service laboratory facilities. Application of the appropriate analytical methodology and operational protocols lends invaluable support to management decisions involving the procedures employed for environmental cleanup at uncontrolled hazardous waste sites.

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USE OF A REGULATED ACCESS LABORATORY FOR SCREENING AND PREPARATION OF HAZARDOUS WASTE SITE SAMPLES

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INTRODUCTION

The investigation and cleanup of uncontrolled hazardous waste sites create a need for special waste sample screening and analysis capabilities, presenting some unique challenges to the analytical laboratory. The potentially highly hazardous nature of these samples and the typical lack of available information about any hazardous properties require that extreme caution be taken in the analytical process during sample preparation.

However, concentrated hazardous waste samples can be handled safely with the proper equipment and precautions. A regulated access laboratory at the U.S. Environmental Protection Agency's (EPA) National Enforcement Investigations Center (NEIC) is being used for analytical support of the agency's hazardous waste program. Since April 1980, the Regulated Access Laboratory at NEIC has been operated by Fred C. Hart Associates as part of the EPA's Field Investigations of Uncontrolled Hazardous Waste Sites contract.

PURPOSE OF LABORATORY

The Regulated Access Laboratory is designed to handle highly toxic and carcinogenic materials. The facility provides a safe workplace for the preparation of hazardous waste samples collected from uncontrolled hazardous waste sites. The laboratory has been equipped to permit samples to be examined, screened for various parameters which indicate hazard level and extracted and diluted as required so that the prepared extracts can be analyzed safely in an environmental laboratory.

LABORATORY PROCEDURES

The Regulated Access Laboratory receives many types of samples, including solid wastes, sludges, and aqueous and nonaqueous liquids. These samples come from containers such as drums and tanks, as well as from landfill leachate, pits, ponds, lagoons, piles of solid chemical and contaminated soils. Because of the varied and potentially highly hazardous nature of these samples, the laboratory's preparation procedures have been designed to reduce excessive handling of the concentrated sample, to accommodate a wide range of sample types and to produce extracts and other preparations analogous to environmental soil, sediment and water sample extracts.

The sample handling procedures include sample receipt and documentation, initial aliquot preparation, sample screening and extract preparation. All procedures incorporate quality control.

Sample Receipt and Documentation

Packaging and shipping procedures for transporting hazardous waste samples to a laboratory in accordance with Department of Transportation Regulations (49 CFR 173.2) have been described previously.[1] Samples are packed in glass bottles sealed in plastic bags and in turn, sealed inside metal cans filled with an absorbent, noncombustible filler material.

The metal can is brought into the laboratory unopened. The sample bottle is opened only in a laboratory type hood designed for this purpose, taking precautions to avoid contamination of the surrounding area. At this time, all documentation, such as sample tags and chain-of-custody records are verified.

Initial Aliquot Preparation

All required sample aliquots of the sample for the various screening tests and preparations are weighed out into appropriate containers, thus eliminating the handling of large amounts of the sample after this step. Most procedures require no more than one or two grams, but a 20g aliquot is required for preparations used for analysis of extractable organics.

Sampling Screening

All samples are screened by spot tests for pH, cyanide, sulfide and strong oxidants. Conductivity, alkalinity and acidity are determined when appropriate. The spot test results provide hazard information as well as indicating need for quantitative testing. Screening for organic constituents is accomplished by a gas chromatographic scan of organic extracts using a flame ionization detector. By using an internal standard, the approximate concentrations of components can be estimated. Although samplers are instructed not to send radioactive samples, all samples are screened for radioactivity prior to other testing.

Extract Preparation

Samples are routinely prepared for analysis of total metals and acid extractable metals, strong acid anions, volatile organics and semivolatile (acidic and base/neutral) organics. Typical detection limits are 1 to 10 mg/l when the extracts are analyzed by conventional trace level analytical methods. The preparation methods and recommended analysis methods for these parameters are given in Table I.

TABLE I.
Preparation of Extracts for Inorganic and Organic Analysis of Hazardous Waste Samples

Analytical Parameter	Method of Preparation	Method of Recommended Analysis
Total Metals	Dilution in 2% HNO_3	ICP-AES
	Metal Fusion (s,n)	ICP-AES
Acid Extractable Metals	Extraction with 0.1N HCl (s)	ICP-AES
Strong Acid Anions ($SO_4=$, Cl^-, F^-)	Dilution (a, s)	Ion Chromatography
Total Mercury	Persulfate/Permanganate Digestion (s,n)	CV-AAS
Volatile Organics	Dilution in Water	GC/MS (Method 624[2])
Semi Volatile Organics	Shakeout (a)	GC/MS (Method 625[3], 608[4])
	Water and Solvent Extraction (s)	
	Dilution (n)	

Key: a = aqueous samples; n = non-aqueous samples; s = solid samples;
ICP-AES = inductively coupled plasma atomic emission spectroscopy;
CV-AAS = cold vapor atomic absorption spectroscopy
GC/MS = gas chromatography/mass spectrometry

Development of New Methods for Screening Hazardous Waste Samples

Presently, newly developed procedures for screening hazardous waste samples are being tested in the Regulated Laboratory. The new approach permits a detailed organic screening of the sample to determine whether a further analysis is warranted. The organic extracts and sample aliquots prepared by this method permit screening by gas chromatography with flame ionization and Hall electrolytic conductivity detectors, using both packed and capillary columns for pesticides, PCB's, base/neutral and acid priority pollutants, volatile organic priority pollutants and related organic chemicals. Similarly, the inorganic sample preparations permit screening by x-ray fluourescence for priority pollutant metals. If the screenings indicate no detectable pollutants at the lower limits of detection, the need for additional and more expensive analysis can be evaluated.[5]

The new method has several advantages over the previous method. First, it requires a smaller sample size; only 2g are needed for the organic extract preparations. Tentative identification and quantitation of organic and inorganic (metal) priority pollutants can be obtained and, perhaps most importantly, identification of samples which contain contaminants below a specified level can eliminate the need for further expensive analysis. If further analysis is desired, the sample can then be analyzed using procedures designed for environmental levels of pollutants.

LABORATORY DESIGN

Laboratory Layout

A diagram of the laboratory, showing its major features and the location of major equipment is given in Figure 1. The laboratory work area is divided into two rooms (1) a "dry lab" which contains no running water or drains, and (2) a "wet lab" equipped with running water, compressed air and vacuum.

The "dry lab" is equipped with a glove box attached by means of double pass-through doors to a four ft. laboratory type hood. The "dry lab" also contains a laminar flow hood for biohazard work. The "dry lab" is used for work involving large amounts of a sample such as opening sample containers and weighing out samples.

The actual sample preparation occurs in the "wet lab." It is equipped with two, six ft. laboratory type hoods back to back. These hoods are primarily used for screening and preparation work using small quantities or dilutions of the samples. The laboratory is also equipped with a gas chromatograph, flammable solvent storage cabinets, a centrifuge and explosion-proof refrigerators.

The "wet lab" and "dry lab" are adjacent to a small vestibule which serves as contamination reduction area. An emergency phone is located in the vestibule. The vestibule leads to the adjacent men's and women's shower and change rooms, as well as to a door which provides direct access to the laboratory and is used to pass equipment in and out. These three access-ways are provided with electrically interlocked double doors to maintain the laboratory's reduced atmospheric pressure balance. An emergency exit is located in the "wet lab."

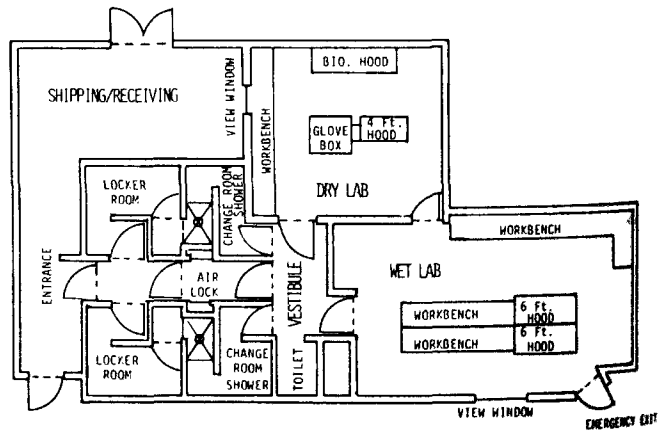

Figure 1.
Floorplan of EPA/NEIC Regulated Access Laboratory

Ventilation System

Laboratory air is exhausted exclusively through the four ft. hood and the two, six ft. hoods. The hood exhauts are equipped with high efficiency particulate air filters and activated carbon filters to remove airborne contaminants. The incoming air is limited to provide a net negative air pressure within the laboratory. The system is designed so that the "dry lab" is at slightly more negative pressure relative to the "wet lab," thus creating a flow of air from the "wet lab" to the "dry lab", *i.e.* toward the area of highest potential contamination.

Laboratory Status Indicators

The laboratory is equipped with filter static pressure gauges, laboratory differential negative pressure gauges and hood airflow indicators as a means of checking the proper functioning of the ventilation system.

Safety Considerations

A number of factors, described here, contribute to the safe operation of the Regulated Access Laboratory. These factors are training of personnel in safe handling of hazardous materials, laboratory design, standard operating procedures and personal protective equipment.

Training

Laboratory personnel undergo extensive training to prepare them to function safely in the Regulated Access Laboratory and to assure that all laboratory operations take place in a safe manner. Personnel attend courses in basic first aid and cardiopulmonary resuscitation as well as laboratory safety and safe handling of chemical carcinogens. Training in use of self-contained breathing apparatus and other respiratory protective equipment is also provided.

SAFETY FEATURES

Design

The Regulated Access Laboratory contains the following safety and contamination control features:

- Restricted and controlled access. Only authorized personnel are allowed to enter the regulated area of the laboratory. Access is controlled by an electric access control system. A daily roster of personnel entering the laboratory is maintained.
- Maintenance of reduced atmospheric pressure. The regulated area is maintained at a lower atmospheric pressure than the surrounding non-regulated area. The laboratory entrances are equipped with electrically interlocked double doors, which allow access to the laboratory while maintaining the lower inside pressure. Maintenance of the reduced internal pressure is checked daily.
- Ventilation system. The laboratory ventilation system provides for approximately 12 air changes per hour. All exhaust air, which exits through the laboratory type hoods, is treated by filtration through high efficiency particulate air (HEPA) filters and activated carbon filters to remove particulates and trace organics.
- Laboratory type hoods. Open-face hoods with an average linear face velocity of 100 feet per minute provide a working space for concentrated hazardous waste samples. The face velocity is checked daily.
- Glove box. A glove box provides an isolation area, primarily for preparation of highly toxic or carcinogenic standards. The glove box is kept under negative pressure of 0.5 inches water gauge with respect to the surrounding space.
- Shower and change area. Shower and change areas are used for thorough personal decontamination prior to leaving the regulated area.

Standard Operation Procedures

Use of standard operating procedures for all laboratory operations assures that safety practices are followed. These standard procedures include procedures for handling samples, housekeeping, waste disposal, and spill containment and cleanup. The standard operating procedures for handling hazardous waste samples include the following safety practices:

- Samples are only opened in laboratory type hoods
- Only small aliquots of samples (20 g or less) are handled at one time
- The initial step in sample preparation, involving examining the entire sample and weighing out small amounts for the various procedures, is always performed by two people. One person (called the processor) carries out the steps required to transfer and weigh the sample aliquots while the other assists by recording data, preparing labels and obtaining supplies and reagents for the processor. By restricting the arms of the processor, properly protected, to the inside of the four-foot hood during aliquot preparation, the chance of spreading contamination is reduced.
- No one may work alone in the laboratory.

Because the waste samples handled by the Regulated Access Laboratory may be highly hazardous, the standard operating procedure for spill containment and cleanup require that cleanup personnel are fully protected against exposure to unanalyzed hazardous waste samples. If a sample is spilled outside a hood or glove box, the laboratory must be evacuated, and the cleanup crew must reenter wearing self-contained breathing apparatus and other protective equipment. Emergency escape air masks stored inside the laboratory can be used if required for respiratory protection during evacuation of the laboratory.

In general, prudent practices for handling hazardous chemicals in the laboratory are followed.[6]

Personal Protective Equipment

Protective clothing is worn at all times while hazardous waste samples are being processed. Disposal Tyvec © hooded suits are worn over launderable jumpsuits, and Tyvec © booties are worn over washable sneakers. Goggles or safety glasses and nitrile gloves are worn routinely. Heavy gloves, made of various materials, are available and are used during cleanup of spills. Two pairs of gloves are always worn during operations involving high probability of direct contact with undiluted hazardous waste samples.

Personnel remove all clothing and other gear on leaving the laboratory before washing or showering. Although the standard operating procedures for sample preparation reduce the potential for contamination of laboratory personnel, the use of personal protective equipment further eliminates the likelihood of skin or eye contact with toxic and potentially carcinogenic samples. Respiratory protective equipment is not used except for emergencies such as spill containment.

PROBLEMS

Problems have been encountered due to space limitations of the laboratory. The most limiting factor is the availability of laboratory hood space, since many operations must be carried out in a hood. The hood space limitation requires that work be scheduled so that operations requiring the same hood are performed at different times.

Use of separate laboratories in different locations for sample preparation and analysis is sometimes cumbersome and creates problems with quality control. Since analytical quality control results are not immediately available, problems with preparation procedures may not be discovered rapidly.

Handling potentially hazardous materials and being confined in the laboratory create stressful working conditions. While the work of processing samples on a production basis becomes very routine, a high degree of alertness is required at all times. Since laboratory personnel do not see an end result, i.e., a final analysis of the sample, they receive no immediate feedback from their work, and therefore interest level and morale suffer. Involvement with the analysis of sample extracts with institution of the new procedures described above is expected to improve this situation. Additionally, rotation of laboratory personnel between the Regulated Access Laboratory and the analytical laboratories is expected to reduce negative effects of confinement.

ACCOMPLISHMENTS OF THE PROGRAM

During approximately one year that the Regulated Access Laboratory has been in operation, more than 550 hazardous waste samples, from almost 100 sites, have been screened and prepared for analysis. Work on most sampling projects is completed in 15 work days or less using the routine procedure described. The laboratory has handled a number of high priority requests which have been completed in one week or less.

The laboratory has prepared samples for analysis of 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (TCDD), using the extraction and cleanup procedures described in the *Federal Register*.[7] This work required preparation of pure TCDD standards. Another accomplishment of the laboratory is the preparation of samples using the EP Toxicity procedure required by the Resource Conservation and Recovery Act Regulations.[8]

Since its opening, the laboratory has operated without a serious accident or significant exposure. Several minor accidents involving cuts from broken glassware have occurred, but procedural changes have been made to reduce the chance of this type of injury.

The analytical results from hazardous waste samples prepared in the Regulated Access Laboratory are being used by both Headquarters EPA and Regional EPA offices for the development of enforcement cases involving uncontrolled hazardous waste sites. The NEIC facility has provided a central location where high hazard samples can be handled safely and prepared for analysis using standard and special request procedures.

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THE USE OF LABORATORY SCREENING PROCEDURES IN THE CHEMICAL EVALUATION OF UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

The disposal of hazardous waste materials has been and remains a major problem for the scientific community as a whole. Disposal practices have and unfortunately still include the deposition of hazardous waste materials at geologically/hydrogeologically unsuitable locations. Nationwide, it is believed that thousands of uncontrolled hazardous waste landfills remain undiscovered and/or uninvestigated. These sites generally are devoid of disposal records or the information concerning the types of deposited wastes is incomplete.

The most favorable and cost effective approach to investigating these uncontrolled waste sites is through an initial exploratory phase and a secondary confirmational phase. The major factor in the cost effectiveness of the exploratory phase of an investigation manifests itself in the use of screening procedures.

TYPES OF SCREENING PROCEDURES

Numerous types of screening procedures, whether or not recognized or identified by that terminology, have been used by analytical environmental scientists for many years. These procedures include, but are not limited to, the determination of pH, conductivity, total organic carbon, methylene blue active substances and phenols. These particular tests have been and continue to be viable screening procedures in most landfill situations.

Of greater concern today, however, are the presence and ultimate effects and/or impacts of organic materials in landfills. The types of screening procedures developed and presented in this paper represent cost effective and technically viable means for detection of volatile or non-volatile chromatographable organic constituents.

These screening procedures rely upon total chromatographic response of samples or sample extracts compared to the response of appropriate standard materials. These scans include halogenated organic scan via either electron capture detection (ECD) and/or modified Coulson's electrolytic conductivity detection (Coulson's), organic nitrogen/phosphorous scan, volatile halogenated/non-halogenated scan and organic scan via flame ionization detection.

Halogenated Organic Scan

The halogenated organic scan (ECD or Coulson's) is a gas chromatographic analysis with electron capture or electrolytic conductivity detection designed to scan sample extracts for the possible presence of many hazardous halogenated organic compounds. Responses are caused by the presence of compounds such as the majority of the U.S. E.P.A. designated Priority Pollutant Pesticides, polychlorinated biphenyls, as well as many other halogenated organics.[1, 2] Many non-halogenated organics containing the elements oxygen, nitrogen, phosphorus, or sulfur may also cause a response. Various clean-up procedures, or the use of the chlorine specific detector, can be incorporated into the analysis to remove many of these "interferences".

Quantification is based upon a summation of chromatographic response calculated as chlorine, using the response factor and chlorine content of Lindane as a standard. The selection of the ECD or Coulson's detector for this scan is generally a function of sensitivity and specificity. Often, the halogen specific Coulson's detector is used in the confirmatory phase of the investigation as opposed to the exploratory phase.

This scan test, regardless of the detector selected, is based upon a solvent extract chromatographed on a OU17/QF1 (or equivalent) pesticide column. The screening procedure is operationally defined as beginning at the retention time of dichlorobenzene and concluding at the retention time of methoxychlor.

Volatile Halogenated Organic Scan

The volatile halogenated organic scan is a chromatographic analysis, with electrolytic conductivity detection, operated in the halogen specific mode, designed to scan samples for the possible presence of many volatile hazardous halogenated organic compounds.

This screening procedure can also be used in conjunction with a flame ionization detector, in order to assure the detection of both halogenated and non-halogenated organics, most notably materials such as benzene, toluene and xylenes. The process uses chromatographable organic materials on a carbowax 1500/carbopack C and/or a SP-1000/carbopack B column. This scan test is operationally defined as beginning at the retention time of methylene chloride and concluding at the retention time of monochlorobenzene.

The choice of lindane and carbon tetrachloride as the standards for these procedures is somewhat arbitrary. These materials do provide approximate mean response factors under the condition of the test on ECD and flame ionization detectors, however.

The presence of compounds such as the majority U.S. E.P.A. designated Priority Pollutant Volatiles are detected. This detector is specific to halogenated organics, thus increasing the sensitivity. Quantification is based upon a summation of chromatographic response calculated as chlorine, using the response factor and chlorine content of carbon tetrachloride as a standard.

Organic Nitrogen/Phosphorus Scan

Organic nitrogen/phosphorus scans are again a gas chromatographic analysis with detection via a nitrogen-phosphorus specific detector, designed to scan samples for a variety of organonitrogen and organophosphorus compounds. This analysis is generally custom designed to fit the specific needs of the particular site under investigation. Chromatographic conditions are selected to provide a scan for the possible presence of organonitrogen and organophosphorus compounds with similar chemical structure and polarity. This analysis presupposes knowledge of the probable identities of the types of compounds which may be present. In the absence of any information on the specific site being investigated, a solvent extract is chromatographed on a SP-2250 column and results are presented based upon the response factor and nitrogen content of dimethylaniline.

Organic Screening Procedure

The organic screening procedure (FID) is completed with the use of flame ionization detection and is designed to scan samples for a variety of organic compounds. This versatile analysis is generally custom-designed to fit the specific needs of the site. Chromatographic conditions are selected to provide a scan for the possible presence of compounds with similar chemical structure and polarity. This analysis presupposes knowledge of the probably identities of the types of compounds which may be present. In the absence of any information regarding the site, a solvent extract is chromatographed on a SP-2250 column and the results are presented based upon the response factor and carbon content of naphthalene.

Quantification is based upon a summation of chromatographic response calculated as carbon, using the response factor and carbon content of a carefully selected specific organic compound as a standard. As was the case with nitrogen/phosphorus scans, multiple Organic Scan (FID) analyses employing different chromatographic columns and/or conditions may be necessary in order to screen for the variety of chemical structures and polarities which are suspected to be present.

APPLICATION OF SCREENING PROCEDURES

The initial or exploratory chemical evaluation of uncontrolled hazardous waste sites has been completed using numerous types of screening tests. The use of these screening tests has provided a cost effective means of defining those areas of a site (soil, sediment, surface and/or groundwater) and the types/classes of chemical compounds which require more in-depth examination prior to or during a secondary confirmational phase or before formulation and implementation of remedial action plans for a site.

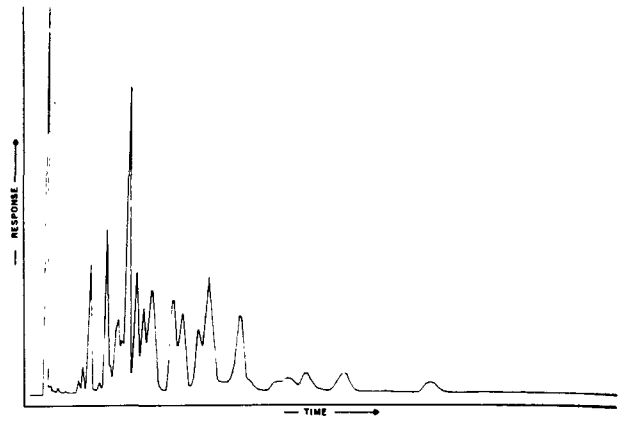

Figure 1.
Halogenated Organic Screening Procedure
Typical GLC/ECD Chromatogram

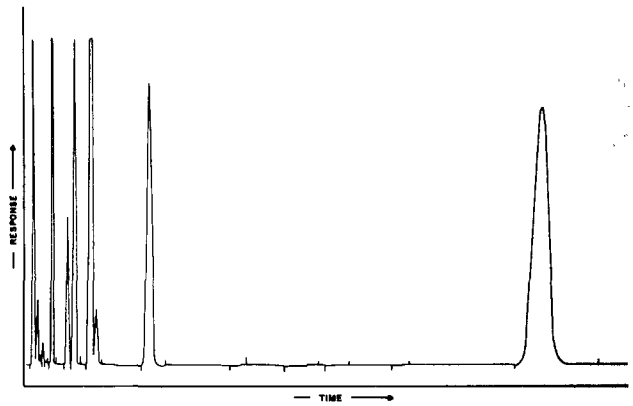

Figure 2.
Volatile Organic Screening Procedure
Typical GLC/FID Chromatograph

Landfill investigations performed by Recra Research, Inc. have confirmed the usefulness of these procedures. A typical Halogenated Organic Scan chromatograph is shown in Figure 1. This scan procedure has detected numerous halogenated organic materials, including but not limited to the following:

- chorobenzenes (di-, tri-, tetra-, penta-, and hexa-)
- chlorotoluenes
- hexachloro - 1,3 - butadiene
- hexachloropentadiene
- lindane (and other BHC isomers)
- pesticides (including DOT's, aldrin, etc.)
- polychlorinated biphenyls
- polybrominated biphenyls
- phthalate esters.

The volatile halogenated and non-halogenated organic screening procedure has been proven via GC/MS con-

firmation to detect the following types of organic materials:

- trichloroethylene
- methylene chloride
- 1,1,1 - trichloroethane
- tetrachloroethylene
- dichloroethylenes
- chlorabenzene
- benzene
- toluene
- xylenes
- styrene

An example of a chromatograph resulting from this procedure is included as Figure 2.

The organic screening procedure and the nitrogen-phosphorus screening procedures have also been used to detect numerous organic constituents including but not limited to the following:

- polynuclear aromatics
- chlorobenzenes
- chloronaphthalenes
- aniline (including substituted anilines)
- nitrosoanines

Based upon the broad scope extractions[3, 4] used and the columns employed, the detection of these types of organics is not surprising. The advantage of these screening procedures lies primarily in the time savings afforded due to the total chromatographic character of the test, the use of only one standard material and hence the reduced cost of the analysis. Generally screening procedures can be completed for less than half the cost of analyzing a "laundry list" of suspected organic materials.

The advantages of these screening procedures also include the estimate of halogenated organics, for example, which have illustrated 14 μg/g (as chlorine) and yet undetectable levels of a list of 16 specific organic constituents. The final advantage of screening procedures is that the chromatographs may possibly be suitable for additional review and prediction of the specific organic constituents or class of constituents which comprise the screening results, assuming that operational conditions are known. A particular example of this application is the ability to detect the presence of PCB's in the halogenated organic scan chromatograph.

The major disadvantage in the use of screening procedures at an uncontrolled hazardous waste site investigation is in the loss of specificity for detection of particular organic materials. Since most sites, however, are being investigated via the primary exploratory and secondary confirmatory design, this disadvantage does not outweigh the cost savings realized by use of the screening procedures.

RECOMMENDATION

Based upon Recra Research, Inc.'s work at various uncontrolled hazardous waste sites the following analytical program is recommended for use in exploratory efforts at other sites.

- pH
- Conductivity
- Total Organic Carbon
- Total Recoverable Phenols
- Organic Scan (FID)
- Halogenated Organic Scan (ECD)
- Volatile Organic Scan
- Nitrogen-Phosphorus Organic Scan

Additionally, it is recommended that samples from these sites also be analyzed for the toxic heavy metals including beryllium, cadmium, chromium, copper, nickel, lead, zinc, silver, arsenic, antimony, selenium, thallium and mercury.

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COMPATIBILITY FIELD TESTING PROCEDURES FOR UNIDENTIFIED HAZARDOUS WASTES

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INTRODUCTION

US EPA's Environmental Response Team was established in October 1978 to provide technical assistance to On-Scene Coordinators (OSCs), Regional Response Teams (RRT), EPA Headquarters and Regional Offices, as well as other governmental agencies in the area of multimedia, emergency environmental problems.

The Office of Research and Development (ORD), Municipal Environmental Research Laboratory (MERL) in Cincinnati, Ohio, has the lead role for research and development relating to hazardous waste environmental emergencies. Through a program at its Oil and Hazardous Materials Spills Branch (OHMSB) in Edison, New Jersey, MERL is developing prototype equipment and experimental techniques for controlling wastes and providing analytical support to environmental incidents requiring emergency response.

In this paper, the authors describe ERT's field testing procedures for segregating unidentified hazardous waste with portable identification equipment. The compatibility classification scheme is based on pH, total organic vapors, oxidation potential, flammability, water reactivity and radioactivity.

COMPATIBILITY TESTS

The primary purpose of the Compatibility Field Test is to have a method for segregating uncharacterized drums of waste into separate storage areas. The tests (Table I) can be either performed at the drum head (staging area) or at a mobile unit located within the site's "hot zone." This procedure permits rapid analysis and results in an expedited drum segregation operation. The selection criteria for the different categories is shown in Table II.

FLAMMABILITY

Although a standard flash point test would furnish helpful information about the unidentified hazardous waste, this method becomes impractical when dealing with large numbers of drums on an emergency operation. For example, if a test could be performed every 20 minutes, it would take approximately 3 man-years to analyze 20,000 drums.

Since it is possible to move, stage and sample between 100-200 drums per day, the drum segregation operation would range between 20-40 weeks. Thus, a simple flammability technique is used to separate flammables from non-flammables.

Such a technique could simply consist of placing 2-5 ml representative hazardous waste sample in a disposable beaker. The beaker is placed in a large sand box and a propane torch is slowly passed over the unidentified waste. Obviously, the ambient temperatures will affect the results, therefore, it is important to simulate ambient summertime temperature. If a flame is observed, then the sample is classified as flammable. A non-flammable classification is assigned to the waste after the torch has been passed over the waste several times.

RADIATION

Radiation monitoring should be one of the initial tests performed on unidentified hazardous waste drums and it should be performed as soon as possible to prevent worker exposure. Thus, the monitoring should be conducted as soon as drums are placed in the staging area and opened.

Since normal environmental gamma radiation background is approximately 0.01 to 0.02 milliroentgen per hour (mR/hr) on a gamma survey instrument, routine employee exposure should not be more than 2-3 times background levels. At no time should routine employee exposure be 10 mR/hr or above without the advice of a qualified health physicist.

pH

The pH of a waste affects not only its corrosivity, but also its compatibility with other wastes. If a barrel of acidic wastes were to leak and come in contact with a barrel of another waste containing a sulfide or cyanide, accelerated corrosion of the second drum would occur and the resultant co-mingling of the wastes would evolve poisonous hydrogen sulfide or hydrogen cyanide gas.

Table I.
Compatibility Field Tests

Test	Category	Category
1. pH*	Caustic (NF)	A
	Caustic (F)	B
	Acid (NF)	C
	Acid (F)	D
2. Water Reactive		E
3. Oxidative/Reductive	Oxidizer (F)	F
	Oxidizer (NF)	G
4. Radioactive		H
5. Volatile vapor/gas		
6. Flammable		

*the pH level depends on when the release of cyanide, sulfide and sulfide gases pose a threat.
(F) Flammable
(NF) Non-Flammable

Similarly, co-mingling of caustic wastes with ammonium salts or amine salts could lead to the evaluation of irritant ammonia gas or amine vapors.

The guard against these possibilities, caustic and acid wastes must be segregated. It is widely accepted that both cyanide and sulfide ions must be kept above a pH of 9 in order to remain in aqueous solution. Therefore, caustic wastes (Categories A and B) were defined as those with a pH above 9, and acidic wastes (Categories C and D) were defined as those with a pH below 9.

pH can be determined by a variety of colorimetric and electrochemical techniques, each of which has its disadvantages when used on "dirty" samples containing organic layers, sludges or concentrated solutions. For instance, standard pH electrodes are easily fouled and require constant cleaning and recalibrating. Most colorimetric indicators and papers are easily obscured by grease, sludges or deeply colored solutions. Interfering chemicals may even cause false color changes.

The pH method selected for this protocol utilizes a multi-band pH paper strip which contains a reaction zone and a series of indicator colors (fixed) for reference. The entire strip is dipped into the waste and the color reaction allowed to occur. The strip is withdrawn and any excess sludge, organic or water wiped-off by squeezing it between the thumb and forefinger, while wearing rubber gloves. The color comparison of the reaction zone and the indicator color is made assuming that the indicator color and the reaction zone are both affected in the same way by the grease, sludge or concentrated solution.

WATER REACTIVITY

One purpose of hazardous waste segretation at a site or a spill is to ensure that antagonistic effects do not occur due to contact between incompatible wastes. While many hazardous substances at a scene may be relatively stable and compatible in a dry state, the high probability that water may contact these materials warrants consideration of the consequences of such an occurrence. Thus, water reactivity, aside from being among the chartacteristics identifying a solid waste as a hazardous waste, is important in assessing the waste segregation strategy.

The characteristic of reactivity, as defined in the RCRA regulations (40 CFR 261.23), is exhibited if a representative sample of the waste has any of several properties. Properties 2, 3 and 4 of the material are of principal concern to this discussion:

(2) It reacts violently with water
(3) It forms potentially explosive mixtures with water
(4) When mixed with water, it generates toxic gases, vapors or fumes in a quantity sufficient to present a danger of human health or the environment.

The EPA laboratory manual, "Physical Chemical Methods for Evaluating Solid Waste," does not include a specific procedure for evaluating reactivity. The reason given is the diversified nature of the material properties listed in the regulation. In practice, however, water reactivity is commonly observed during the course of other tests. The authors believe the dangers posed by the three properties above explain why water reactivity should be determined.

In routine hazardous waste management, established laboratory safety procedures and a general knowledge of waste composition, are helpful in preventing a potential disaster due to the wetting of the reactive substance. Since the EPA proposed Comprehensive Hazardous Substance List contains 21 reactive chemical wastes and nine additional acutely hazardous chemical wastes, caution must obviously be observed in the laboratory. But what about in the field?

The same analytical safety precautions should be applied in the field where reactive substances are known to be present. Such items as ammonium picrate or fulminate of mercury should be segregated and perhaps not even sampled if such materials are labeled or strongly presumed to be present. In questionable cases, however, the authors recommend a simple water reactivity screening test be applied to check for the evaluation of heat or other violent reaction or the generation of toxic vapors.

While the authors have not tried this test yet, it should be relatively safe if precautions against explosion and toxic vapor hazards are taken. Unknown organic vapors, cyanide, hydrogen sulfide, chlorine, ammonia and hydrogen could be generated in small amounts. Hence, the authors recommend the reactivity test be conducted after other waste characterization testing has been evaluated and some idea of the waste composition has been gained.

Briefly, the tests should be conducted as follows:

(1) Place 500 ml distilled water in a one liter metal beaker in an explosion-proof hood, if available, or behind a substantial barrier. Analysts should wear appropriate protective gear.
(2) Insert a thermometer in the beaker and record the temperature after equilibration.
(3) Place an explosive atmosphere measuring device and an organic vapor measuring device in position to pick up any gases generated in the beaker headspace using laboratory clamps, etc.
(4) Introduce about one gram (one ml) of waste into the beaker.
(5) Observe the beaker measuring devices.

(6) If no changes are observed in temperature or headspace gases, add an additional 4 grams (4 ml) of waste, added 1 gram (1 ml) at a time and recheck instruments.
(7) If still no reaction is observed, add an additional 5 grams (5 ml).

Wastes testing positive to water reactivity should be isolated and protected from rain or other water sources as well as possible. Complete confinement, however, (i.e., enclosure in a walled building) is not recommended because of a possible explosion hazard from confining explosive vapors.

REDOX FIELD TEST KIT

The oxidation reduction (REDOX) potential field test kit was developed as a screening procedure for analyzing and classifying drums as those containing oxidizing or reducing agents at uncontrolled hazardous waste sites. The segregation of drums by redox potential is a necessary first step in a clean-up activity due to the danger of explosion associated with proximate storage or shipment of waste chemicals which have strong oxidizing or reducing properties. This hazard was recently demonstrated when approximately 40,000 drums containing chemical wastes exploded at the abandoned "Chemical Control Corporation" hazardous waste site in Elizabeth, New Jersey.[1]

The REDOX Test Kit permits measurement of the REDOX potential of drum samples through use of a portable battery-operated instrument, electrode probes and electrolyte solutions. The measurement of oxidation-reduction potential (ORP) or Electromotive Force (EMF) of a sample solution can be performed with a platinum sensing electrode and a standard reference electrode, usually calomel or silver-silver chloride. Although the instrument and electrode probes are readily available, the unique feature of the Test Kit rests in its ability to perform REDOX measurements not only in aqueous but also organic matrices such as are found at hazardous waste sites. Operation of the kit involves using the electrolyte solutions to generate a known REDOX potential (EMF) and monitoring changes in the EMF caused by the addition of sample to the electroyle. The entire procedure for obtaining REDOX measurements requires only a few minutes and can be performed by inexperienced operators.

The feasibility of ORP measurements is based on the ability of the sensing electrode to generate and the meter to indicate, 10 mv or less change in potential. At very low concentrations, microgram quantities can cause measurable EMF changes. However, such sensitivity would mean that most tests would be positive. Therefore, it is preferable to use a standard test solution that will generate a known EMF, and monitor changes in the EMF caused by the addition of the sample. For example, a 0.001 N solution of ferrous ammonium sulfate will generate a cell po-

Table II
Selection Criteria for the Compatibility Field Testing Methods

Category	High pH 9	Low pH 9*	HNU or OVA on vapor space		Flam.	Redox	R/A	B/T
A-Caustic (NF)	+	–	–	–	–	–	–	–
B-Caustic (F)	+	–	+	+	+	–	–	–, +
C-Acid (NF)	–	+	–	–	–	–	–	–
D-Acid (F)	–	+	+	+	+	–	–	–, +
E-Water Reactive	–	–	–	–	–	–	–	+
F-Oxidizers (F)	–	–	+	+	+	+	–	–
G-Oxidizers (NF)	–	–	–	–	–	+	–	–
H-Radioactives	–	–	–	–	–	–	+	–

*At pH 9 the release of cyanide, sulfide and sulfide gases pose a threat.

(F) Flammable R/A Radioactivity
(NF) Non-Flammable B/T Beaker test for water reactivity

tential of approximately 380 mv versus a silver-silver chloride reference electrode. When an oxidizing agent is added to the test solution, the Fe^{++} of the ferrous ammonium sulfate will be oxidized to Fe^{+++}, raising the cell EMF.

The test is very sensitive and a reaction with only a small portion of an oxidizing agent will give a positive test. Failure to obtain a positive test would indicate an absence of any strong oxidizing agents. Potassium chromate can be used in place of the ferrous ammonium sulfate as a standard test solution for determining the presence of reducing agents.

The test kit consists of a portable pH meter capable of EMF measurements (Fisher Scientific Accumet Model 150, for example), and a platinum sensing combination electrode with a silver-silver chloride reference electrode. Two types of combination electrodes are currently used: Orion Model 96-78 and Fisher Scientific platinum REDOX electrodes. In addition, the kit contains 0.001 normal ferrous ammonium sulfate and 0.001 normal potassium chromate standard test solutions, measuring flasks, disposable 50 ml volume beakers, and disposable containers for taking sample measurements.

In the field, a chemical waste sample is added to a standard test solution and then the change in potential (mv) is measured with the pH meter and electrodes. Each standard test solution gives a constant reading. Changes in those readings either in the negative or positive direction upon addition of sample, indicates the presence of an oxidizing or reducing agent.

Thus by using the ferrous ammonium sulfate test solution, the standard reading with the silver-silver chloride reference electrode is 380 mv. A threshold change of 50 mv in the positive direction (over 430 mv) indicates the presence of oxidizing agents. The potassium chromate test solution gives a standard reading of 630 mv. A threshold change of 50 mv in the negative direction (less than 580 ms) indicates the presence of reducing agents.

An actual field evaluation was performed during January 1980 at the Ottati and Goss site in Kingston, N.H. Two test kits were successfully used to screen drums containing chemical wastes for the presence of strong oxidizing agents. Two minor problems were encountered: electrode probe clogging and freezing temperatures. The clogging problem was easily resolved, however, by proper probe cleaning between samples. The cold weather, however, caused the probe electrolyte to freeze and therefore prevented use of the kit at ambient temperatures. Remedial measures involved using the kit in a small heated shed, located at the site.

VOLATILE VAPOR/GASES

The objective of taking total vapor concentration values just inside the barrel's bung hole is to assist in determining whether or not the headspace has a potentially explosive atmosphere. In utilizing total vapor concentrations as a guide for determining the presence of organic materials or explosion materials, a number of factors should be considered:

(1) The uses, limitations and operating characteristics of the monitoring instrument must be recognized and understood. Instruments such as photoionizers and organic vapor analyzer (OVA) do not respond to all substances that may be present or may respond differently to identical substances when compared to one another.
(2) Hazardous other than detectable gases/vapors such as phosgene, HCN, chlorine, liquid/solid particulates and other harmful conditions may exist.
(3) Potential for an explosive atmosphere exists when the instrument reaches its maximum reading of 2,000 ppm and should be checked with an explosive meter.

The primary purpose of the total vapor testing is to determine explosion potential. If the selected instrument reads 2,000 ppm, one has to make a decision as to the classification. The authors practice has been to classify the waste as flammable if 2,000 ppm readings are obtained until further confirmation is available. This decision takes into consideration instrument limitations, ambient temperatures, weather conditions, operator experience and sampling rate.

ACKNOWLEDGEMENT

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NOVEL APPROACHES TO SCREENING OF AQUEOUS EFFLUENTS FROM HAZARDOUS WASTE SITES

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INTRODUCTION

One of the central issues in management of uncontrolled hazardous waste sites is control of contamination of surface and ground waters due to leaching, followed by the entry of the leachates into water supplies rendering them unsuitable for use. The extent of this problem is underscored by the attention it received at the 1980 National Conference on Management of Uncontrolled Hazardous Waste Sites.[1] The majority of papers presented in this conference addressed this problem in some manner. Topics dealing with site assessment and subsurface investigations dealt heavily with the intrusion of leachates into groundwaters. Remedial techniques and methods for treatment, as well as case histories, dealt to a large extent, with containment of aqueous effluent from the hazardous waste sites.

Silka[2], in a discussion of assessment of groundwater contamination, states that "because of their proximity to population centers, both industrial and municipal impounds have the potential to directly affect human health." The preliminary finding of surface impoundment assessment, conducted by the EPA, indicates that almost one-third of the 25,000 impounds utilized for storage, treatment, and disposal of liquid waste have a high potential to contaminate usable aquifers.

Timely detection, chemical characterization, and quantification of toxic contaminants in aqueous effluents from waste sites is an essential first step in alerting the public to the potential health hazard and institution of preventive and mitigation steps. Monitoring of the quality of ground and surface waters in water supplies affected by toxic contamination is a necessary activity during decontamination and effluent containment periods of response activity. During post-closure periods the water quality of affected aquifers and/or surface waters must also be monitored to assure that no toxic materials are leaching into water supplies.

Chemical characterization of water samples, in terms of detection and quantification of toxic materials that might be present in the aqueous effluent from uncontrolled hazardous waste sites is, unfortunately, complex, time-consuming, and an expensive proposition, when carried out routinely over a period of decades at numerous hazardous waste sites.

An operationally simple and cost-effective method is needed to indicate whatever ground and/or natural waters are contaminated or uncontaminated. Such a method, based on differentiation between gross chemical character of natural waters and gross character of contaminated water was developed and is described in this presentation.

CONCEPT

The organic chemicals contained in natural, unpolluted water come mainly from biomass activity and are composed of carbohydrates, proteins, lipids, and their degradation products.[3] As such, the chemicals are distinctly different from those supplied by leachates from hazardous waste dumps, which are composed largely of refractory materials. Such differences in overall chemical compositions provide a means for differentiating between natural and man-made contributions to receiving waters.

A method of multicomponent pattern recognition provides a means for such differentiation. Using this method, it is possible to define a complex chamical composition as a separate entity, and to differentiate it quantitatively and qualitatively from other chemical compositions such as might be found in an industrial waste.

The pyrographic met hod of analysis is used as a physical vehicle for application of this concept to pollution detection and monitoring in water.[4] In this method, organic matter is subjected to elevated temperatures in the absence of oxygen, leading to thermal fragmentation of parent organic compounds. When such a moleculár fragmentation was carried out in the presence of a large excess of water, the processes were linear with concentration and independent for each organic compound in a mixture. The pyrographic pattern produced by a mixture of organic compounds is a simple arithmetic summation of contributing patterns of each compound present.

A recorded pattern of pyrolytically produced fragments for a given water sample reflects the total nature of its organic composition, and can be interpreted and differentiated in a number of ways. Using *a priori* established calibration patterns for individual components to be found in a mixture, the pattern produced by a mixture can be analyzed mathematically. The system can be calibrated and then differentially analyzed in terms of unique organic compounds, classes of organic materials, or in terms of

any other arbitrarily defined organic compositions, such as are found in industrial waste or in a biomass-produced organic matter.

Normally it is possible to set a linear equation for each peak of a composite pyrogram, and then solve a series of simultaneous equations for unknown concentrations of organic materials represented by the pyrogram. A maximum number of components, into which data can be solved, equals the number of peaks observed on a pyrogram.

METHODOLOGY

There are three essential components to this methodology: instrumental hardware, mathematical logic, and computation means.

Instrumental Hardware

The instrumental hardware[5] consists of a water sample injector, flow stabilization controller, pyrolysis chamber, gas chromatographic column, ånd flame ionization detector. Associated components include a supply of carrier gas, oxygen, and hydrogen, as well as electronic and data reduction equipment. Data reduction operations can be connected by telephone to a remote time-shared computer or performed in the field using simpler electronic calculators. A photograph of a compact field instrument is shown in Figure 1.

Mathematical Logic

When a single chemical entity (such as an organic compound) is being pyrolyzed, a number of derivative molecular fragments are produced. They are revealed on a chart of the potentiometric recorder as a series of peaks with varying retention times and peak intensities.

Many organic compounds will produce similar products when pyrolyzed. Showing up on a pyrogram as peaks with identical retention times. However, the intensities of such peaks will vary. Those variations in intensities produce a pattern specific to that of the parent material.

If more than one organic compound is pyrolyzed simultaneously (such as is the case when a sample containing a mixture of compounds is analyzed), the pyrographic representation will be a summation of pyrograms produced by individual components. In this case, each common peak for each component will be a summation of contributions

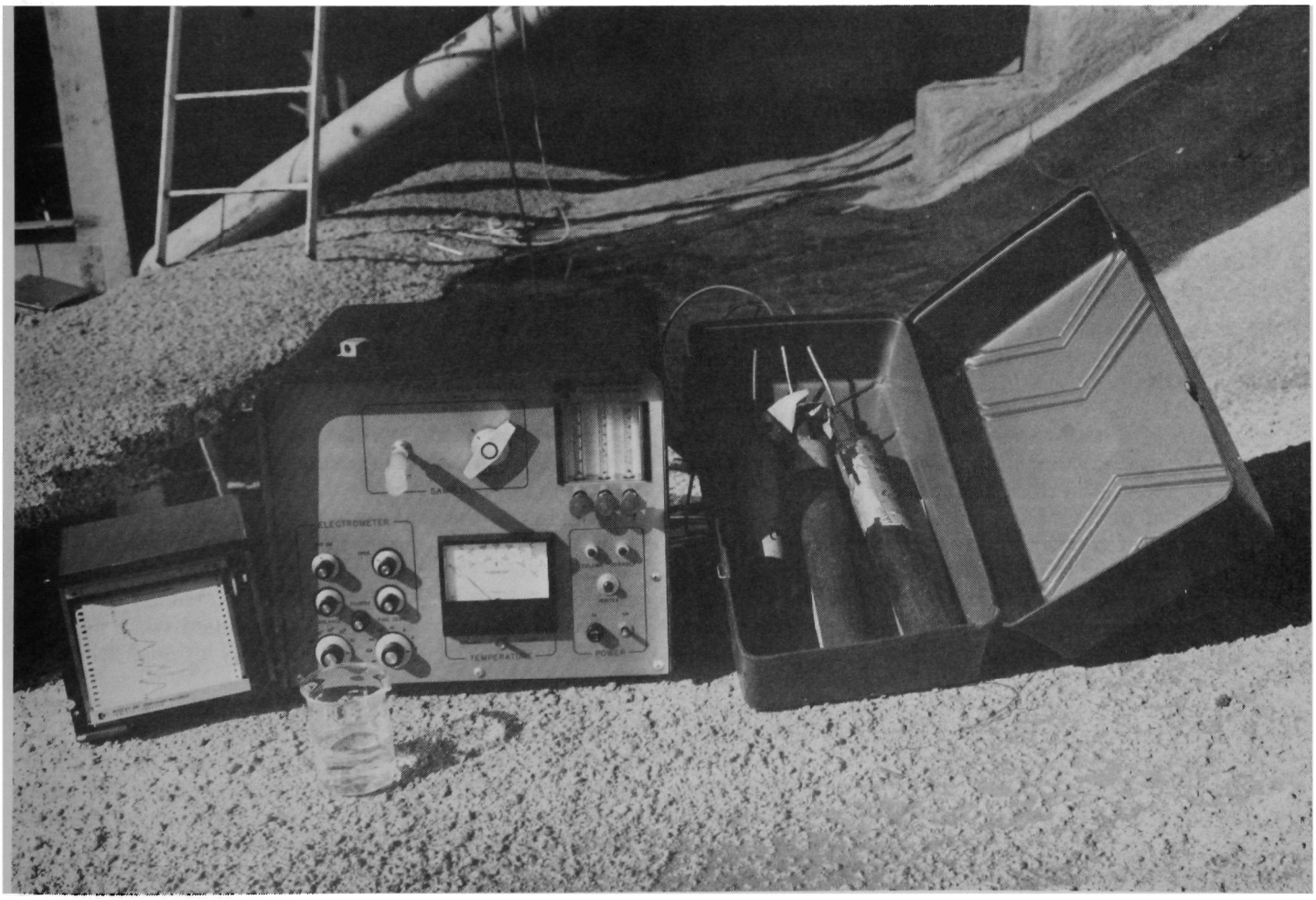

Figure 1.
Pyrographic Instrumentation

from each component. The specific peaks will, of course, appear independently.

Whether two or 2000 compounds are present in analyzed mixtures, the common peaks will be summations of contributions from each contributing compound, and specific peaks will appear with identities of their own. In strictly mathematical terms, a pyrographic representation of data becomes a sum of various numbers. Any mathematical sum, of course, can be divided into smaller numbers.

Normally, it is possible to set a linear equation for each peak of a pyrogram, and then solve a series of simultaneous equations for the unknown concentrations of organic materials represented by the pyrogram. A maximum number of components, into which pyrographic data can be solved, equals the number of peaks observed on a pyrogram.

The organic compositions into which pyrographic information can be differentiated are defined by calibrations, which provide the coefficients for a series of simultaneous equations. The system can be calibrated in terms of molecular entities, classes of organic materials, or any other arbitrarily defined combination of organic molecules.

The mathematical technique for treatment of pyrographic data in the described manner was described.[6] The technique is based on the use of least-squares solution to a number of linear equations.

Computations

In past studies, the data were transferred by telephone lines to time-shared computers which performed the necessary calculations. With the advent of increased sophistication in compact calculators, computing operations could be performed on site, making the system totally field-sufficient.

APPLICATION

Application of this methodology to screening of aqueous effluents from uncontrolled hazardous waste sites is based on the assumption that natural, background chemical composition of uncontaminated waters is definable, either in empirical terms of pyrographic patterns or in fundamental terms of organic class composition (carbohydrates, proteins, lipids), and is distinctly different from the composition of industrial chemical wastes. Because of these empirical and fundamental differences, industrial chemical waste can be differentiated from natural chemical background of unpolluted water and characterized in terms of nature and quantity. Support for this proposition can be found in the literature.[7,8]

Natural Waters

Extensive data on organic composition in inland polluted waters were collected by Birge and Juday[3] over 50 years ago. Their study included a series of Wisconsin lakes widely different in hydrological and limnological characteristics (from clear, gravel glaciated bed lakes to lakes undergoing entrophication) and ranging in organic content from 4 to 34 mg/l.

The analysis of water samples from such diverse lakes disclosed that in all cases organic load was comprised essentially of three classes of organic matter: carbohydrates, proteins, and lipids. Such natural organic composition is derived largely from biomass activity and decay of vegetable matter. A typical range of organic compounds in inland lakes as reported by Birge and Juday is shown in Table I.

Table I.

Organic Composition of Natural Waters According to Birge and Juday[3]

	Concentration, (mg/l)			Total Org. Load
	Carbohydrates	Proteins	Lipids	
Class 1 Lake	2.6	1.0	0.1	3.7
Class 3 Lake	18.7	3.8	0.2	22.7
Class 4 Lake	28.6	4.9	0.2	33.6

As total organic load in fresh water increases (from clear, gravel bed lakes to swampy lakes) the increase in concentration of carbohydrates is proportionally greater than increases in concentrations of proteins and lipids. This is so because proteins and lipids come primarily from algal sources, while carbohydrates are also supplied by decaying vegetation of swampy waters.

Using this model as an example, a study was designed and executed in Georgia[9] using natural, unpolluted waters of wide-ranging hydrologic and limnologic character. The organic content of the water was characterized pyrographically, both in empirical form (as a series of peaks on a pyrogram) and also in fundamental terms of organic class composition. The organic class compositions were computed from empirical pyrograms after the system was calibrated with model compounds for carbohydrates, proteins, and lipids.

Included in the study were streams, rivers, reservoirs, and swamp water sources in the southeast region of the United States. This region is well-suited for such an investigation because it is neither highly industrialized nor populated and still contains many unpolluted water sources. Those waters also represent a variety of hydrochemical types:

COWEETA HYDROLOGICAL STATION: The Coweeta Hydrological Station is maintained by the U.S. Department of Agriculture in the Appalachian Mountains on the border of North Carolina and Georgia. The water source has a low mineral and organic content. An extensive hydrological record is available for this watershed.

PIEDMENT REGION STREAMS: Near Athens, Georgia, are a number of swift-moving streams, rivers, and reservoirs. Alcovy River and Clark Hill Reservoir were used as water sources in this study.

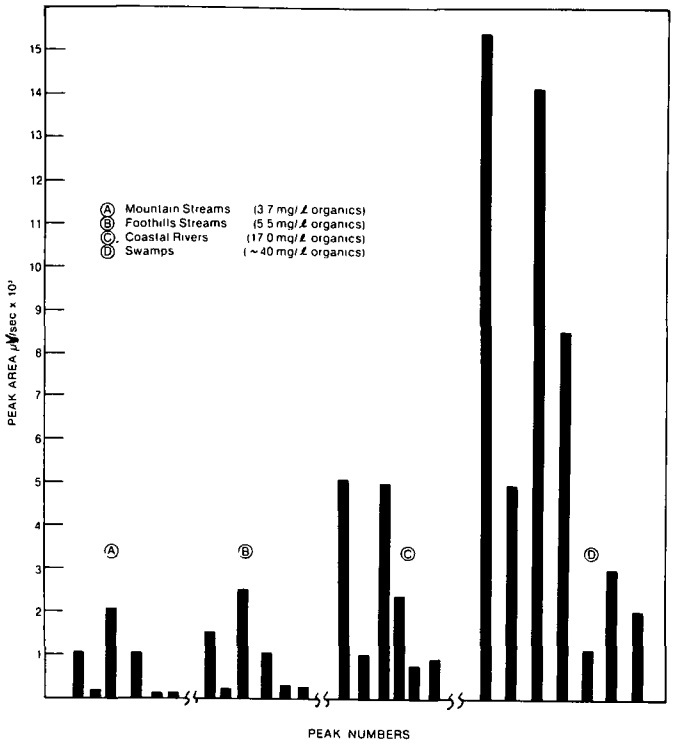

Figure 2.
Pyrographic Patterns for Natural, Unpolluted Waters

COAST PLAINS RIVERS: The U.S. Department of Agriculture, Hydrological Model Watershed in Tifton, Georgia, was used in this study. The watershed comprises the Little River and its tributaries. The tributaries flow through cultivated lands, and carry some degree of agricultural pollution. However, water from the tributaries filters through swamps before it reaches the Little River.

COASTAL SWAMPS: Two principal swamps of the area are the Everglades in Florida, and the Okefenokee in Georgia. Culturally unpolluted waters of swamps contain large quantities of organic matter. Water samples from Okefenokee swamps were examined only in empirical terms of pyrograms (digital and analog), while swamp waters from the Everglades were analyzed in fundamental terms of principal organic classes present (carbohydrates, proteins, and lipids).

A number of water samples were collected from each watershed and analyzed pyrographically in triplicate. Empirical pyrographic data is displayed in analog form in Figure 2 and in digital form in Table II. Pyrographic instrumentation was also calibrated for carbohydrates, proteins, and lipids. The data, expressed in terms of organic classes, was computed and are reported in Table III.

An examination of the data reveals that organic composition of unpolluted natural waters is indeed definabled either in fundamental terms of principal classes of organics present, i.e., carbohydrates, proteins and lipids, or in empirical terms of pyrographic patterns. The natural waters were diverse, ranging from pure mountain streams to coastal swamps, and while quantity of organic matter in each water source differed, the types of organics present were similar.

Table II.
Pyrographic Data: Empirical Patterns for Natural Waters
(Peak area in microvolts/sec)

Peak No.	Coweeta[a] Watershed No. 6 Stream	Coweeta[a] Watershed No. 6 Pond	Coweeta[a] Watershed Main Stream	Average[a] Response
1	1126	1113	980	1073
2	149	168	156	158
3	2043	1996	2213	2084
4	1029	906	1005	980
5	148	175	212	178
6	158	206	201	188

	Shoal Creek[b]	Alcovy River[b]	
1	1434	1712	1573
2	170	199	185
3	2400	2778	2589
4	1023	1153	1088
5	279	348	314
6	270	268	269

	Little River[c] Tifton	
1	5257	5257
2	965	965
3	5246	5246
4	2443	2443
5	697	697
6	914	914

	Big[d] Water	Floyd[d] Prairie	Cravens[d] Island	Spillway[d]	
1	12,590	15,960	16,990	16,100	15,410
2	4,246	5,224	5,257	4,931	4,915
3	12,260	15,607	15,265	13,377	14,128
4	6,030	9,114	9,876	9,357	8,594
5	829	1,236	1,137	1,221	1,106
6	1,765	3,199	3,536	3,286	2,947
7	2,376	2,643	1,891	1,800	2,178

(a) Mountain Streams
(b) Foothill Streams
(c) Coastal Plains River
(d) Okefenokee Swamps

The empirical patterns shown in digital form in Table II and analog form in Figure 2 suggest that patterns observed for low organic carbon content waters (mountain and foothill streams) are quite similar. There is also a similarity in the patterns for high organic content waters from coastal rivers and swamps.

Based on the literature[3] as well as observations reported here, it appears that natural organic composition of unpolluted waters can indeed be defined pyrographically either in fundamental terms of classes present or empirically in the form of pyrographic patterns. Hence, it should be possible to differentiate such compositions from industrial chemical waste using multi-compound pattern recognition and differentiation.

INDUSTRIAL WASTES

Pyrographic patterns for various industrial wastes were reported in an EPA report.[7] Waste effluents for this study

Table III.
Organic Composition in Natural Waters as Determined by the Pyrographic Method

	Total Organic Load (mg/l)	Organic Class Concentration, mg/l		
		Carbohydrates	Proteins	Lipids
Mountain Streams				
Coweeta	3.7	2.2	1.4	0.1
Foothill Streams				
Alcovy R.	5.2	3.4	1.6	0.2
Shoal Cr.	5.8	4.7	1.0	0.1
Coastal Plains Rivers				
Little R.	17.5	11.7	5.1	0.7
Mills Cr.	16.6	11.2	4.8	0.6
Swamps Everglades				
Moving Streams	24.7	19.7	3.7	1.3
Everglades Ponds	33.4	27.9	3.9	1.6

were supplied by 20 major industrial operations in Alabama, Florida, Georgia, Mississippi and South Carolina including: (1) Hercules, Inc., Hattiesburg, Mississippi; (2) Air Products and Chemicals, Inc., Escambia Plant, Pensacola, Florida; (3) Merck and Co., Inc., Medicinal Chemical Plant, Albany, Georgia; (4) Monsanto Company Plant, Pensacola, Florida; and (5) Delta Airlines, Inc., Atlanta, Georgia. The industry sources can be classified as chemical, food, textile, paper and pulp, oil refinery, brewing, pharmaceutical and aircraft maintenance.

Samples of industrial waste discharges were collected at the points of discharge into receiving waters and were preserved by freezing in dry ice. The collected samples were analyzed pyrographically under standard conditions.

The calibration constants for 19 industrial waste effluents (one plant reclaimed its waste, and could not technically be considered as a waste discharger) were examined with the object of determining the differences between pyrographic patterns. The data are reported in Table IV. A few representative patterns are presented graphically in Figure 3.

Examination of reported data reveals that pyrographic patterns of industrial waste are indeed different from pyrographic patterns of natural unpolluted waters and hence can be determined and differentiated from natural organic background.

DETECTION OF WATER CONTAMINATION

Liquid and solid chemical wastes are usually either disposed of in landfills, in open pits (impoundments) or stored in 55-gallon drums. Contaminants enter groundwaters from impoundments as a result of ground penetration. They can also enter surface waters as a result of runoff. Chemical wastes stored in 55-gallon drums may leak out with the passage of time and enter surface waters.

Chemicals that enter natural, unpolluted ground and/or surface waters alter gross their chemical composition. In addition to carbohydrates, proteins and lipids which are found in natural waters, man-made refractory and persistent chemicals appear. Due to dilution by receiving waters, such man-made contaminants or pollutants are usually found in trace quantities and in many instances could be present in concentrations lower than that of organic compounds present naturally in water.

The task is then to detect and quantify trace amounts of contaminants in the presence of natural organic background of water, under conditions when natural organic background of water can be greater than that of the contaminants. Hence, there could be two distinct and different situations:

- The nature of hazardous waste contamination is unknown.
- The nature of hazardous waste contamination is known.

Depending on the situation, two different approaches to detection and quantification of water contamination by the hazardous waste can be implemented.

Detection of Unknown Contaminants

In many instances the exact nature of chemicals disposed of at a given hazardous waste site is unknown and extensive trace analytical work must be undertaken to establish whether surrounding water sources are contaminated or not.

Using the pyrographic method of analysis, it is possible, however, to develop an empirical pattern, visual examination of which will indicate whether or not contamination of ground or surface water supplies took place. As shown in Table II and graphically displayed in Figure 2, pyrographic representations of unpolluted natural waters are distinct and characteristic. In cases where water is polluted by man-made chemicals, pyrographic patterns will become

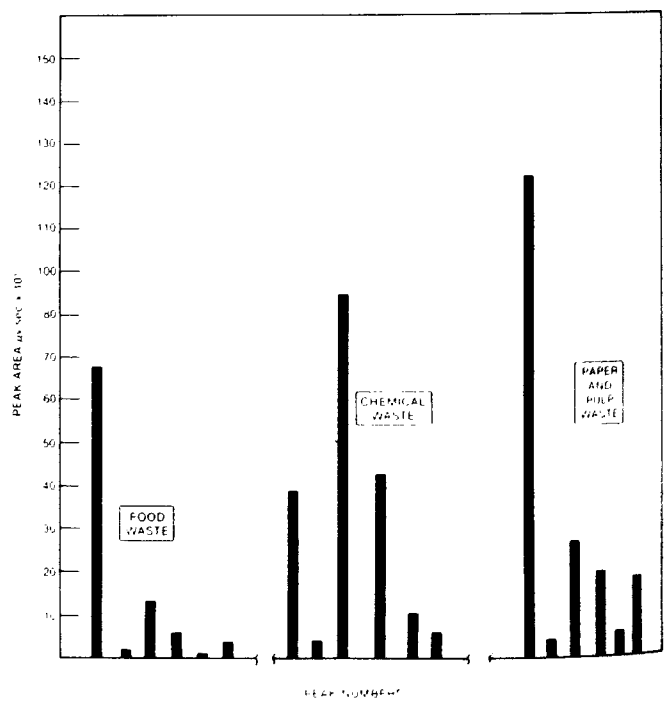

Figure 3.
Pyrographic Patterns of Industrial Wastewaters

Table IV.
Pyrographic Fingerprints of Industrial Waste Effluents
(Peak Magnitude x 10^{-3})

Food and Beverage

Peak No.	Average Retention Time	Food-A	Food-B	Food-C	Brewing
1	1.9	67.9	22.5	342.1	248.5
2	2.2	2.1	1.4	29.5	39.4
3	3.3	13.3	31.6	147.0	129.9
4	4.0	5.9	12.0	144.6	110.8
5	6.5	0.7	2.8	21.2	15.8
6	14.0	3.8	8.4	61.0	54.4

Various Industrial

Peak No.	Average Retention Time	Paper and Pulp	Oil Refining	Pharmaceutical	Aircraft Maintenance
1	1.9	96.6	34.6	2320.7	237.7
2	2.2	4.5	2.2		17.6
3	3.3	32.9	46.5	115.7	324.6
4	4.0	25.0	20.9	87.8	122.9
5	6.5	5.1	6.2	19.5	7.6
6	14.0	29.0	16.8	60.5	25.4

Textiles

Peak No.	Average Retention Time	Textile A	Textile B	Textile C	Textile D	Textile E
1	1.9	607.0	669.6	2,289.5	1,229.0	681.5
2	2.2	110.9	83.9	555.2	328.4	102.2
3	3.3	576.5	293.4	3,213.5	2,050.0	363.1
4	4.0	569.2	152.8	2,364.0	1,571.0	228.2
5	6.5	95.4	279.0	392.8	210.1	36.5
6	14.0	156.1	117.9	1,252.0	565.4	171.5

Chemical Industrial

Peak No.	Average Retention Time	Chemical A	Chemical B	Chemical C	Chemical D	Chemical E	Chemical F
1	1.9	38.2	85.9	4008.0	49.6	11.7	45.2
2	2.2	4.2	7.2	328.0	5.0	2.4	2.3
3	3.3	84.3	75.1	330.5	42.7	8.7	32.6
4	4.0	39.4	35.4	1444.7	26.2	3.6	31.2
5	6.5	10.6	5.8	27.1	2.2	1.1	1.6
6	14.0	6.5	38.8	327.0	12.3	3.7	14.7

distorted and the ratio and magnitude of peaks will change.

In practice, it should be possible to match visually a pyrogram of a water sample that is suspected to be polluted by hazardous waste with a series of pyrograms typical of known types of natural waters. Pyrographic patterns shown in Figure 2 are quite representative of the majority of types of unpolluted natural water found in the country.

If no pollution (intrusion of hazardous waste) took place in ground or surface water, the pyrographic pattern developed will match one of the types of natural, unpolluted waters, as shown in Figure 2. If ground or surface waters have been contaminated by man-made hazardous wastes, then the pyrographic patterns or representations of water sample will be distorted and the ratios and magnitudes of the peaks will be different from those of natural unpolluted waters.

A visual examination of pyrographic patterns provides the simplest form of detection of the presence of hazardous waste (or other man-made pollutant) in the natural waters. The magnitude of contamination can be estimated visually from a degree of pyrogram distortion or computed mathematically as described below.

The pyrographic instrument can be calibrated for detection of principal natural water organics: carbohydrates, proteins and lipids. By solving a series of simultaneous linear equations, the concentration of each class of compound can be determined. The computation logic is also provided with a statistical measure of the quality of such computations: these are "residual value" and "percent fit."

The residual value reflects the quantity of information that could not be fitted into the calibrated model and "percent fit" reflects a degree of agreement between calibration factors and observed, unknown data. "Low residual values" and high "percent fits" indicate that calibration factors and analyzed substances match, and no other than calibrated compounds are present in the sample. In case of natural water, it means that only carbohydrates, proteins and lipids are found.

High "residual values" and low "percent fits" indicate that materials other than natural organics (carbohydrates, proteins and lipids) are present in the sample. The higher is "residual value" and the lower is "percent fit," greater is the probability of contamination of water.

In case of a natural water the instrumentation system is calibrated for carbohydrates, proteins and lipids using known chemicals: glucose, albumin, and oleic acid. An example pyrographic analysis of two synthetic solutions of standard solutions is shown in Table V. Here one can see that observed and actual values for each compound are close, "percent fit" is high, and "residuals" are low. Thus, no other than natural organics are present in this sample. In practice, when "percent fit" falls below 75% and "residual value" increases over 1000, then one may assume that the water sample is contaminated by other than natural organic matter.

Table V.
Pyrographic Analysis of Synthetic Solutions

		Chemical Concentration (mg/l)				
	Run #	Albumin	Glucose	Oleic Acid	Residual	Percent Fit
Series A	1	9.69	22.47	3.17	117.449	98
	2	7.12	20.88	3.4	343.97	95
	3	8.04	19.44	3.3	140.839	99
	Avg Found	8.28	20.93	3.29		
	Actual Present	10	20	3		
Series B	1	19.14	9.3	.92	128.886	96
	2	18.69	9.41	99	149.194	96
	3	19.52	9 59	.97	152.734	96
	Avg. Found	19 12	9 43	.96		
	Actual Present	20	10	1		

Detection of Known Contaminants

The nature of chemical waste present at a given hazardous waste site might be known and a sample of waste matter might be available for calibration. In such cases, an accurate determination of the natural organics present in the water and a calculation of amounts of hazardous waste can be made. The instrumental system is calibrated in the usual manner for carbohydrates, proteins and lipids, but is additionally calibrated for one or more suspected hazardous waste compositions. After the analysis is performed, the concentrations of natural organic and contaminants are computed as shown in Table VI.

Table VI.
Analysis of Mixed Industrial Wastes in Natural Water Matrix

Natural Background
Proteins 1.22 mg/l
Carbohydrates 7.47 mg/l
Lipids .46 mg/l

		Volume Percent From Each Source						
Waste Source	Run:	1	2	3	4	5	Average	Actual
Chemical		0.48	0.42	.44	.46	.5	0.46	0.5
Textile Finishing		0.66	0.66	.87	.91	.98	0.86	1.0
		Conc'n. of Organic Carbon From Each Source (mg/l)						
Chemical		0.91	0.8	0.86	0.87	0.95	0.87	
Textile Finishing		2.85	2.67	2.7	2.82	3.84	2.67	

Here the technician has used a sample of natural water from the Okonee River, Georgia, contaminated with two types of industrial waste. The natural organic background of the water was 9.15 mg carbon/l, to which small quantities of chemical and textile waste were added (equal to approximately 3.5 mg carbon/l). The man-made contaminants represented approximately one-fourth of the organic matter present in the water, a situation likely to be found in real life. The water sample was analyzed five times and results are shown in Table VI. The computer analysis of the pyrogram revealed its natural organic composition and identified and quantified industrial waste present. This example illustrates that hazardous organic waste present in quantities smaller than natural organic background of water can be detected and accurately measured.

CONCLUSIONS

An instrumental method is described for rapid screening of water samples suspected of being contaminated by hazardous wastes. The method can be used for analysis of water samples contaminated by unknown organic pollutants or for the accurate quantification of pollutants, the nature of which is known. The technique is designed for field use and can be applied for empirical characterization of the sample or for accurate quantitative chemical analysis. The described procedure is fast (15 to 20 minutes) and utilizes water samples as received without pretreatment or other preparations.

ACKNOWLEDGMENT

The material in this paper was extracted in part from the EPA reports references (Nos. 7 and 9) (Contract 14-12-802). The authors express our gratitude to Dr. H. Page Nicholson, EPA Athens, Ga., for his support and encouragement in this work.

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AMBIENT MONITORING FOR SPECIFIC VOLATILE ORGANICS USING A SENSITIVE PORTABLE PID GC

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ABSTRACT

With the intensifying concern over organic chemical contamination at spills, dump-sites and chemical manufacturing facilities, a need has emerged for rapid assessment of ambient air pollution by volatile chemicals. We have recently tested a portable photoionization detector (PID) gas chromatograph, in several field incidents. The unit (Photovac 10A10, Thornhill, Ont.) is lightweight, completely portable, and requires only compressed air for operation. It has a measured sensitivity in the .1 to 10 ppb range for a wide variety of commonly occurring volatile organic contaminants such as vinyl chloride, benzene, chlorinated methanes, ethanes and ethylenes and even low volatility compounds like nitrobenzene and xylenes. A characteristic of the PID system is enhanced sensitivity to aromatic and unsaturated molecules over the FID detector. However, the Photovac PID has an uncharacteristic sensitivity to halogenated methanes and ethanes. This unusual and theoretically unexpected sensitivity (e.g., $CHCl_3$ can be detected at the 5-10 ppb level and 1, 2-di chloroethane at the 1-5 ppb level in 1-5c.c.air samples) makes the instrument even more useful for general air pollution monitoring. There is no need to have different detectors (such as Electron Capture) in order to determine all the volatile haloalkenes and other alkenes of interest.

The paper describes several incidents involving specific volatile organics.

(1) We used the instrument to measure vinyl chloride in the vicinity of a plastics manufacturer. Levels of VCM below 0.2 ppb were easily detected and semi-quantitated in the field.
(2) Nitrobenzene was monitored in the vicinity of a ten-year-old spill site which was being dredged from a river bottom. Maximum ambient contaminant levels never exceeded 20 ppb of nitrobenzene 100-300 feet downwind of the dredge operation. Organic quantitation and calibration were conducted in the field.
(3) Acrolein was monitored for an OSHA study against a background of 15 or more solvent peaks in another manufacturing facility. The OSHA safety level of 0.1 ppm was never exceeded and sensitivity was found to exceed 30 ppb even in the presence of interfering solvent peaks.

In the above studies, and several others that will be discussed, a key feature is the ability to make in-field measurements. Techniques for field calibration will be discussed in detail. One promising technique is the use of the two-column option which has two distinct field use benefits.

a. A short column can be used to enable rapid 'screening' type analysis with very short retention times at ambient temperature (e.g., 4 min. for detection of nitrobenzene).

b. Two-column referencing of known retention times. This technique of using a second column (and field standards) to identify retention times, provides a high level of confidence in the positive identification of unknown ambient contaminants before one collects time-integrated field samples for laboratory analysis using GC/MS as an identification tool.

The combination of field screening and measurements on a portacle GC, with integrated field samples and follow-up GC/MS analysis, provides a powerful tool to settle questions of ambient organic contamination. Our technique for doing such work will be discussed in detail.

MEASUREMENT OF FUGITIVE HYDROCARBON EMISSIONS FROM A CHEMICAL WASTE DISPOSAL SITE

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INTRODUCTION

One of the primary concerns is air quality near chemical waste disposal sites, especially existing chemical landfills that were not constructed and operated according to criteria now required by the Resource Conservation and Recovery Act (RCRA). Since hydrocarbon emissions from landfills and disposal sites are fugitive emissions, they are difficult to monitor. Quantifying the emission rates of air contaminants from landfills has not been practical because of the complexity and costs. The transfer behavior of organic pollutants between the solid-air interface has been studied in detail for pesticide volatilization[1] and theoretical estimation techniques have been reported for the air pollution aspects of volatilized organic compounds from waste disposal sites.[2, 3, 4] However, at present the extent of air contamination from chemical waste disposal sites remains largely unknown.

In this paper, the authors describe a technique that can be used to measure air quality close to waste disposal sites and to calculate the emission rate of a fugitive emission area source (open source) at minimum cost.

SOURCE DESCRIPTION

The Hooker Chemicals and Plastics Corporation is currently building a clay-lined waste containment facility at a chlorine production complex in Montague, Michigan, to contain chemical residues and contaminated soil from various locations at this site. The Michigan Department of Natural Resources (DNR) established several air quality conditions to be met during and after the transfer period. Before beginning restoration activities, it was necessary to determine background ambient concentrations and emission levels of the perchlorinated organic compounds of concern. The DNR had chosen hexachlorocyclopentadiene (C-56) to represent those compounds.

C-56 is a nonflammable liquid with a very pungent odor; the odor threshold is as low as 0.33 ppb; some individuals can detect as little as 0.15ppb.[5] It is a key intermediate in the production of the cyclodiene group of chlorinated pesticides and flame retardants. Unlike some of the pesticides derived from it, C-56 degrades rapidly by photolysis, giving water-soluble degradation products. Tests on its stability towards hydrolysis at ambient temperature indicated a half life of about 11 days at pH 3-6, which was reduced to 6 days at pH 9. The present TLV for industrial exposure is 0.01 ppm, or about 7% of the lowest vapor concentration shown to produce chronic toxic effects in laboratory animals.[5]

Two inactive sites contained C-56 wastes that were to be relocated to the new waste containment facility. The first site is a roughly triangular above-grade dump partially covered with soil, varying in height from 0 to 15 ft above a flat ground surface. Trees were located on two opposite sides of the site. The second site was an abandoned production facility for chlorinated hydrocarbons, approximately 200 ft square with a brine lake to the north. The remaining areas surrounding the site were open.

MEASUREMENTS AND METHODS

Measurements of pollutant concentration and meteorological variables were made at the waste disposal sites in June 1980. Descriptions of the equipment and methodology follow.

Open Source Sampling

The major difference between open sources and point sources is that open sources do not have a definable point of emissions. There is no established protocol for sampling open sources; the methods employed depend upon the type of information needed, the physical configuration of the source, meteorological conditions at the time of sampling, and interferences due to other point and fugitive sources. The following methods have been developed and were considered for sampling fugitive and open sources: 1) quasi-stack approach, 2) grid/flux approach and 3) upwind/downwind approach.[6] The quasi-stack approach was unsuitable because the two sites were not isolable and the grid/flux approach was eliminated because the disposal site was heterogeneously soil-covered and the abandoned production facility was not amenable to gridding.

The upwind/downwind approach is generally favored because it preserves the integrity of the source and any process associated with it. It also eliminates any construction to capture emissions, which may prove expensive. Continuity of the emissions is generally of secondary importance since the magnitude of the ambient air volume into which the emissions are dispersed is large enough to

provide a degree of smoothing to cyclic or intermittent emissions. Best of all, the upwind and downwind measured ambient concentrations truly reflect the actual pollutant levels at the sampler locations.

Meteorological Variables and Atmospheric Stability

Dispersion models, normally used to predict concentrations surrounding a point source of known emission rate, are used in reverse for open source sampling calculations. Several downwind concentration readings are taken to calculate the source emission rate (after subtraction of the upwind or background concentration).

Because of the relative ease of application, the Gaussian plume model was used in conjunction with Turner's[7] determination of the dispersion coefficients σ_y and σ_z, the crosswind and vertical standard deviations of plume spread.

Comparison of predicted and measured pollutant concentrations from point sources indicate that, with sufficient meteorological information, the predictions of the Gaussian plume model can be generally within a factor of two of measured values. The accuracy achieved using the Gaussian plume model depends to a great extent on the accuracy of predicting or measuring σ_y and σ_z.

The detailed meteorological measurements required for the most accurate determinations of σ_y and σ_z are generally not available for inexpensive, rapid sampling and analysis projects. The Pasquill-Gifford determinations of σ_y and σ_z as given by Turner, where σ_y and σ_z are functions of the distance from source and an atmosphere stability parameter only, are strictly applicable only to dispersion over relatively smooth surfaces, which fortunately was the case in this study.

Pasquill-Gifford atmospheric stability categories were determined using the protocol described in Figure 1. The upwind-downwind method is strongly influenced by meteorological conditions, requiring a wind consistent in direction and velocity throughout the sampling period. For this reason upwind-downwind sampling is futile during stable air (stability classes E and F) and very unstable air (stability class A). Typically then, weather with strong frontal activity and conditions conducive to inversions are avoided, and upwind-downwind sampling is best practiced between 9 a.m. and 4 p.m. By confining the sampling to periods of moderately unstable to neutral conditions,

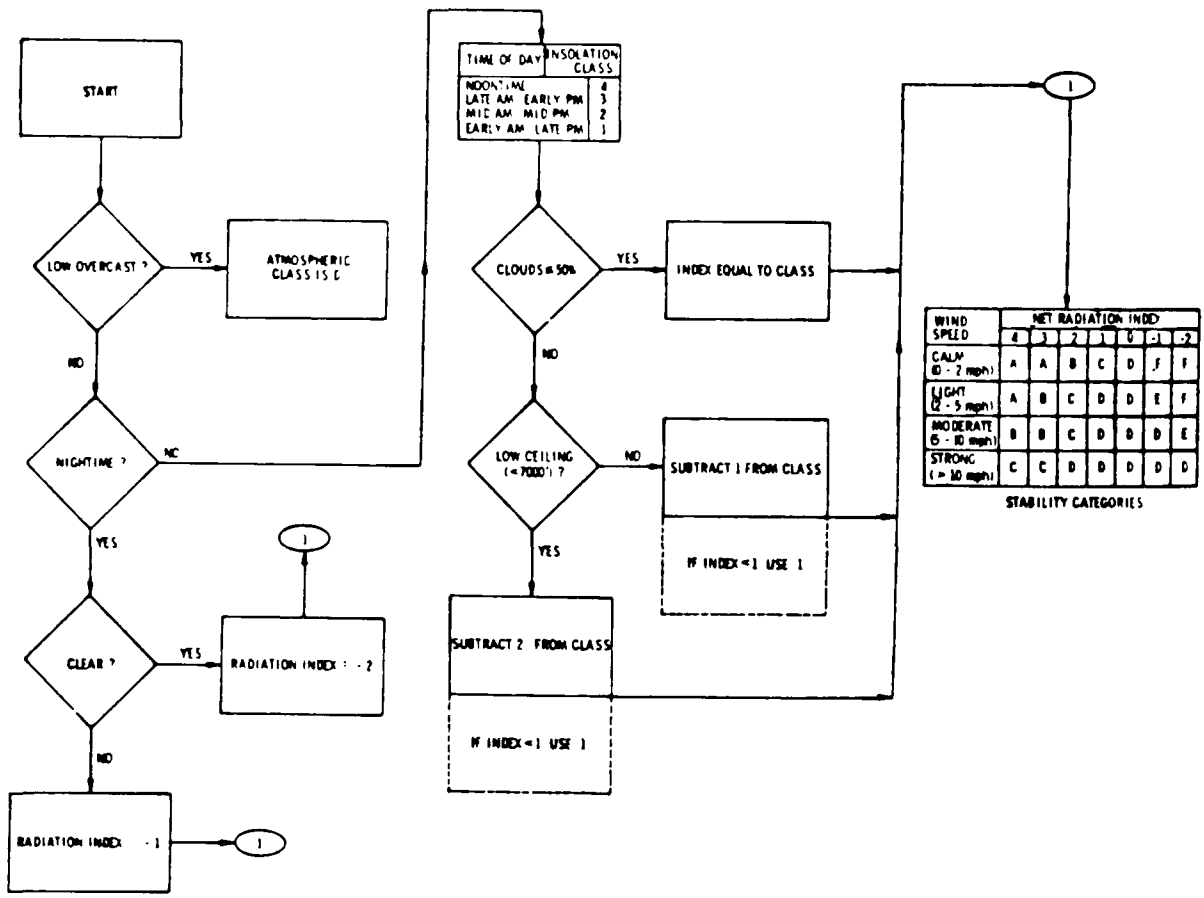

Figure 1.
Flow Chart for Determining Atmospheric Stability Class.

the accuracy of the Gaussian plume model may be enhanced.

Given the stability class and the downwind distance of the sampler from the source, continuous functions are then used to calculate values for σ_y and σ_z.[8]

Wind speed and direction were monitored continuously with a Climatronics model EWS portable weather station with a 10-ft tower. An example of its output is shown later in Figure 4.

Sampling and Analysis of C-56

Pollutant concentrations of C-56 were measured by collecting air samples in a packed porous polymer tube at a height of about four feet above ground level. Eight samplers were used simultaneously; one sampling position was upwind from the source and seven were positioned in an array downwind from the source.

The C-56 sampling and analysis procedure followed NIOSH Method No. P&CAM 308 for hexachlorocyclopentadiene in air.[8] In this procedure a known volume of air is drawn through a tube containing Porapak T (an ethyleneglycodimethylacrylate monomer), followed by in-field, ultrasonic-assisted desorption with hexane, subsequent gas chromatographic analysis with a ^{63}Ni electron capture detector and comparison of peak heights with those obtained from injection of standards.

The sorbent tube used for collection of C-56 in air is shown in Figure 2. The pumps used to pull air through the sorbent tubes were MSA Model G personnel pumps, which are rechargeable-battery-operated, diaphragm-type with a sample flow indicator and a sample rate control valve. They were operated for 90-113 minutes at a rate of 1.6-2.0 l/min. During sampling, the flowmeter float position of each pump was checked periodically to ensure that the proper flow rate was maintained. The combined sampling/analysis detection limit is 0.001 ppb.

During the C-56 sampling period, sulfur hexafluoride (SF_6) tracer gas was released at two known rates at an upwind location that approximated the virtual point of emission for the area source being sampled, based on the atmospheric stability class and the width of the area source. Ground level release rates of 100% SF_6 were measured with a soap bubble flowmeter.

Downwind samples were collected in Mylar bags in a sealed metal container. To collect an air sample, the bag was opened to the atmosphere and a pump connected to the sealed container. The pump, operating at about 3 l/min, created a light vacuum which pulled the ambient SF_6 sample into the bag. The sampling duration was about three minutes per sample.

SF_6 analysis was conducted in the field with an AID Model 511 portable gas chromatograph equipped with a 6 ft x 1/8 in. Molecular Sieve 5A column operable at 104 °F and an electron capture detector. Analysis followed a procedure supplied by the equipment manufacturer[10] Standards of SF_6 were prepared in the field by dilution of a 1.00 ppm SF_6 standard furnished by a commercial supplier. The combined sampling/analysis detection limit was 0.02 ppb.

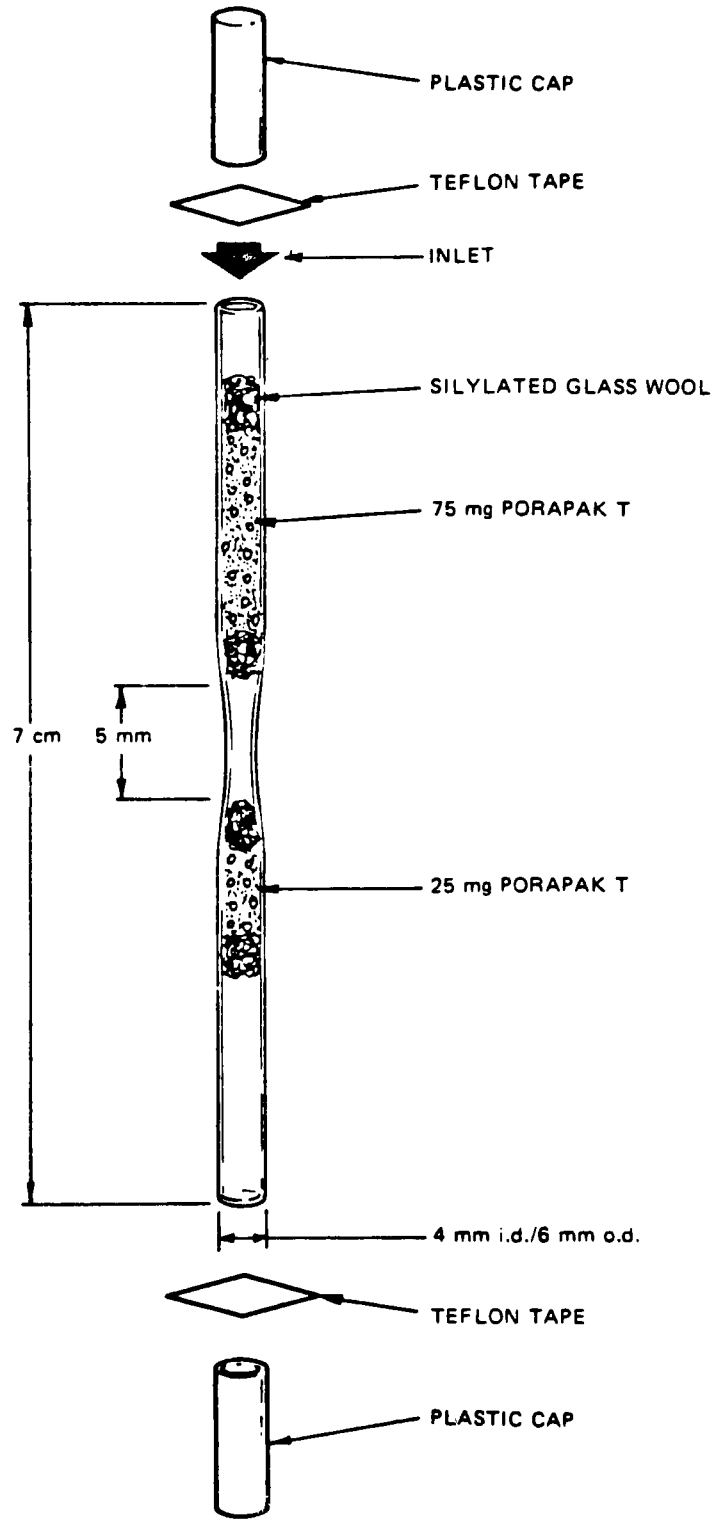

Figure 2.
Sorbent Tube for Collection of Hexachlorocyclopentadiene (C-56) in Air.

DATA ANALYSIS AND RESULTS

In this section, the discussion focuses on the use of the Gaussian plume model for area sources in combination with the ratio equation technique for estimating the emission rate of an inactive chemical waste disposal site.

Plume Dispersion Model

For a continuous point source, the Gaussian plume dispersion model is a rather simple form of calculation. Because the source under study was at ground level with little or no plume rise (H = 0), and since ground level concentrations were taken (z = 0), the model was simplified to:

$$\chi = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

Where X is the mean concentration at the point of measurement; y is the distance from the sampler to the plume centerline; Q is the source emission rate; u is the mean horizontal wind speed at the height of emission; and σ_y and σ_z are the Gaussian standard deviations in the pollutant concentration distribution in the horizontal and vertical, respectively, at the point of measurement, and are both functions of the distance from the source (X).

For fugitive source sampling the concentrations are measured and the emission rate Q is of interest. The model then becomes:

$$Q = \chi\pi\sigma_y\sigma_z u \exp\left[\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

When sampling can be done along the plume centerline (y = 0), the model is further simplified:

$$Q = \chi\pi\sigma_y\sigma_z u$$

In dealing with dispersion of pollutants from a defined area rather than a point of emission, an approximation can be made by treating the area as a source having an initial horizontal standard deviation of plume spread, σ_{yo}. A virtual distance x_y can then be found that will give this horizontal dispersion coefficient, depending upon stability class. Then equations for a point source may be used, determining σ_y as a function of $x + x_y$. How this is done is shown in Figure 3.

In this procedure, the area source is treated as a cross-wind line source with an initial normal distribution, a fairly good approximation for the distribution across an area source. The initial standard deviation for a roughly square area source can be approximated by $\sigma_{yo} = S/4.3$, where S is the length of a side of the area.[7] For a ground-level area source, the vertical dispersion coefficient σ_z is left untreated as having originated from the actual source

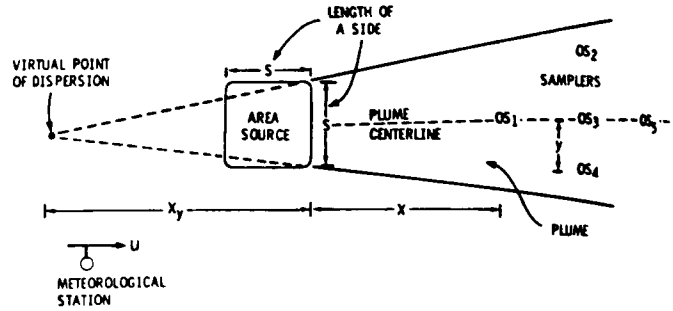

Figure 3.
Schematic Diagram of the Gaussian Point Source Plume Model Applied to an Area Source.

rather than the virtual point.

The dispersion model then becomes:

$$Q = \chi\pi(\sigma_y^2 + \sigma_{yo}^2)^{1/2}\sigma_z u$$

In this sampling program the area source dispersion model concept was used only to find the virtual point of emission in order to site the SF_6 tracer gas release point. By knowing the disposal site side length S and the atmospheric stability class, a distance x_y upwind from the disposal site edge was found at which to release the tracer gas and allow the SF_6 plume to travel across the area source to be measured at several downwind locations.

During C-56 sampling, two grab samples were collected at each of three downwind plume centerline locations for on-site analysis of SF_6. Emission rates of C-56 were then calculated by a ratio equation technique:

$$E_{C\text{-}56} = \frac{\chi(C\text{-}56)}{\chi(SF_6)} \times E_{SF_6} \times \frac{MW_{C\text{-}56}}{24.45} \times \frac{P}{P_S} \times \frac{T_S}{T}$$

Where $E_{C\text{-}56}$ is the emission rate of C-56 in g/hr; χ(C-56) is the concentration of C-56 at the sample point; $\chi(SF_6)$ is the concentration of SF_6 in 1/hr, $MW_{C\text{-}56}$ is the molecular weight of C-56 (272.77)[6]; and 24.45 is the molar volume of a gas at STP in 1/mole.

The measured concentrations of C-56 and SF_6 should be a mean concentration over the same time interval as the time interval for which the σ's and μ are representative, typically three minutes. An often-forgotten calculation in plume dispersion modeling is to correct for time-averaging differences due to increased meander of wind direction with time. When estimating emission rates (or concentrations) from a single source for the time intervals greater than a few minutes; the best estimate apparently can be obtained from[7]:

$$\chi_s = \chi_k\left(\frac{t_k}{t_s}\right)^p$$

Where χ_s is the desired concentration estimate for the sampling time t_s; χ_k is the concentration estimate for the

Table I.
Calculation of C-56 Emission Rate by SF_6 Tracer Gas Ratio Method, Run 1, Abandoned Production Area.

Sample point	Corrected C-56 concentration, ppb	SF_6 concentration, ppb @7.0 cc/min, SF_6 release rate	SF_6 concentration, ppb @4.0 cc/min, SF_6 release rate	C-56 emission rate, g/hr @7.0 cc/min, SF_6 release rate	C-56 emission rate, g/hr @4.0 cc/min, SF_6 release rate
S_4	0.053	0.71	0.46	0.35	0.31
S_5	0.047	1.13	0.57	0.20	0.22
S_6	0.032	0.75	0.30	0.20	0.27

Average C-56 emission rate = 0.26 g/hr
Confidence limits (95%) = ±0.05

shorter sampling time t_k; and p should be between 0.17 and 0.2. Equation (6) is most appropriately applied to sampling times less than two hours.

Ground Level Concentrations

An example of the average ground-level concentrations of C-56 and SF_6 tracer gas taken during one of the emission test runs is given in Table I. The form of the meteorological data collected during each run is shown in Figure 4. When the wind direction is shown to be steady (< 45° shift) over the sampling period, only the plume centerline samplers need be used in estimating the emission rate of the source. Of course, the precision of the calculated emission rate usually will improve with less wind direction meandering. The ratio of predicted to observed concentrations of SF_6 ranged from 0.4 to 0.8 for all runs, which were conducted under stability class C.

The estimated emission rate of C-56 shown in Table I applies only to the ambient conditions experienced during the sampling period. Any factor that could change the volatilization rate, such as increased temperature or disturbance of the soil cover, will cause a corresponding change in emission rates from a chemical waste disposal site.

CONCLUSIONS

The results of the calculated emission rates from sampling chemical waste disposal area sources indicate that a tracer gas-ratio equation technique can estimate emission rates with good precision, provided a few open source sampling rules-of-thumb are followed. Seasonal or weather-dependent trends on the emission rate can be monitored with relative ease. The technique as described is fully portable and can be assembled rapidly. Knowledge of gas chromatograph operation in the field is the only difficult skill necessary. Two people can make two or three runs per day, weather permitting.

Regardless of how inaccurate the emission rate estimation is, the ambient concentrations measured are real values and can have an accuracy ascribed to them. The concentration of C-56 in test atmospheres was determined by NIOSH in control experiments by sampling with bubblers containing hexane and subsequently analyzing the bubbler solutions by GC/ECD. The determinations with Porapak T sorbent sampling gave values averaging 100% of those found by bubbler sampling over the range of the method. Sorbent sampling for C-56 has a precision of 8% over the concentration range of 13-865 $\mu g/m_3$; the precision of the analytical method is 3%.

While the collection and analysis method described herein is specific for C-56, methods are also available to quantify emission rates of many organic chemicals simultaneously using the tracer gas/area source technique. Low concentrations of a wide variety of pollutants are expected at chemical landfills and sorbent trap sampling is considered to be more reliable, accurate, precise, and sensitive than grab sampling.[11,12]

Monsanto Research Corporation has developed a combination sorbent system based on Tenax-GC, Porapak R and Ambersorb XE-340 for use in collecting a broad range of organic compounds.[13] Over 30 different sorbent materials were evaluated in this EPA-sponsored program (Contract No. 68-02-2774), whose goal was to choose a collection of commercially available materials that, when used in combination, showed promise for quantitatively trapping compounds varying widely in volatilities and polarities.

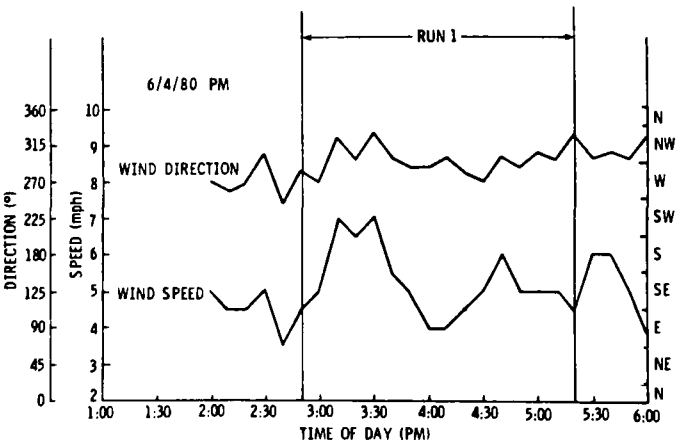

Figure 4.
Meteorological Data for Run 1, Abandoned Production Area.

Tenax-GC is the only high-temperature (750°F) adsorbent (2, 6-diphenyl-p-phenylene oxide) available which allows the quantitative thermal desorption of low volatility organic compounds. Porapak R is one of the highest-capacity polymeric adsorbents (n-vinyl pyrrolidone) with a reasonable background level and with an overlap in the range of utility with Tenax-GC.

Ambersorb XE-340 (a carbonized styrenedivinyl benzene) gives less difficulty with the desorption of compounds of intermediate volatility, fewer detrimental effects by water, and less reactivity with collected samples than with charcoal adsorbents. Also, its range of utility leaves the smallest gap between polymeric and carbonaceous adsorbents in the types of compounds collected. These sorbent materials are packed into three separate tapered glass tubes for sampling, with flow being directed either in series or in parallel. If sampling is done with the sorbent tubes in series, the arrangement is Tenax-GC at the air intake, Porapak R in the middle and Ambersorb XE-340 last.

ACKNOWLEDGEMENTS

The authors are grateful to Hooker Chemical and Plastics Corporation for the opportunity to present the results of this work.

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A STUDY OF THE EMISSION RATE OF VOLATILE COMPOUNDS FROM LAGOONS

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INTRODUCTION

Theory

Nusselt[1] has described the rate of evaporation of water from a lagoon as follows:

$$G = 39A_m\left(\frac{D}{L}\right)^{0.22} \cdot (W_o)^{0.78} \cdot (C_w - C_o) \quad \ldots\ldots\ldots (1)$$

G = kilograms of water evaporated per hour

A_m = surface area of the lagoon in square meters

D = diffusivity coefficient of water in square meters per hour

L = a dimension of the lagoon surface. For a circular lagoon, L, in meters, is the diameter. For an irregular shaped lagoon, such as square, oblong or elliptical, etc., it is the diameter, in meters of a circle of area equal to the lagoon surface. For long narrow lagoons, L will be the smaller dimension in meters.

W_o = wind velocity in meters per second

C_o = humidity content of the air at a distance above the lagoon surface, or the humidity of the air blowing across the lagoon.

$$= \frac{\text{g water}}{\text{dry air containing the water}}$$

Nusselt's equation may be applied to the evaporation rate of a volatile compound which is dissolved in the lagoon water if one replaces C_w, the moisture content of the air at the immediate surface of the lagoon by C_v, the volatile content of the air at the immediate surface of the lagoon. Assuming that there is no volatile compound in the incoming air, Nusselt's C_o for the volatile compound is zero. Nusselt's equation for a volatile compound dissolved in the lagoon water then becomes, in pounds per hour

$$G_A = 39A_m \cdot \left(\frac{D}{L}\right)^{0.22} \cdot (W_o)^{0.78} \cdot (C_v) \cdot (2.205) \quad \ldots\ldots (2)$$

C_v is derived as follows:

C, the molar concentration of a volatile compound in the lagoon water

$$= \frac{\frac{\%}{M_v}}{\frac{100 - \% + \%}{M_w \quad M_v}}$$

where % is the weight percent of the compound in the lagoon water. Because this value is most frequently less than one, the above equation can be reduced, with negligible error to:

$$C = \frac{\%}{100} \cdot \frac{M_w}{M_v} \quad \ldots\ldots\ldots (3)$$

M_w = molecular weight of water = 18

M_v = molecular weight of compound = 28.96

The mole-fraction of a volatile compound P* at the lagoon surface (in the air) is the product of the molar concentration and the vapor pressure (V.P.) of the pure compound, in atmospheres, at any temperature, i.e.,

$$P^* = (C)(V.P.) \quad \ldots\ldots\ldots (4)$$

$$\text{From equation (3) } P^* = \left(\frac{\%}{100}\right)\left(\frac{M_w}{M_v}\right)(V.P.) \quad \ldots\ldots\ldots (5)$$

$$\text{also } \% = \left(\frac{\text{Pounds of compound in the lagoon}}{\text{Pounds of waste in the lagoon}}\right)100$$

$$\% = \frac{L_o}{V} \cdot \frac{100}{8.34\,(sp.gr)} \quad \ldots\ldots\ldots (6)$$

L_o = Pounds of volatile compound in the lagoon

V = total gallons of waste in the lagoon

sp.gr = specific gravity of the waste

Combining equations (5) and (6):

$$P^* = \frac{(L_o)(M_w) \cdot (V.P.)}{V \cdot (8.34)(M_v)(sp.gr)} \quad \ldots\ldots\ldots\ldots (7)$$

$$C_v = \frac{\text{wt. of compound in the air at the lagoon surface}}{\text{wt. of air containing this compound}}$$

$$= \frac{(P^*)M_v}{(1-P^*)M_A} \quad \ldots\ldots\ldots\ldots (8)$$

M_A = molecular weight of air

Again, because the concentration of a volatile compound in wastewater is usually less than 1%, P* is small compared with unity so equation (8) can be reduced to:

$$C_v = \frac{P^* M_v}{M_A}$$

Combining equations (7) and (8)

$$C_v = \frac{(L_o)(M_w)(V.P.)}{(V)(8.34)M_v(sp.gr)} \cdot \frac{M_v}{M_A}$$

$$C_v = \frac{(L_o)(M_w)(V.P.)}{(V)(8.34)M_A(sp.gr)} \quad \ldots\ldots\ldots\ldots (9)$$

Thus

$$\frac{M_w}{M_A} \cdot \frac{1}{8.34} = 0.07453$$

Therefore

$$C_v = \frac{0.07453}{(sp.gr)} \cdot \left(\frac{L_o}{V}\right)(V.P.) \quad \ldots\ldots\ldots\ldots (10)$$

The analogous Nusselt expression now becomes

$$G_A(\#/hr) = 39A_m\left(\frac{D}{L}\right)^{0.22} \frac{(0.07453)}{(sp.gr)} \frac{L_o}{V} (V.P.)$$

$$(W_o)^{0.78}(2.205). \quad \ldots\ldots\ldots\ldots (11)$$

but $L_o = (0.0834)(V)(\%)(sp.gr)$- - -from equation (6)

substituting for L_o and combining the constants

$$G_A(\#/hr) = 0.53452A_m\left(\frac{D}{L}\right)^{0.22} (\%)(V.P.)(W_o)^{0.78}$$

$$E_o \quad \ldots\ldots\ldots\ldots (12)$$

Note, the sp.gr. of the waste is eliminated.

E_o = Initial evaporation rate of volatile compound.

APPLICATION

In order to evaluate the emissions in real-life operation in the lagoon, one assumes the following arbitrary conditions:

- The volume of waste in the lagoon is maintained constant
- The feed volume and composition is constant
- The discharge volume is equal to the feed volume
- Temperature and wind velocity are constant
- Steady state condition.

Table I.

Symbols used in material balance

V = lagoon volume in U.S. gal

F = feed rate in gal/hr

= discharge rate in gal/hr

K = volatile compound in the feed, lb/hr

L_o = amount of volatile compound in the lagoon at start, i.e., time-zero, lb

E_o = initial evaporation rate of a volatile compound in lb/hr as computed from equation (12)

Table II.
Material Balance Over a Lagoon for One Volatile Component

Time Hrs	Am't in Lagoon lbs	Feed Rate lbs/hr	Disch Rate lbs/hr	Evap. Rate lbs/hr	Net Am't in Lagoon
0	L_o				
1st	L_o	$+K$	$-K$	$-E_o$	$= L_1$
2nd	L_1	$+K$	$\frac{-L_1F}{V}$	$\frac{-E_oL_1}{L_o}$	$= L_2$
3rd	L_2	$+K$	$\frac{-L_2F}{V}$	$\frac{-E_o \cdot L_2}{L_o}$	$= L_3$
nth	L_{n-1}	$+K$	$\frac{-L_{n-1}F}{V}$	$\frac{-E_o \cdot L_{n-1}}{L_o}$	$= L_n$*

summarizing,

$$L_n = L_{n-1}\left(1 - \frac{F}{V} - \frac{E_o}{L_o}\right) + K$$

let $X = 1 - \frac{F}{V} - \frac{E_o}{L_o}$, a constant because F, V, E_o and L_o are constants.

Then $L_n = (L_{n-1})\,X + K$. . . . . .(13)

Using this approach, outlined in Tables 1 and 2, one can write:

Time from start	Volatile Content of Lagoon	
n = 0	L_o	$= L_o$
n = 1 hr	$L_oX + K$	$= L_1$
n = 2 hrs	$(L_oX + K)\,X + K = L_oX^2 + KX + K$	$= L_2$
n = 3 hrs	$(L_oX^2 + KX + K)X + K = L_oX^3 + KX^2 + KX + K$	$= L_3$
n = n hrs	$L_oX^n + K + KX + KX^2 + KX^3 \ldots + KX^{n-1}$	$= L_n$

Because $K + KX + KX^2 + KX^3 \ldots + KX^{n-1}$ is a geometric progression with X less than 1, the sum $S_\infty = \frac{K}{1-X}$

Thus, $L_n = L_oX^n + \frac{K}{1-K}$. . . . . .(14)

Where n is very large, X^n becomes very small and so L_oX^n may be neglected.

Equation (14) becomes $L_n = \frac{K}{1-X}$ . . . . . .(15)

Equation 15, represents the steady state and L_n will be now designated L_s

In arriving at a steady state, i.e., when n is many hours, the following equations are used:

initial pounds of a volatile compound in a lagoon

$$L_o = (0.0834(V)(\%)(\text{sp.gr.})\ 16$$

pounds of a volatile compound in lagoon at a steady state

$$L_s = \frac{K}{1-K} \text{ pounds}$$

pounds of a volatile compound in feed to lagoon

$$K = 0.0834(F)(\%)(\text{sp.gr.})\ \text{lb/hr}$$

$$1 - X = \frac{E_o}{L_o} + \frac{F}{V} \text{ a fraction less than unity}$$

evaporation rate of a volatile compound in 16/hr.

$$E_s = \frac{E_o L_s}{L_o} \text{ lb/hr}$$

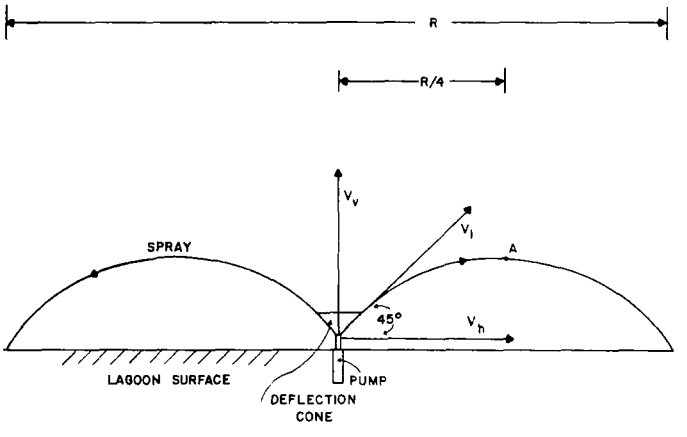
percent of a volatile compound in a lagoon at the steady rate

$$\%_s = (\%\text{ at start})\frac{L_s}{L_o}$$

Initial evaporation rate of a volatile compound in a lagoon is given in equation (12). D and V.P. are calculated for the specific operating temperature.

EMISSIONS OF A VOLATILE COMPOUND IN AN AERATED LAGOON

Consider the case of a lagoon containing less than 1% of a volatile compound in water. At the center of the lagoon, a water pump withdraws lagoon water and directs the stream vertically against a deflector plate to produce a cone of droplets. The maximum trajectory is attained when the initial direction of the droplets is 45° from horizontal.



V_I = initial velocity of the droplets in ft/sec

R = maximum diameter of the spray falling back into the lagoon

The horizontal and vertical components of the velocity V_h and V_v of a droplet are $V_I \cos 45°$ and $V_o \sin 45°$ respectively and are both equal to $0.7071V_I$. The maximum height

attained by a droplet will be, theoretically, at a distance $\frac{R}{4}$ from the deflector plate.

Let t seconds be the time for a droplet to reach maximum height, i.e., to reach the point A.

Then:

$$V_h t = \frac{R}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

From Newton's Laws of Gravity:

$$t = \frac{V_y}{32} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Combining equations (16) and (17) and letting $V_h = V_v = 0.7071 V_I$:

$$V_I = 4R^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

and, from equation (16):

$$t = 0.08839R^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

The total flight time for a droplet = 2t sec:

$$2t = 0.17678R^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

For a spherical water droplet:

$$\frac{\text{surface area}}{\text{volume}} = \frac{4\pi r^3}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

H = water delivered by the pump comp.

$$\text{or, } \frac{(H)(3785)}{60} = 63.083H \text{ cm}^3/\text{sec}$$

The surface area of this mass of water, as spherical drops, r cm radius

$$= \frac{3}{r} \cdot 63.083H$$

$$= 189.25\frac{H}{r} \text{ cm}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

Arnold[2] has studied the diffusion of a volatile compound from a liquid surface into air and arrived at this conclusion:

$$Q = 2A_c y^* \sqrt{\frac{d\theta}{\pi F_v}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

θ = time in seconds = $0.17678R^{1/2}$

π = 3.1416

F_v = correction factor, which approaches unit for dilute solutions of volatile compounds

L_o = amount of volatile compound in the lagoon, lb.

V_L = volume of liquid waste in the lagoon, U.S. gal

M_w = Mol. wt. of water = 18

M_v = Mol. wt. of volatile component

V.P.= vapor pressure in atmospheres of the volatile compound at T°F sp.gr. = specific gravity of the liquid waste

Substituting these values in equation (22) one obtains:

$$Q = \frac{2H}{r}\left(\frac{189.25}{8.34}\right) \cdot \frac{L_o}{V_L} \cdot \frac{M_w}{M_v} \cdot \frac{(V.P.)}{(sp.gr)} \sqrt{\frac{d(0.17678R^{1/2})}{\pi}} \quad \ldots (23)$$

The emission in lb/hr

$$E_o = \frac{Q}{\theta} \cdot \frac{3600 \text{ sec} \times M_v}{\frac{HR}{22400 \times \frac{(460+5)}{460+60}}} \cdot \frac{\text{LB.}}{454 \text{ gm}} \quad \ldots\ldots\ldots\ldots (24)$$

substituting for Q from equation (23), and simplifying:

$$E_o = \frac{150.315}{(460+T)} \cdot \frac{H}{r} \cdot \frac{L_o}{V_L} \cdot \frac{(V.P.)}{(sp.gr)} \quad \frac{d}{\pi} \cdot \frac{1}{\sqrt{0.17678R^{1/2}}} \quad \ldots (25)$$

When the value of E_o is obtained, E_s may be calculated by the procedure described previously.

NOMENCLATURE

$A_{m,c}$	Surface area, m = m^2; c = cm^2
C	Molar concentration of a compound in water
C_v	Gms compound as gas divided by gms dry air containing the compound
C_w	Humidity content of air = gms water/gmw dry air containing the water
D	Diffusivity coefficient of a compound in air in m^2/hour
d	Diffusivity coefficient of a compound in air in cm^2/second
$E_{o,s}$	Evaporation rate of a compound in pounds/hour; o – initial, s = steady state computed from equation (12)
F	Feed rate, gal/hr = discharge rate (in a lagoon)

G, G_A	G = Kg/hr; G_A = lb/hr
H	gpm
K	Amount of a compound in a feed stream, lb/hr
L	A lagoon dimension in meters
$L_{o,s}$	Pounds of a compound in a lagoon; o=at state, s=at steady state
$M_{w,v,A}$	Molecular weights of w = water, v = compound, A = air
P*	Mole-fraction of compounds in air at lagoon surface
Q	Gas volume, vol. of compounds emitted to air in θ seconds, cm^3/sec
sp.gr.	Specific gravity of a liquid waste
V	Operating volume of a lagoon in gal
V.P.	Vapor pressure of pure compounds, atm
W_o	Wind velocity m/sec
X	$1 - \frac{F}{V} - \frac{E_o}{L_o}$
y*	partial pressure in atmospheres of a compound in air surrounding water droplets = $\frac{L_o}{V_L} \cdot \frac{M_w}{M_v} \cdot \frac{V.P.}{8.34(sp.gr)}$
%	Weight percent of compounds in water or lagoon liquid
θ	Time in sec
π	3.1416
F_v	Arnold's correction factor, becomes 1 for dilute systems.

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3. Schlessinger, G.G., "Vapor Pressures, Critical Temperatures, and Critical Pressures of Organic Compounds." *Handbook of Chemistry and Physics*, 54th Ed. D-162 to D-188.

4. Fuller, *Atomic and Structural Diffusion Volume Increments. Perry 5th Edition (3-233) CRC.*

Appendix 1.
Vapor Pressure of Selected Compounds Based on Reference (3)

OCPDB Ident.No.	Compound	70°F	90°F	110°F	130°F	150°F
90	Acetone	0.2229	0.3586	0.5580	0.8426	1.2383
110	Acetonitrile	0.0972	0.1617	0.2595	0.4032	0.6087
240	Amyl Acetate	0.0056	0.0108	0.0199	0.0348	0.0594
380	Benzene	0.0796	0.1327	0.2126	0.3288	0.4974
790	Carbon disulphide	0.3813	0.5817	0.8614	1.1386	1.7487
810	Carbon tetrachloride	0.1095	0.1761	0.2738	0.4118	0.6068
890	Chlorobenzene	0.0094	0.0165	0.0278	0.0452	0.0716
930	Chlorform	0.1923	0.3066	0.4732	0.7091	1.0349
1120	Cyclohexane	0.0924	0.1504	0.2366	0.3609	0.5355
1244	dichloroethane	0.2171	0.3416	0.5208	0.7715	1.1139
1660	Ethanl	0.0578	0.1056	0.1848	0.3113	0.5069
1670	Ethyl Acetate	0.0902	0.1513	0.2445	0.3826	0.5813
1990	di-Ethyl ether	0.5214	0.8032	1.2006	1.7461	
2360	iso-Propyl Alcohol	0.0438	0.0819	0.1467	0.2524	0.4191
2500	Methanol	0.1233	0.2155	0.3622	0.5879	0.9243
2510	Methyl Acetate	0.2065	0.3342	0.5228	0.7933	1.1714
2620	Methylene Chloride	0.4773	0.7646	1.1849	1.7826	2.6108
2640	Methyl ethyl ketone	0.1062	0.1763	0.2826	0.4385	0.6612
2860	Perchloroethylene	0.0192	0.0341	0.0582	0.0957	0.1525
2910	Phenol	0.0006	0.0013	0.0026	0.0050	0.0091
3230	Styrene	0.0083	0.0151	0.0264	0.0444	0.0722
3349	Toluene	0.0310	0.0556	0.0955	0.1583	0.2538
3395	1,1,1-trichloroethane	0.1331	0.2192	0.3485	0.5369	0.8039
3411	1,1,2-trichloroethylene	0.0795	0.1334	0.2158	0.3379	0.5138
3430	Freon	0.3280	0.5108	0.7790	1.1315	0.6195
3541	Xylene(s)	0.0085	0.0158	0.0280	0.0478	0.0787

APPENDIX 2

Diffusivity Coefficient

The diffusivity coefficient "d", is measured in cm^2/sec. In Arnold's equation, the diffusivity coefficient d is in $cm^2 sec$.

In Nusselt's equation, the diffusivity coefficient "D" is measured in m^2/hr.

$$D = 0.36d$$

Fuller[4] has derived values for d, using the relationship

$$d = \frac{0.001T^{1.75}\left(\frac{1}{M_1}+\frac{1}{M_2}\right)^{1/2}}{P[(\Sigma V_1)^{1/3}+(\Sigma V_2)^{1/3}]^2} \quad cm^2/sec$$

D values for a selected group of hazardous compounds is presented for a range of temperatures in Appendix (2).

Table III
Values of Diffusivity Coefficient D (m^2/hr)

Compound	70 °F	90 °F	110 °F
Methanol	0.05687	0.06069	0.06460
Ethanol	0.04338	0.04630	0.04928
Phenol	0.03000	0.03199	0.03405
Acetone	0.03724	0.03974	0.04231
M.E.K.	0.03231	0.03448	0.03671
Methyl Acetate	0.03475	0.03708	0.03948
Ethyl Acetate	0.03067	0.03273	0.03484
Methyl Amine	0.05585	0.05960	0.06345
di-Methyl Amine	0.04282	0.04572	0.04867
Ethyl Amine	0.04284	0.04572	0.04867
Hexane	0.02837	0.03027	0.03222
Xylene	0.02587	0.02761	0.02939
Toluene	0.02827	0.03017	0.03212
Benzene	0.03146	0.03357	0.03573
Di-Ethyl Ether	0.03159	0.03371	0.03589
Methylene Chloride	0.03689	0.03936	0.04191
Chloroform	0.03203	0.03418	0.03639
Carbon Tetrachloride	0.02878	0.03071	0.03270
Freon ($C_2F_3Cl_3$)	0.02578	0.02751	0.02929
PCB (1 chlorine)	0.02068	0.02207	0.02350

Example 1

To determine the steady state emissions of methanol from a receiving lagoon.

Basis for Model

The receiving lagoon has an operating volume of 600,000 gallons.
The feed rate is constant at 6667 gph
The methanol concentration in the feed averages 0.09%.
The feed weight is 8.34 lb/gal
The temperature is constant at 70°F
The wind velocity is steady at 4 m/sec.

The initial evaporation rate E_o will be determined using Nusselt's modified equation;

$$E_o = 0.53452\, A_m \cdot \left(\frac{D}{L}\right)^{0.22} \cdot \% \cdot (V.P.) \cdot W_o^{0.78} \quad \ldots\ldots(12)$$

The the steady state evaporation rate E_s will be determined from the relationship;

$$E_s = E_o \cdot \frac{L_s}{L_o}$$

The parameters needed are:

L_o = the pounds of methanol in the lagoon at zero time
= 600,000 gallons $\times \frac{8.34\ lb}{gal} \times \frac{0.09\ lb}{100\ lb}$ = 4503 lb Methanol

F = 6667 gph

V = 600,000 gal

L = 40 m

$K = \frac{4503 \times 6667}{600{,}000} = 50$ lb/hr

$A_m = 0.7854\, L^2 = 1256.64 m^2$

W_o = 4 m/sec

% = 0.09

V.P. = 0.12324 Atm (App 1)

D = $0.05687 m^2/hr$ @ 70°F

Accordingly,

E_o = (0.53452)(1256.64)(0.23638)(0.09(0.1234) (2.94854)
= 5.193 lb/hr Methanol.

To determine the emissions at the steady state, E_s, first determine L_s, the methanol content of the lagoon at the steady state

$$L_s = \frac{K}{1-X}$$

K = 50 lb

$$1-X = \frac{E_o}{L_o} + \frac{F}{V} = \frac{5.193}{4503} + \frac{6667}{600{,}000} = 1.2264410^{-2}$$

$$L_s = \frac{50}{1.2264410^{-2}} = 4076.7 \text{ lb Methanol}$$

$$E_s = E_o \cdot \frac{L_s}{L_o} = 5.193\,\frac{(4076.7)}{4503} = 4.7 \text{ lb/hr Methanol}$$

Example 2.

Ammonia emissions from an aerated lagoon at the steady state. An aeration lagoon is 45 ft in diameter, has an operating volume (V) of 300,000 gal.

A feed stream at 10.5 pH, containing 0.1% NH_3 enters the lagoon at a rate (F) of 210 gph.

Mass of ammonia in the lagoon at zero time:

$$L_o = 300{,}000 \text{ gal} \times \frac{8.34 \text{ lb}}{\text{gal}} \times \frac{0.1 \text{ lb } NH_3}{100 \text{ lb}} = 2502 \text{ lb.}$$

Mass of ammonia entering the lagoon each hour:

$$\text{is } K = 210 \text{ gal} \times \frac{8.34 \text{ lb}}{\text{gal}} \times \frac{0.1 \text{ lb } NH_3}{100 \text{ lb}} = 1.7514 \text{ lb.}$$

An aeration pump transfers 3390 gpm of lagoon water to a deflector which produces an umbrella-like spray cover which completely covers the lagoon.

The flight time of droplet in seconds will be;

$$\sqrt{\frac{\text{lagoon diameter in feet}}{5.6568}}$$

In this case, the lagoon diameter is 45 ft, therefore flight time (G) 2t = 1.186 seconds

Assume the water droplets (r) average 0.25 cms radius. The weight of water suspended as droplets at any time is:

$$\frac{3390 \text{ gal}}{\text{min}} \times \frac{8.34 \text{ lb}}{\text{gal}} \times \frac{454 \text{ g}}{\text{lb}} \times \frac{1 \text{ min}}{60 \text{ sec}} \times 1.186 \text{ sec.} = 253720 \text{ g.}$$

Total surface of the droplets, A_c = 253720
$\times \frac{4\pi r^2}{4}$ (droplet area)
$3\pi r^3$ (droplet wt.)

$$= 253720 \times \frac{3}{r} \text{cm}^2$$

when r = 0.25 cm A_c = 3,044,642 cm^2

The vapor pressure (V.P.) of pure ammonia (NH_3) at 70 °F is 8.5513 Atmospheres

The molar concentration of 0.1% ammonia is 1.06×10^{-3}

y^* = (molar concentration)(vapor pressure) = $\mathbf{9.05 \times 10^{-3}}$

The diffusivity coefficient (d) of ammonia from water to air at 70°F = 0.23785 cm^2/sec.

The volume of ammonia gas entering the atmosphere from the aeration lagoon V $\text{cm}^3 = 2A_c y^* \sqrt{\frac{d\theta}{\pi}}$ according to Arnold.

V = 16513 cm^3/1.186 sec

Amount of ammonia emitted, lb/hr:

$$E_o = 16513 \text{ cm}^3 \times \frac{\text{mole}}{22400 \text{ ml}} \text{ N}$$

$$E_o = 16513 \text{ cm}^3 \times \frac{\text{mole}}{22400 \text{ ml}} \times \frac{17 \text{ g}}{\text{mole } NH_3} \times \frac{\text{lb}}{454 \text{ g}} \times$$

$$\frac{3600 \text{ sec}}{\text{hr}} \times \frac{1}{1.186 \text{ sec}} = 83.8 \text{ lb Ammonia/Hr.}$$

To determine the emission rate of ammonia at the steady state proceed as follows:

L_o = 2502 lb

L_s = lb ammonia in the lagoon at the steady state

$$L_s = \frac{K}{1-X}$$

K = 1.7514 lb

$$1-K = \frac{E_o}{L_o} + \frac{F}{V}$$

$$= \frac{83.8}{2502} + \frac{210}{300{,}000} = 0.0342$$

$$L_s = \frac{1.7514}{0.0342} = 51.21 \text{ lb}$$

Emissions at the steady state

$$E_s = \frac{E_o \cdot L_s}{L_o} = 1.715 \text{ lb/hr.}$$

Steady state emissions of ammonia is 1.75 lb/hr.

Thus, the ammonia concentration leaving the lagoon in the liquid, at the steady state is

$$\frac{L_s}{(8.34)V} = \frac{51.2}{(8.34)(300{,}000)} = 2 \times 10^{-5}$$

$$= 20 \text{ mg/l}$$

AIR MONITORING OF A HAZARDOUS WASTE SITE

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INTRODUCTION

Versar Inc., as a contractor to the U.S. Environmental Protection Agency for air quality emergency response, performs ambient monitoring, dispersion modeling and other support functions as requested by the Division of Stationary Source Enforcement. In this capacity, Versar and GEOMET, Inc. (prime contractor) responded to a request to perform ambient air sampling at Rollins Environmental Services' (RES) waste treatment and disposal facility near Baton Rouge, Louisiana. This paper focuses on Versar's approach to the identification and quantification of airborne pollutants from a hazardous waste facility.

Community residents had complained of odors and respiratory impairment which they attributed to the RES waste treatment and disposal facility. To determine what action could be supported by air quality impacts, ambient air concentrations were needed for hazardous pollutants emitted from the site. Sampling and analysis were complicated by the wide range of compounds which are brought to RES for treatment and/or disposal. It was anticipated that emissions would be variable and that reactions could occur among components of the waste in liquid or solid form, or among gaseous pollutants emitted from the facility. Since the airborne pollutants were not well identified at the outset of this program, a two-phase approach was designed to identify and quantify organic air pollutants. The study was intended to provide a quick response assessment of airborne emissions from the facility, as opposed to providing a long-term ambient air quality evaluation.

Using solid adsorption columns composed of Tenax or activated charcoal for sampling, and using gas chromatography (GC) and gas chromatography/mass spectrometry for analysis (GC/MS), the Phase I program was intended to identify pollutants that were present in the highest concentrations. RES management placed restrictions on sampling which allowed Versar to collect only around the perimeter of the site (i.e., "fenceline" samples).

Upwind samples did not contain detectable concentrations of any pollutants. Therefore, downwind concentrations presented in this report also reflect downwind minus upwind concentrations.

Benzene and toluene were present in the highest concentrations and were quantified during Phase I of the project. The maximum concentrations at the fenceline were 0.5 and 2.4 ppm, for benzene and toluene, respectively. Compounds that were only tentatively identified and therefore not quantitied, included ethyl benzene, 1,1,1-trichloroethane, methylene chloride, tetrachloroethylene, chloroform, and meta-xylene. Since the impact to the general public was an important consideration for this study, fenceline sampling did allow for a suitable data base to determine impacts from the facility.

The Phase II program was designed to provide quantitative air quality data and utilized a portable GC and calibration standards for benzene, toluene and the tentatively identified compounds of Phase I. The use of a portable GC greatly assisted in the selection of areas of expected maximum concentrations and was useful in providing feedback on appropriate sampling times. Maximum concentrations were again found for benzene and toluene, with maximum fenceline values of 0.2 and 0.4 ppm, respectively. Tentative identification included several compounds that were not observed during Phase I, including pentenenitrile and methyl pentene.

DESCRIPTION OF RES FACILITY

The RES facility is located 12 miles north of Baton Rouge on 165 acres of land. It is designed to treat and/or dispose of liquid and solid wastes generated by area industries, such as from chemical, petrochemical, refining and synthetic polymers plants. Treatment and disposal practices include landfarming, landfilling, incineration, biological treatment and physical/chemical treatment.

Area residents had filed numerous complaints alleging that activities at RES were creating an odor problem and were adversely affecting the health of the community. It appears that many of the complaints were associated with odors from the biotreatment area and the landfarm area.

Prior to the Phase I program, however, RES had changed to a subsurface injection system for landfarm application, which reduced odors and organic emissions; also, the emissions from the biotreatment area were substantially reduced to meet a State-issued order. Modifications to the facility between Phase I and II sampling included closing a number of landfill pits to reduce odors, as requested by the State.

The data collected during the sampling programs were considered to accurately represent ambient conditions at the time they were obtained, (Phase I—September 25-26,

1980, and Phase II—November 12-13, 1980). Versar's experience with modifications of the type used at the facility would suggest that the ambient concentrations had been substantially higher before the corrective action had been taken during the summer and fall of 1980. It is therefore possible that complaints about the facility prior to these modifications were the result of higher concentrations than those observed during the sampling program.

By the time the Phase II program began, the most distinctive and unpleasant odors were found to be associated with the mixing pit rather than the landfarm or biotreatment areas. The mixing pit combines ash with liquid wastes as a treatment method. Gaseous and particulate emissions are emitted from this source.

SAMPLING

Air Quality

Phase I of the two-phase sampling program involved collecting 46 air and eight liquid samples. Activated charcoal and Tenax were each used to collect 23 air samples. The height of the intake in all samples was approximately four feet, to represent the approximate breathing level. In Phase I, the air sample volumes through the adsorption columns were from 1 to 150 liters. During this phase, the strongest odors were detected downwind of the mixing pit and the biotreatment area.

These areas were evaluated by selecting upwind and downwind sampling sites, where concurrent upwind and downwind sampling was performed. As previously stated, detectable concentrations were not found in any of the upwind samples. Phase I was characterized by fairly variable winds. The highest concentrations and the largest variety of compounds were generally observed downwind of the mixing pit. The sampling sites for Phase I are shown in Figure 1.

In Phase II, the same basic sampling approach was used as in Phase I, but feedback was obtained on site selection and optimum sample volumes through the use of an on-site Hewlett Packard 5880 dual channel GC. Sample volumes were increased over Phase I since breakthrough of pollutants into the back sections of the adsorption columns did not occur. Volumes in the range of 150-400 liters were obtained during Phase II. Wind flow was fairly consistently out of the east through east-southeast during Phase II, which was the optimum wind flow to evaluate fenceline concentrations downwind of the mixing pit and biotreatment area. The location of the sampling sites for Phase II is shown in Figure 2.

Sampling was performed from 3:00 to 6:00 a.m. in order to coincide with minimum dispersion conditions and therefore relatively high ambient air concentrations. Afternoon sampling was also performed to coincide with maximum activity periods. The early morning hours of November 12, 1980, were particularly suitable for sampling since stable conditions (relatively poor dispersion) occurred with clear skies and light but reasonably steady winds, 3.5 to 5.0 mi/hr between 1:00 and 6:00 a.m.

The sampling protocol was essentially the same for Phases I and II, with the exception that a GC was not in the field during Phase I. The basic protocol was as follows:

(1) Based on current wind direction data, downwind and upwind sites were selected.
(2) A steel support post was used to provide a sample intake height of approximately four feet.
(3) The seals on the adsorption tube were broken, and the tube was attached to the end of approximately one foot of neoprene tubing. The pump and tubing were downstream of the sample.
(4) Sampling times generally were two hours; however, some samples were taken for as long as four hours.
(5) The sample was stored in the GC trailer at 4 °C until it was analyzed. Ice was contained in sealed plastic bags to minimize sample exposure to moisture.

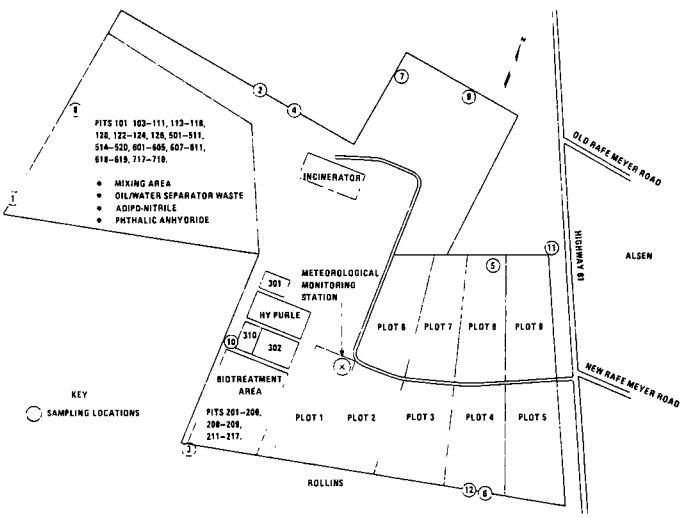

Figure 1.
Air Sample Locations—Phase I

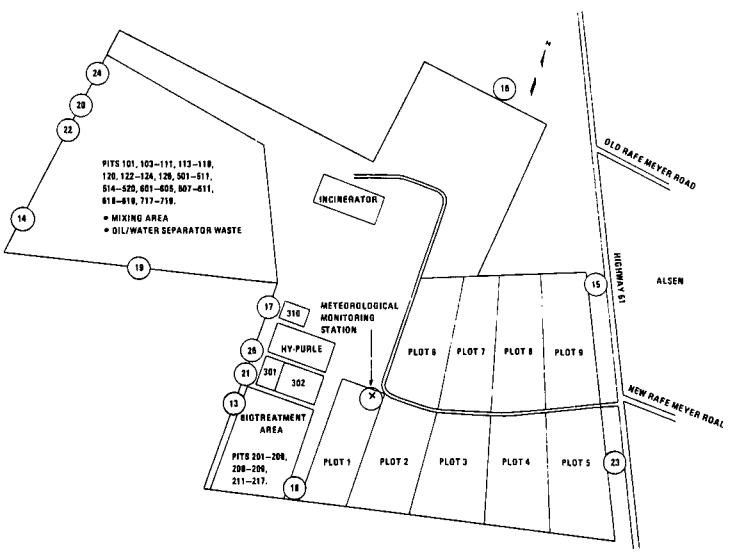

Figure 2.
RES Phase II Air Sampling Locations
(All Sampling Sites Were Within Fenceline, Except 15, 16 and 23)

Blanks were taken for quality control purposes by breaking the seals on the glass adsorption tubes, capping and then handling the same as the samples. No contamination was found during either Phase I or II.

The information associated with each sample including the sampling period, sample volume, site location and other specifications associated with each sample is summarized in Tables I and II. During Phase I, the results of the analyses indicated that the charcoal and Tenax adsorption tubes provides similar results. During Phase II most of the samples were collected on charcoal.

Liquid Samples

Liquid samples were taken at eight holding pits during Phase I to assist in the evaluation of emissions from this facility. GC qualitative analysis of the volatiles from these samples did not indicate any compounds different from those identified or tentatively identified during the air sampling program. For selecting appropriate adsorption tubes and to aid in the selection of calibration standards for field analysis, liquid samples can be a useful preliminary step in an overall evaluation. By performing GC/MS and/or GC analysis on the volatile gases of the liquid samples, an indication of probable airborne pollutants can be made.

Table I.
Sample Log Summary, Phase I

Site	Sample Number	Pump Number	Type of Filter	Flow Volume (liters)	Date	Start Time	Stop Time
1	5	7	Charcoal	51.7	9/25/80	3:40pm	4:27pm
	6	3	Charcoal	1.88			
	7	4	Tenax	98.7			
	8	8	Tenax	11.3			
2	1	2	Charcoal	11.6	9/25/80	3:15pm	4:23pm
	2	5	Charcoal	143.0			
	3	1	Tenax	2.65			
	4	6	Tenax	136.0			
3	13	8	Tenax	14.4	9/25/80	4:47pm	5:47pm
	14	4	Tenax	126.0			
	15	7	Charcoal	66.0			
	16	3	Charcoal	2.40			
4	9	2	Charcoal	9.86	9/25/80	4:42pm	5:40pm
	10	5	Charcoal	122.0			
	11	6	Tenax	116.0			
	12	1	Tenax	2.26			
5	17	1	Charcoal	1.29	9/25/80	6:00pm	6:33pm
	18	6	Charcoal	52.8			
	19	5	Tenax	95.7			
	20	2	Tenax	5.61			
6	21	3	Charcoal	1.36	9/25/80	6:04pm	6:38pm
	22	7	Charcoal	37.4			
	23	4	Tenax	71.4			
	24	8	Tenax	8.16			
7	27	3	Charcoal	2.40	9/26/80	6:34am	7:34am
	28	7*	Charcoal	--			
	29	4	Tenax	126.0			
	30	2	Tenax	10.2			
8	31	8	Tenax	16.8	9/26/80	6:35am	7:45am
	32	6	Tenax	140.0			
	33	5	Charcoal	147.0			
	34	1	Charcoal	2.73			
9	39	3	Tenax	3.28	9/26/80	7:50am	9:12am
	40	2	Charcoal	13.9			
	41	4	Charcoal	114.8			
10	35	1	Charcoal	2.34	9/26/80	8:10am	9:10am
	36	5	Charcoal	126.0			
	37	6	Tenax	120.0			
	38	8	Tenax	14.3			
11	47	2	Tenax	10.5	9/26/80	9:43am	10:45am
	48	4	Tenax	130.0			
	49	7	Charcoal	68.2			
	50	3	Charcoal	2.48			
12	43	8	Tenax	16.3	9/26/80	9:35am	10:43am
	44	6	Tenax	136.0			
	45	5	Charcoal	143.0			
	46	1	Charcoal	2.65			

* Stopped before pickup; battery failure.

Meteorological Monitoring

A portable wind system was set up at the same, well-exposed location for both phases, as shown in Figures 1 and 2. This station was expected to represent general flow for the entire facility except for conditions associated with light winds (e.g., less than two miles per hour.) The terrain is quite flat. The wind vane was oriented by compass readings to the nearest degree, and the reduced data corrected for the 4 degree east magnetic declination.

The height of the wind vane and anemometer was approximately eight feet above ground level which is relatively low for monitoring wind data. Although wind speeds were relatively low and wind flow was somewhat more variable than at the more standard ten meter level, sufficient documentation for general flow was obtained.

Relative humidity values were obtained from wet bulb and dry bulb temperature readings from a sling physchrometer. On the sample log sheets, cloud cover data and weather events were recorded to provide an indication of atmosphere stability and possible interference from precipitation. These data are documented in Tables III and IV.

ANALYSIS

The procedures followed in analyzing the samples in the field (Phase II) and in the Versar analytical laboratory are discussed in the following section. This description pertains specifically to Phase II; however, similar laboratory procedures were used for Phase I.

GC Analysis

GC analysis in the field was performed using an HP 5880 gas chromatograph equipped with a flame ionization detector. GC analysis in the analytical laboratory was performed using an HP 5700 gas chromatograph equipped with a flame ionization detector. GC analytical conditions were as follows:

	Field	Laboratory
Gas Chromatograph	HP 5880	HP 5700
Detector	FID	FID
Column	6.1 m s.s. 10% SP-1000	6.1 m s.s. 10% SP-1000
Carrier Gas	30 ml/min N_2	30 ml/min N_2
Hydrogen	30 ml/min	30 ml/min
Hydrogen	30 ml/min	30 ml/min
Air	350 ml/min	250 ml/min
Oven Temp., initial	100 °C for 8 min	105 °C for 8 min
program rate	4 °C/min	4 °C/min
final	200 °C for 16 min	200 °C for 16 min

Charcoal samples were analyzed using NIOSH Method P+CAM 127 as outlined in the NIOSH *Manual of Analytical Methods*. The use of carbon disulfide as the

Table II.
Sample Log Summary, Phase II*

Sample No.	Pump No.	Start Time (CST)	Stop Time (CST)	Operator	Date	Site Number/ Comments	Sample** Volume (liters)
1	4806	0447	0641	Sullivan	11/12	Site #13	199
2	4815	0436	0629	Sullivan	11/12	Site #14	210
3	5934	0434	0625	Feldman	11/12	Site #15	207
4	4806	0643	0841	Sullivan	11/12	Site #13	206
5	4815	0630	0831	Sullivan	11/12	Site #14	225
6	5934	0637	0830	Feldman	11/12	Site #16	210
7	5949	1410	1618	Koch/Allen	11/12	Site #18	271
8	4816	1426	1609	Sullivan	11/12	Site #19	176
9	5195	1416	1625	Koch/Allen	11/12	Site #21	273
10	5942	1400	1604	Koch/Allen	11/12	Site #16	202
11	5156	1440	1616	Sullivan	11/12	Site #20	188
12	5942	1606	1753	Allen	11/12	Site #16	174
13	5949	1619	1802	Allen	11/12	Site #18	219
14	5195	1627	1806	Allen	11/12	Site #21	211
15	4816	1610	1757	Koch/ Sullivan	11/12	Site #19	183
16	5156	1617	1805	Koch/ Sullivan	11/12	Site #20	211
17	5934	0412	0547	Koch	11/13	Site #20	175
18	5156	0422	0550	Koch	11/13	Site #22	176
19	5949	0356	--	Allen	11/13	Site #16, pump stopped	--
20	5942	0408	0556	Allen	11/13	Site #23	180
21	4816	0611	0734	Allen	11/13	Site #16	146
22	5942	0557	0727	Allen	11/13	Site #23	150
23	4815	0404	0615	Koch	11/13	Site #17	244
30	4816	1741	2132	Sullivan	11/13	Site #20	427
31	5156	1738	2120	Sullivan	11/13	Site #24	469
32	5949	1754	--	Sullivan	11/13	Site #18, pump stopped	--
33	5942	1805	2143	Sullivan	11/13	Site #17	371
34†	4806	1934	2234	Allen	11/13	Site #24	109
35†	5195	1935	2235	Allen	11/13	Site #24	397
36†	4815	1945	2244	Allen	11/13	Site #18	331
37	5156	2121	0015	Koch	11/13	Site #24	367
38	4816	2132	0018	Koch	11/13	Site #20	307
39	5942	2149	0034	Koch	11/13	Site #25	281
40	5934	2218	0000	Allen	11/13	Site #23	195

* Except where indicated as a Tenax sample, all samples were collected on charcoal tubes.
** Corrected to standard temperature and pressure.
† Tenax sample (low flow).

desorption solvent unfortunately precluded its quantification as a possible contaminant.

During Phase II, three compounds were chosen as indicators for ambient onsite analysis. These were benzene, toluene and meta-xylene. Work in Phase I had identified these as compounds of interest to be quantified onsite. All Phase II samples were screened by GC to determine those with the highest concentrations. The three samples with the highest concentrations were selected for GC/MS analysis to qualitatively identify a wide range of pollutants. After GC/MS analysis, GC analysis was then used to quantify the identified pollutants.

Standards were prepared in carbon disulfide for those identified components for which reference materials were available. These were benzene, toluene, ethyl benzene, 1,1,1-tetrochloroethane, methylene chloride, tetrachloroethylene, chloroform and meta-xylene. Ambient air concentrations were calculated from the amount measured in the extract and the volume of air sampled.

Table III.
Meteorological Data, Phase I
September 25-26, 1981

Date	Time (cst)	Wind Speed (mph)	Average Wind Direction (degrees)	Relative Humidity (§)
9/25	1600	4	250 (variable)	——
	1700	4	200 (variable)	66
	1800	5	040	70
9/26	0700	6	050	91
	0900	9	055	88
	1000	8	055	75

GC/MS Analysis

Prior to the qualitative analysis of the air samples collected on Tenax and charcoal tubes, the GC/MS calibration was verified by a direct injection of parabromo-fluorobenzene and the characteristic ions and relative ion abundances were verified. For samples collected on charcoal, a 2-microliter injection of the methanol charcoal tube extract was chromatographed into the mass spectrometer. For samples collected on Tenax, the Tenax tube was thermally desorbed at 180 °C for 4 minutes using Matheson purity helium (99.9999%) to purge the desorbed components onto the GC column. All samples were chromatographed and analyzed using the following GC/MS conditions:

Column	1% SP-1000 on 60/80 Carbopack B 2.44 m x 2 mm ID glass
Oven Temp., initial	45 °C
initial hold	3 min.
program rate	8 °C/min
final	220 °C
Scan Range	34-257 AMU
Ion Source Voltage	70 eV
Scan Rate	2.7 seconds
Electron Multiplier Voltage	2400 V
Run Time	35 minutes

Background-subtracted spectra were obtained for all peaks and compared to in-house reference spectra and spectra obtained from EPA/NIH/MSDC Library Search System. Confirmation of identified compounds was obtained by analysis of standard reference materials under the same conditions as the samples. The standards and samples were matched for retention times and mass spectra.

The following criteria are the minimum requirements that were used for the interpretation of the mass spectra to confirm identification of any pollutant:

- The mass spectra contained all ions present above 10 percent relative abundance in the mass spectrum of the reference with the general agreement of ±20% of the relative abundance in the reference mass spectrum.
- Ions present in the experimental mass spectrum that are not present in the reference spectrum must not exceed 10% of the total ion abundance in the experimental mass spectrum.

Table IV.
RES Onsite Meteorological Data, Phase II

November 12, 1980

Sunny skies in the morning, 3/10 cloud cover, high cloud (thin) becoming 8/10 high cloud cover by sunset.

Time (CST)	Wind Speed (mph)	Average Wind Dir.* (Degrees)	Range** (Degrees)	Relative Humidity (%)
0100	3.5	085	70	---
0200	4.0	075	60	---
0300	5.0	065	40	---
0400	4.5	055	40	---
0500	4.5	055	40	67
0600	5.0	060	50	---
0700	6.5	060	70	---
0800	7.0	045	60	---
0900	7.5	055	55	44
1000	10.0	070	65	---
1100	9.0	065	65	---
1200	9.0	060	75	---
1300	9.0	065	65	---
1400	7.0	050	80	32
1500	6.5	055	85	26
1600	2.5	100	60	41
1700	2.5	095	20	53
1800	2.5	050	75	58
1900	Calm	---		---
2000	Calm	---		---
2100	2.5	035	65	---
2200	3.0	055	55	---
2300	2.5	040	75	---
2400	2.5	040	60	---

* Wind direction was corrected for magnetic declination of 4° East, associated with compass orientation of wind vane. Wind speed and wind direction averages are based on the period 60 minutes preceding the indicated hour.

**The second highest maximum and second lowest minimum were determined and used to estimate the range of the wind direction for the period. This provides a rough indication of the horizontal variability of wind direction which is a function of atmospheric stability.

---Data not available.

November 13 and 14, 1980

9/10 high cloud cover in the morning becoming overcast by afternoon; trace of precipitation occurred between 1900-2000 CST

Time (CST)	Wind Speed (mph)	Average Wind Dir.* (Degrees)	Range** (Degrees)	R.H. (%)
0100	4.5	070	55	---
0200	5.0	065	50	---
0300	5.0	070	50	59
0400	5.5	085	50	---
0500	5.5	075	70	56
0600	5.0	075	55	---
0700	4.5	090	50	---
0800	5.0	055	80	56
0900	7.0	085	70	---
1000	7.5	090	60	---
1100	8.0	080	55	---
1200	8.0	075	75	---
1300	12.5	105	55	---
1400	12.0	110	35	---
1500	12.0	110	70	---
1600	8.0	110	60	---
1700	9.0	105	55	---
1800	9.5	105	40	77
1900	9.0	095	40	---
2000	8.0	095	40	86
2100	9.0	105	50	---
2200	12.5	110	40	82
2300	13.0	110	35	86
2400	10.0	095	40	81

November 14, 1980

0100	7.0	095	50	---

•The retention time of the experimental mass spectrum must be within ±5 scans or ±30 seconds of the reference compound.

Detection limits were 10 mg/l in solution, and all components that did not meet these criteria are considered tentative identification.

Two charcoal tube samples (Nos. 9 and 38) and one Tenax tube sample (No. 35) were analyzed by GC/MS for identification of major organic compounds. The presence of methylene chloride, acetone, carbon disulfide, chloroform, 1,2-dichloroethane, 1,1,1-trichloroethane, benzene, hexane, toluene and ethyl benzene was confirmed by mass spectra in the Tenax sample (No. 35). Other trace components that were tentatively identified by library search were:

2-pentenenitrile
acetone
isopropyl alcohol
tert-butanol
4-penten-2-ol
cyclopentanone, o-methyloxine
hexanedinitrile
ethane, 1,2-dichloro
isopropyl ether
1-pentene, 2-methyl
2-pentenenitrile
hexane
butanoic acid, 3-3 dimethyl
2-butanone

Also, tentatively identified by in-house spectra were tetrachloroethylene and trichlorotrifluoroethane. Due to the desorption procedures used for GC/MS analysis, quantification of these samples (9, 35 and 38) was not feasible by GC or GC/MS.

Table V.
Concentrations of Benzene and Toluene in Air as Calculated from the Charcoal Tube Extracts, Phase I

Site	Field No.	Laboratory Sample Number	Benzene (ppm)	Toluene (ppm)
2	1	6171	0.05	2.3
2	2	6172	0.05	2.4
4	9	6175	0.03	1.4
4	10	6176	0.02	1.0
8	33	6203	0.004	0.02
10	36	6206	0.007	0.05
			TLV = 10	TLV = 200

Table VI.
Phase II GC Results Summary (Concentrations in ppm)*

Sample #	Site #	Benzene	Toluene	Ethyl Benzene	1,1,1 Tri-chloroethane	Methylene Chloride	Tetrachloro-ethylene	Chloro-form	Meta-xylene	Comments
1	13	.006	.006							GC Run Onsite
2	14	.056	.021		.084	.019		.241		GC Run Onsite
3	15	(UPWIND SAMPLE)								No significant peaks
4	13	.003	.001							GC Run Onsite
5	14									No significant peaks GC Run Onsite
6	16	(UPWIND SAMPLE)								No significant peaks GC Run Onsite
7	18									Early peak GC Run Onsite
8	19	.004								GC Run Onsite
10	16	(UPWIND SAMPLE)								No significant peaks
11	20	.089	.240						.011	GC Run Onsite
12										No significant peaks
13	18	.060	.063	.055	.059	.064				
14	21	.012	.034						.020	GC Run Onsite
15	19	.057	.052		.0132	.042	.138			
TLV**		10	200	100	--	100	100	50	--	
16	20	.215	.428						.026	GC Run Onsite
17	20									No significant peaks GC Run Onsite
18	22	.031	.108							GC Run Onsite
20	23	(UPWIND SAMPLE)								No significant peaks
21	16	(UPWIND SAMPLE)								No significant peaks
22	23	(UPWIND SAMPLE)								No significant peaks
23	17									No significant peaks GC Run Onsite
31	24									No significant peaks
33	17	.016	.030	.022	.026	.015	.039			
37	24									No significant peaks GC Run Onsite
39	25									Some small peaks
40	23	(UPWIND SAMPLE)								No significant peaks
TLV**		10	200	100	--	100	100	50	--	

* Blanks indicate that pollutant concentrations are below detection limits.
** Threshold limit value.

RESULTS AND CONCLUSIONS

The quantitative data obtained during the Phase I and II programs, are summarized in Tables V and VI, respectively. For each compound, threshold limit values (TLVs) are provided only to indicate a point of comparison. However, since TLVs are associated with an eight-hour average applicable to the workplace, they are not suitable for exposure assessments of the general population. Although the observed concentrations for which TLVs were in place were substantially below these values, it is beyond the scope of this paper to make any evaluation regarding health effects associated with exposure of the general public to these concentrations.

For both the Phase I and Phase II air sampling programs at Rollins Environmental Services, many organic compounds were identified by GC and GC/MS analyses. Samples upwind of RES did not indicate significant con-

centrations of organic pollutants and odors were generally not noticeable at the upwind sampling sites. Benzene and toluene were usually found in the highest concentrations in the downwind samples. During Phase I, the highest values for benzene and toluene were found to be 0.05 ppm and 2.4 ppm, respectively. Phase II sampling indicated a maximum of 0.2 ppm for benzene and 0.4 ppm for toluene. A number of organic compounds were present, but in concentrations not high enough to allow for positive identification. For example, pentenenitrile which could possible be toxic at relatively low levels, was tentatively identified.

To perform a more detailed identification and quantification of the pollutants emitted from this facility, a longer-term program would be necessary. A sampling program during the summer quarter, when the highest emission of volatile organics could be expected, may result in detection of substantially greater pollutant concentrations. Caution must be exercised in drawing conclusions from a short-term program such as performed during Phases I and II of the study. Although in Phase II, conditions were such that relatively high concentrations would be expected (i.e., sampling was performed from three to six a.m. with fairly light winds and clear skies), a short-term sampling program would not be expected to contain values near the annual maximums. The variability of waste being treated and disposed of is a factor that makes a long-term program more meaningful.

The RES incinerator was not operational during either Phase I or Phase II of the Versar sampling program. This could explain some differences between these results and those of a previously performed short-term program. Although that program produced results that were generally of the same order of magnitude as our study for benzene and toluene,[3] one sample from the previous program indicated a fenceline concentration of 6.1 ppm for benzene, which is substantially higher than any concentrations measured during our program. In addition, the qualitative identifications of other compounds were different from those observed during this study.

Although short-term sampling programs have limitations, the results provide an indication of ambient concentrations to evaluate the need to collect a more long-term data base or to take enforcement action. To complete the evaluation, a health effects review of the data obtained from the sampling programs would be necessary. This will be performed by the Environmental Protection Agency (Region VI). At the time of this writing, the health effects review had not been completed.

GENERAL RECOMMENDATIONS FOR RELATED PROGRAMS

(1) Perform analysis of volatiles from liquid samples, if possible.
(2) Choose adsorption medium on the basis of pollutants anticipated to be present.[4,5,6]
(3) Use screening techniques to choose areas of maximum expected concentrations, such as portable Gas Chromatography equipment with a flame ionization detector to measure total hydrocarbons, obtaining grab samples in collection bulbs in conjunction with an onsite Gas Chromotrograph, etc.
(4) Sample collection periods should be chosen to ensure that a sufficient quantity of sample is obtained to allow for identification and quantification, but not so large that saturation of the absorption medium occurs and breakthrough problems result or that the collection efficiency is significantly reduced by high flow rates.[4,5]
(5) Calibration of portable pumps used to draw the samples should be performed at least on a daily basis.
(6) Proper handling, such as refrigeration of samples, chain-of-custody documentation, etc., are essential to ensure defensibility of the data collected.
(7) The use of an onsite wind system is highly recommended in lieu of the use of offsite data sources. Upwind and downwind samples should always be taken concurrently with properly documented wind data. Cloud cover and weather events should also be documented.
(8) The field log should include an indication of site activities associated with the sampling periods (e.g., incinerator operation, unloading of waste, truck traffic, landfarm activity, etc.)
(9) If possible, sampling periods should include those associated with maximum anticipated emission terms and poor dispersion conditions, e.g., high activity periods, maximum ambient temperature, poor dispersion conditions, wind flow toward sensitive receptors.

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INFLUENCE OF SAMPLING TECHNIQUES ON ORGANIC WATER QUALITY ANALYSES

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INTRODUCTION

In the past, the role of a groundwater geologist was generally confined to the development of techniques to obtain or remove sufficient quantities of water to satisfy the objectives of a particular project. However, the recent inclusion of approximately 113 organic compounds on the priority pollutant lists has opened a new concern for groundwater geologists. This concern directly relates to the problem of obtaining a sample of groundwater that one can be confident is truly representative of the subsurface fluids. The need to supplement the existing knowledge currently available pertaining to the fate and movement of organic constituents in the subsurface has been documented by several authors.[1,2]

The presence of many trace organics in a groundwater supply system even in very low concentrations may create near-term or long-term health hazards. The complexity of these chemicals has further confused attempts at understanding the fate of most trace organics once they enter the subsurface. Many times compounds not produced or known in a facility's waste stream have been identified in samples of groundwater collected from a particular facility.

Because of the potential acute hazards posed by many of the trace organic compounds (even in the µg/l range), the techniques for obtaining and storing of groundwater samples containing these compounds may differ substantially from classical field sampling techniques. Even with the vast amount of research currently underway with respect to sampling of organics, the state-of-the-art for obtaining samples still lags far behind that of the analytical laboratory techniques.

Because the advanced laboratory techniques are so costly and labor consuming, the necessity for accurate, cost effective sampling techniques becomes more apparent. The money and time involved in analyzing a suite of samples for trace organics can be completely wasted if the samples were incorrectly samples or improperly stored.

AREAS OF SPECIFIC ORGANIC CONTAMINANTS

During a series of recent groundwater investigations, Dames & Moore has attempted to identify potential problem areas in order to improve the efficiency of obtaining and storing samples. Five major areas of concern were identified whereby specific contaminants may be allowed to either enter the groundwater or contaminate the samples before analyses can be instituted. The areas of concern addressed include the following:

- The drilling operations
- Piezometer or well construction materials
- Sampling equipment
- Sampling methods
- Sample preservation

Each of these areas of concern are addressed in more detail in the following sections of this paper.

Drilling

Generally the drilling of a well is required to obtain groundwater samples for analyses. A well should be installed wherever possible to minimize the potential for organic contamination. However, this one operation, which may in fact be the most costly part of a groundwater study, has the potential to introduce the greatest error! Additionally, if error is considered, then it can be very costly from an economical and labor standpoint to redrill a new well. During a drilling operation several operations may lead, directly or indirectly, to the existence of contaminants within the groundwater.

Where depths in excess of about 50 to 75 ft are necesary to drill, rotary drilling or percussion drilling techniques are normally employed. Rotary drilling is generally favored over percussion drilling because it is much faster. However, circulation of drilling fluids or muds during rotary drilling may significantly alter the chemical, mircobiological or hydrogeological makeup of the well walls or some depth into the formation.

The drilling equipment itself may present a source of contamination. Safeguards, such as steam cleaning of the drill rig and equipment, may not be sufficient when investigating trace organics and buying all new equipment for each hole is ludricous. Although hydrologists insist upon all downhole equipment being steam cleaned between each boring when drilling in a hazardous or potentially hazardous site, the potential exists for some areas of the drilling equipment to be missed during any reasonable steam cleaning operation.

For this reason, investigators generally attempt to drill in the upgradient zone first and progress toward the areas which are assumed to contain the greatest potential for

contamination. Additionally, it is a very rare occurrence that a drill rig utilizing hydraulic systems does not leak considerable quantities of hydraulic fluids onto the ground or into the well bore.

When a drilling program is designed to drill through a contaminated zone into a lower, possibly less contaminated zone, interaquifer communication may create an avenue of contaminant transfer. In this case extreme caution and careful placement of intermediate casings will be required. It is for this reason that for all investigations on hazardous wastes sites, the authors feel, the additional expense of maintaining an experienced contaminant hydrogeologist on the rig at all times is warranted.

Another common source of well contamination occurs as a result of surface contamination. Wells that are not completed or sealed sufficiently may allow surface water to be transported down along the casing material to the sampling point. Even good development techniques which may be sufficient to remove all traces of inorganic contaminant may not be sufficient to eliminate the existence of trace organics.

Many authors have discussed the merits and problems associated with the various drilling techniques and as such will not be examined here. Although certain techniques may be favored by field personnel, no technique can be exempt from being a contaminant source. Consequently, it is imperative that a detailed log be maintained at all times during the drilling operations. The drilling log should note all unusual factors that may ultimately lead to inconsistent results.

Piezometer or Well Construction Materials

Discussions by Pettyjohn, *et al.*[1] have compared the merits of preferred well construction material versus the cost of construction versus the quality of data. However, notwithstanding the arguments regarding preferred materials, contaminants may also be introduced into wells during the installation of the piezometer or casing materials.

A common practice during installation of a well is to layout the well materials along the ground and either install it en masse or in discreet sections. This generally results in a considerable quantity of surface material being installed into the borehole along with the piezometer material. The authors have observed several cases in the field where chemically inert well materials and thermally welded joints were utilized in an attempt to limit the introduction of contaminants. However, before installing these materials they were stored along the drill rig prior to installation. This combined with the use of sand filter packs from local quarries can result in very confusing results being obtained from samples collected in these "so called" monitoring wells.

The preferred well materials were described by Pettyjohn, *et al.* as being, in order of acceptance:

- Glass
- Teflon
- Stainless steel
- Polypropylene
- Other plastics and metal
- Rubber

This list of preferred materials must also be considered from a cost benefit point of view. Each particular site must be examined as to what level of risk may be introduced when one utilizes a more reactive material for well construction. This is particularly significant for a consultant who must justify to his client the additional costs involved in utilizing a more inert material, such as glass or teflon.

It is essential to evaluate each material type against the possible effect on the trace organics being evaluated. In any case where a more reactive material is utilized in well construction, one well of the same construction material should be placed outside the contaminated zone to provide background data on the input of trace organics from the uncontaminated aquifer and the influence of the well material. Moreover, the well drilling and well construction methods for the background well should be comparable to that used to install the monitoring well.

During the production of steel casing, considerable quantities of oils and solvents are necessary at various stages. If trace amounts of these materials remain adhered to the casing during installation, contaminants may be introduced either directly or indirectly. Besides the obvious case of oil from the casing getting in the sample, an oil-coated pipe may prevent the complete sealing of the aquifer from either the influence of surface contaminants or intercommunication with another aquifer.

Sampling Equipment

The materials used to construct organic sampling equipment also must be considered. Where possible, rela-

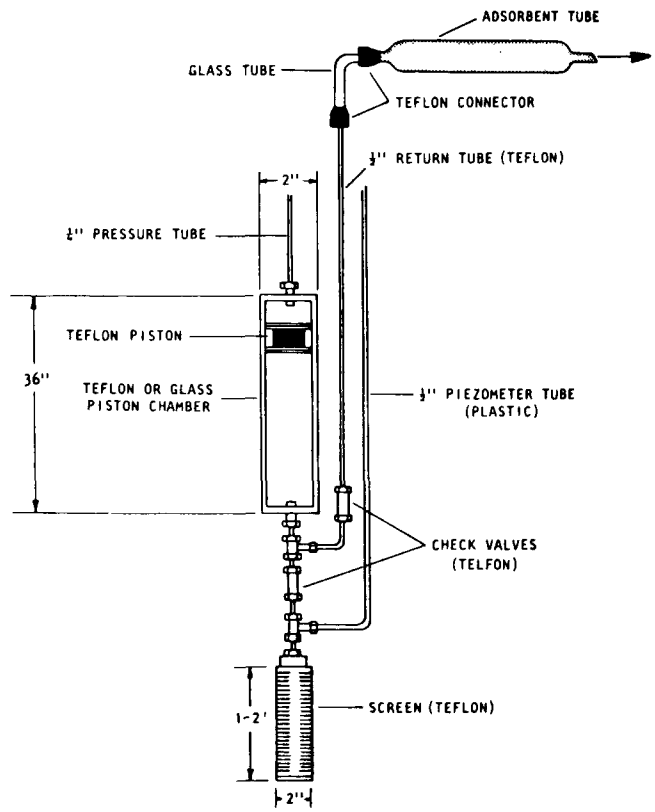

Figure 1.
Dames & Moore Positive Displacement Pump for Volatile Organics

tively inert materials are recommended to limit the possibilities of bleeding organics into the sample or adsorbing organic solutes. The preferred materials are similar to those outlined above for piezometer materials. Pump and sampling devices that allow groundwater to contact metal, rubber or lubricants should not be considered when sampling for organics.

Some sampling equipment, by virtue of its design, may create problems with respect to interwell contamination. Bailers, for example, especially those with triggering devices, are extremely difficult to ensure that they are completely cleaned after each well has been sampled. Further, for many clients it cannot be considered cost effective to dedicate separate samplers for each well.

The uses of adsorbing tubes and positive displacement (in-hole pumps) can greatly improve the efficiency of the sampling equipment. Pettyjohn, *et al.*[1] and others have investigated the use of various adsorbing materials for the extraction of nonpurgeable organics from groundwaters. Dames & Moore is currently investigating the use of adsorbing columns on the return tube of a positive displacement type pump (Figure 1). The authors feel this would essentially eliminate the contamination of groundwater samples that are subjected to various sampling devices and storage jars before arriving at the laboratory for analysis. Additionally, the sample would remain under a positive pressure until being adsorbed. This positive displacement pump will be described in more detail elsewhere in this paper.

Sampling Technique

Water sampling techniques should be designed to meet the primary objective of a sampling program: to obtain a representative sample of the fluid flowing in the aquifer. (That is, obtain a sample retaining the physical and chemical properties of the aquifer fluid.) Preservation methods and *in situ* tests will aid in measuring these properties but are meaningless if the sample of well water is not representative of the actual aquifer.

Water which has stagnated in the well bore has had ample opportunity to change physical and chemical properties such as temperature, pH, dissolved oxygen, total dissolved solids, etc.[3] Volatile organic contaminants and dissolved gasses may have either volatilized or effervesced in the well bore. Stratification of the water according to temperature and specific gravity may lead to different results being obtained from samples collected at different depths, none of which may necessarily be representative of the aquifer.

Consequently, prior to taking a sample, it is necessary to evacuate the well of the stored water in order to allow aquifer water to flow into the well. The EPA recommends evacuating at least two exchanges of water prior to sampling.[4]

The well storage water may be removed by bailing, pumping from the surface, air lift pumping, or by pumping with a submersible pump. However, when pumping, care must be taken not to overpump the well and allow excessive fines to be drawn into the well. This results in increased turbidity and possible damage to the gravel pack.

Care must also be taken in the selection of the pumping method and materials. This selection may be dependent upon the parameters to be measured and on the fluid composition.

Bailers that resemble long, narrow buckets are available, or they may be more sophisticated and allow a sample to be collected from a specific depth. For small wells with low yield, evacuation by bailing is a feasible method of obtaining aquifer water. Bailing, however, becomes labor and time intensive for larger, deeper wells with large volumes of storage. In such cases, some sort of pumping arrangement is more economical with the bailer only utilized in obtaining a sample.

A sample which is obtained by bailer is exposed to the atmosphere during transfer to a sampling jar. This may destroy the test credibility for volatile contaminants and dissolved gasses. Additionally, the sample is exposed to descending pressures as it approaches the surface.

Operation on the more sophisticated bailers becomes difficult in freezing weather as the petlocks and check valves freeze and often samples are lost. Bailers also introduce a certain amount of dissolved oxygen which, in turn, may affect parameters sensitive to dissolved gas composition such as pH, alkalinity and redox-dependent trace metals.

Pumps used for well evacuation include suction lift, airlift and submersibles. When using any type of pump, a foot valve or check valve is required to prevent contamination of the well water by water which has been in contact with the suction hoses or the pump itself.

The suction lift pumps are limited as to the depth from which they may pump (approximately 24 ft). When the water level in the well is drawn down beyond the limit of the pump, confidence that a complete exchange of water has taken place is reduced.

Submersible pumps, on the other hand, are not limited as to the depth of the water level from which they can pump, as are the suction lift pumps. However, the use of submersible pumps involves the installation and withdrawal of the pump from each well during each sampling episode, assuming that cost efficiency dictates that the same pump be used for several wells.

In the case where the pump is used for multiple wells, there may be contamination from surface soils which adhered to the hose during handling. Withdrawal of a pump with a check valve installed becomes laborious, especially for deep settings and requires the use of additional supporting equipment and extra labor. Additionally, submersible pumps require the use of an outside power source requiring additional bulk to be transported during each sampling period.

Air lift pumping is a relatively old method that is gaining increasing attention. This method involves forcing air down a tube inside a casing with a resulting air-water mixture rising up in the annulus.[5] Depending upon the applications, this method is an ideal way to evacuate a well in a very cost efficient timely manner. Equipment is readily obtainable and relatively inexpensive. However, testing by Dames & Moore has indicated that this method generally results in increased dissolved oxygen (D.O.)

values which in many cases have taken several days to return to prepumping levels. Additionally, gas stripping and pH changes may also occur.

Other pumping techniques may also alter the chemical properties of the water through the introduction of dissolved gasses. Suction lift pumps subject the water to negative pressures which will affect concentrations of dissolved gasses. The water may also be contaminated through contact with the pump and the hose.

An experiment was designed and performed by Dames & Moore to evaluate the cross contamination potential by using the same submersible pump for several wells. The experiment and its findings are discussed in a later section.

A positive displacement pump of the type discussed later in this paper has the advantage of being suited for sampling both volatile contaminants and dissolved gasses. The sample is maintained under a positive pressure and is kept from the atmosphere until it reaches the surface. The discharge tube may be connected to a syringe or an adsorbtion column as in Figure 1 to obtain a sample without atmospheric exposure.

The positive displacement pump has the added advantage that it may be installed at various levels within the same borehole, sampling from a small screened section below the pump. The other sampling techniques discussed above are not three-dimensional, that is, it cannot be determined from what level the contaminants are entering the well bore. By installing several positive displacement pumps in a single borehole, the third dimension of contaminant plume can be measured. In Table I, adapted from Barker[2] a comparison of several methods currently employed for the sampling of organic compounds is made.

Sample Preservation

Once the problem of how to obtain a sample has been solved, the next dilemma involves what to do with the sample. Normally the samples are submitted to the analytical laboratory in prerinsed amber glass bottles with teflon lined lids. For many of the organics holding times are critical and unless the laboratory receives the samples within the allotted time frame, the quality of the resultant analyses may be open to scrutiny.

Table I.
Characteristics and Evaluation of Various Methods Used to Sample Groundwaters for Organic Contaminants [Adapted from Barker 1981]

Method	Materials	Contamination Problems	Depth Limit (ft.)	Min. Piez. Dia.(in.)	Air Contact	Degassing-Loss of Volatiles
bailer[1]	T, M	Min		1	Y	minor
high-lift[2] pump	T, G	Min	-	2	N	minor
special piston pump[3]	M, R, T	Min-Sli	-	2.5	N	minor
air squeeze[4]	M, R, T	Sli-Max		1.5	N	minor
air-lift pump[5]	T, M	Min		1.25	Y	major
piston pump	M, R, T	Sli-Max	-	2	Y(?)	minor
jet pump	M, R, T	Sli-Max	-	1.5	N	minor
submersible pump	M, R, T	Max		4	N	minor
suction pump[6] and flask	T, G	Min.	25	0.25	N	major
peristaltic pump	T, P	Min-Sli	25	0.25	N	major
positive displacement pump	P, T	Sli		1.5	N	minor

Materials:
T - teflon
M - metal
G - glass
P - plastic
R - rubber

Materials—T-teflon, M-metal; G-glass; P-plastic; R-rubber.

1 teflon extruded tubing with teflon rod end; glass marble check valve.

2 all glass-teflon, 2-stage pump driven by high purity N_2; Tomson et al., 1980, Groundwater, *18*, pp 444-446.

3 metal with rubber O-ring seals, positive displacement pump driven by compressed gas; Signor (1980); similar to Bennett pump

4 rubber and metal positive displacement pump driven by compressed gas; Middelburg pump (Tole Devices Co Ltd., P.O. Box 456, New Albany, Ind.)

5 polyethylene or teflon tubing and metal air lift pump; such as Johnson Water Sampler (Johnson Div., P.O. Box 3118, St. Paul, Minn.).

6 pump placed behind flask so that water contacts only tubing and glass; hand vacuum pump or peristaltic pump can be used.

Basic holding times and recommended sample volumes were published in the *Federal Register*[6] and are reproduced here at Table II.

During the holding period for the samples, losses or alterations of organics may result from any of a number of causes including:

- •Adsorption onto glass jar walls or particulate matter
- •Precipitation or co-precipitation
- •Biological transformations
- •Chemical reactions (oxidation)

Generally, filtering of samples prior to analysis is not recommended. Precipitates that may have formed during the holding period must be processed along with the water during analyses. This limits the possiblility of some contaminant being adsorbed onto particulate matter and being lost during the filtration. Consequently, very careful piezometer construction and development prior to any sampling is necessary to reduce the concentrations of particulate matter that enters a well.

EXPERIMENT ON PUMP CROSS-CONTAMINATION

An experiment was designed by Dames & Moore personnel specifically to identify and solve the problem associated with cross-contamination resulting from the use of the same submersible pump in several wells. The tests were made on a site with known PCB contamination. PCB's are a compound with known affinity for plastics. Two pumps were used in the experiment, the first a 0.5 hp submersible pump with plastic impellers, the second was an all stainless steel 0.75 hp submersible pump with stainless steel impellers. Both pumps utilized the same collapsible plastic hose for discharge.

Table II.[6]
Sample Volumes, Preservation and Holding Times for Organic Priority Pollutants (from *Federal Register*, December 18, 1979)

Measurement	Sample Volume (ml)	Preservative @ 4°C	Max. Holding Time, Before Analyses or Extraction (days)
BOD	1000	cool	2
COD	50	cool, H_2SO_4 to pH < 2	28
chlorinated organic compounds		cool, 0.008% $Na_2S_2O_3$	7
organic carbon	25 to 500	cool, h_2SO_4 to pH < 2	28
extractables (except phenols)	1000	cool, 0.008% $Na_2S_2O_3$	7
extractables (phenols)	5000	cool, H_2SO_4 to pH < 2; 0.008% $N_2S_2O_3$	7
purgeables (halocarbons and aromatics)	20 to 500	cool, 0.008% $Na_2S_2O_3$	14
purgeables (acrolim and acrylonitrite)	20 to 800	cool, 0.008% $Na_2S_2O_3$	3
pesticides	1000	cool, 0.008% $Na_2S_2O_3$	7

a—should only be added in the presence of residual chlorine

The purpose of the experiment was to estimate the amount, if any, of potential cross-contamination between wells which occurs by utilizing the same pump in the sampling procedures. The contribution of the plastic hose was also to be estimated. Both pumps were used in the experiment to determine the advantages of using all stainless steel parts, as opposed to plastic.

The pumps were used to evacuate a 120 ft deep well known to be contaminated with PCBs. The pumps were then placed in a 55 gal drum of potable water. Samples of the potable water were obtained to develop background levels from the drum prior to placement of the pump. The hose was connected and the discharge directed to recirculate water within the drum. The pump was then run for 1/2 hour, recirculating the potable water. The water from the drum was subsequently sampled.

In order to isolate the contamination from the pump, the above procedure was repeated, but without the hose being connected to the pump in the drum. The first slug of water discharged from the pump was subsequently sampled. The hose was again connected, and the first slug of water through the hose was then sampled. Once the experiment was completed for both pumps, the samples were transmitted immediately to a laboratory for analysis.

The results of the analyses are shown in Figure 2. A significant amount of contamination was measured in the test recirculating water using the plastic impeller pump (approximately 11.4 µg/l). The samples isolated from this pump showed approximately 3 µg/l came from the pump, and a similar amount from the hose. The stainless steel pump produced insignificant levels considering the background levels of the "potable" water. When the hose was connected, however, a marked contamination was noted, approximately 3 µg/l. From this very limited experiment, the authors have concluded that the plastic impellers appear to have an affinity for PCBs and may be responsible for a small amount of cross-contamination. Additionally, a plastic discharge hose, although very convenient to use, does contribute to cross-contamination. Therefore, where multiple wells must be sampled, the choice of pump and hose materials can be significant for low concentration contaminants.

DISPLACEMENT PUMP DEVELOPMENT

To limit the problems outlined in the above sections, the authors believe that a monitoring program allowing an individual positive displace pump to be installed into each well is truly needed when dealing with the problems of trace organics. Such a positive displacement pump is currently being developed by Dames & Moore and is shown in Figure 3.

This pump consists of a 1.75 in diameter tube with an inside piston. Connected to the piston chamber is a short section of well screen. A check valve between the well screen and the piston chamber allows one way flow into the chamber. When pressure is applied to the piston via

a 0.25 in tube at the top of the chamber, the check valve closes and the fluid in the chamber is forced through a second valve out a 0.5 in discharge tube. The present design will enable one liter of fluid to be pumped per stroke of the piston.

A third tube is connected to the 0.5 in tube between the screen and the piston chamber just below the check valve. This permits monitoring of the hydrostatic pressure within the screen.

The pump is suited for installation in various materials, by attaching different well screen sections. By placing a filter pack around the screen, problems from silt migration may be reduced, if not eliminated.

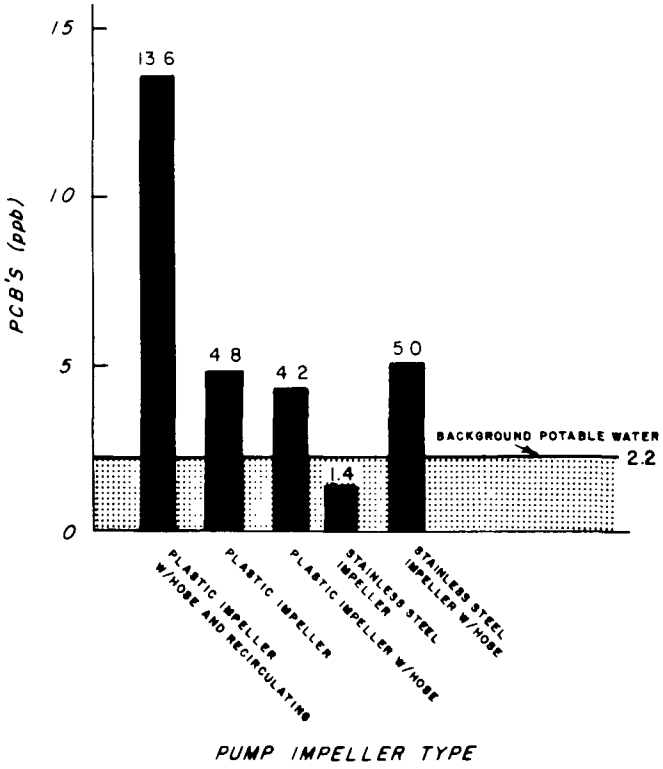

Figure 2.
Cross Contamination Test Results for the Plastic Impeller Pump and the Stainless Steel Impeller Pump

The pump may be constructed of teflon or plastic, dependent upon proposed operations. All pressure connections are made with swaglok fittings, available in teflon.

CONCLUSIONS

This paper was prepared to assist the reader in understanding the complexities involved in sampling groundwater for organic contaminants. Without careful attention to all phases of a sampling program, the results of the sampling program are worthless. This may result in a client performing much additional investigative drilling and sampling to answer questions that may have resulted from erroneous procedures.

Additionally, in many areas low levels of trace organics may remain undetected because of poor sampling

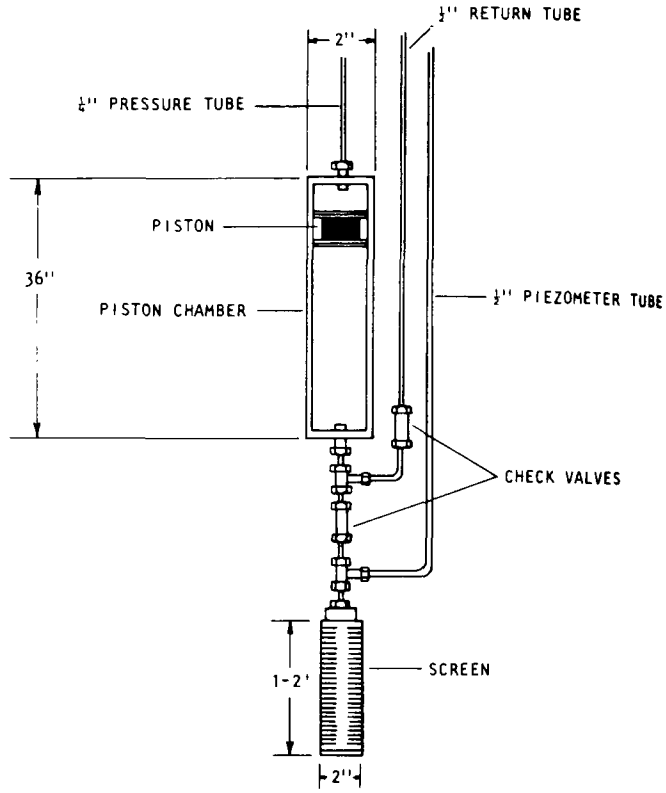

Figure 3.
Dames & Moore Positive Displacement Pump

programs. If allowed to remain undetected, these low levels of trace organics may create a serious health hazard in the long term or at least result in a much more costly investigative program.

Although rapid developments are currently taking place in the field of organic sampling, these are currently only in developmental stages and as such, modifications and improvements are constantly being made. Consequently, proven standard cost effective techniques for sampling organics still lags far behind the analytical laboratory techniques.

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SPECIAL SAMPLING TECHNIQUES USED FOR INVESTIGATING UNCONTROLLED HAZARDOUS WASTE SITES IN CALIFORNIA

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INTRODUCTION

The primary purpose of this paper is to briefly discuss some special sampling techniques used to characterize the nature and extent of contamination at selected uncontrolled hazardous waste sites in California. These include techniques for sampling soil, waste, groundwater and gases. The methods are discussed as they were applied to specific sampling problems at four sites: (1) Occidental Chemical Company, Lathrop, Ca., (2) McColl Site, Fullerton, Ca., (3) Mola Development Site, Huntington Beach, Ca. and (4) General Electric Company, Oakland, Ca.

The techniques for soil and waste sampling discussed are: (1) Hollow-stem augering with drive sampling, (2) Rotary drilling with drive sampling, (3) Bucket augering and (4) Trenching. The two techniques for groundwater sampling discussed are: (1) Single completion wells with submersible pump sampling and (2) Multiple cased wells. Installation of gas collection wells is covered under gas sampling. Most of the information presented herein is derived from the files of the California Department of Health Services.

SITE DESCRIPTIONS

Occidental Chemical Company, Lathrop, Ca.

The facility is located in the Central Valley of California approximately 50 miles south of Sacramento, the State capitol. It is built on the flood plain of the San Joaquin River with useable groundwater from 20 feet down to 300 ± feet. It is a fertilizer manufacturing and pesticide formulating plant handling a wide variety of organohalogen, organophosphate and carbamate type pest control agents. For a period of 10-15 years, the nemnatocide DBCP, (1, 1-dibromo-2-chloro-propane), were also manufactured there.

Wastes from fertilizer manufacturing consisted largely of a gypsum slurry which was ponded until just recently. Wastes from the pesticide formulating and manufacturing activities consisted of equipment washes, unrecoverable bad batches, run-off, raw material containers and returned obsolete off-specification consumer products. Until the mid-1970s, all the liquid wastes were discharged to an unlined ditch and pond.

In the 1950s and 1960s, the solid wastes were either burned in open pits or buried in trenches. These trenches were not apparent from observation of the ground surface at the start of investigations. These practices resulted in gross contamination of surface and near surface soils, and of the ground water to depths greater than 200 ft.

McColl Site, Fullerton, CA.

This site is located in Southern California about 17 miles southeast of downtown Los Angeles. It is a seven acre site bounded on three sides by homes and on the fourth by a golf course. It consists of six sumps covering about four acres containing an estimated 50,000 yd^3 of acid petroleum tars.

The wastes were generated by the local petroleum refineries during the 1940's from high octane fuel production. The material is a black tarry substance with a firm crust that softens upon warming by the sun. On very hot days, the waste flows and up-wells. It contains large quantities of sulfur dioxide, benzene and other hydrocarbons, tetrahydrothiophenes and arsenic. It is highly acidic (pH of the slurry is less than one). When the crust is broken, large quantities of sulfur dioxide and other extremely odorous compounds are released.

Mola Development Site, Huntington Beach, Ca.

This site is located along the Southern California coast 25 miles southeast of downtown Los Angeles on a plateau overlooking a wildlife preserve. It is bounded on four sides by homes and apartment houses.

It was originally a stream bed used as a sand quarry. Subsequently, it was used as a disposal site for acid petroleum tars and other petroleum wastes during the 1940s. Thereafter, it was operated as a permitted site for drilling muds and building demolition wastes. It was estimated to contain approximately 100,000 yd^3 of petroleum wastes and 200,000 yd^3 of drilling muds and building demolition wastes.

The petroleum waste characteristics are very similar to those of the McColl Site wastes, but somewhat diluted by water. Similar types of gases were being generated by the wastes along with significant quantities of methane and carbon dioxide. The rate of gas generation was slower although the gases were no less odorous. The absorptive

capacity of loosely compacted building demolition wastes and the pooling of water on the layers of drilling mud caused the tarry petroleum material to up-well in pools on the surface. The up-welled material became more flowable on warming.

General Electric Company, Oakland, CA.

This facility is located in Northern California, near downtown Oakland. It is bounded on one side by homes and on another by a food processing firm that draws water from 150-200 foot depth. The water table aquifer is at 10-20 ft. The facility was a transformer repair shop that handled PCB (polychlorinated biphenyl) and other types of transformer oils in bulk quantities.

Spills and leaks of PCB's and other transformer oils resulted in significant soil contamination and a layer of PCB containing oil up to 6 inches thick floating on the water table.

SOIL AND WASTE SAMPLING TECHNIQUES

Hollow-stem Augering With Drive Sampling

This technique (Figure 1) employs a continuous flight hollow-stem auger to bore to the desired depth in the soil or waste. The sample is then obtained using various types of drive sampling devices. The auger is usually plugged during drilling and the plug is removed to advance the sampler ahead of the auger.

The unlined ditch and ponds at Occidental were sampled at surface, 2, 5, and 10 ft depths using this technique. The hollow-stem auger not only provided support for the bore holes but also controlled sloughing of the more highly contaminated soils into depths of less contamination. A split-barrel sampling device was selected for obtaining samples because it allowed the taking of a relatively undisturbed core, the physical inspection of the sample, and efficient transfer of the sample for splitting and containerization. The top 1-2 in. were generally discarded as a further step to control the effects of sloughing.

The sampler was thoroughly cleaned with scap, water and acetone between each use. Sampler decontamination procedures generally depends on the type of waste and the contaminants of concern. In this case, since contamination of soils with organics and heavy metals was anticipated, both an aqueous and organic decontamination solutions were used.

Rotary Drilling with Drive Sampling

This technique (Figure 2) is different from the previous one only in the drilling method. The desired depth is reached by boring with a rotary drilling rig using some type of fluid to circulate the cuttings and support the bore holes. The sampler is advanced ahead of the drill bit.

This system was used to obtain discrete core samples from the McColl Site petroleum waste sumps. A "dry" drilling technique (augering or compressed air rotary) could not be used because of the large quantities of sulfur dioxide and other noxious gases released by breaking the crust and maintaining an open hole. The prevailing winds carried these gases directly into the adjoining homes. Water was found to be an adequate fluid for controlling these emissions.

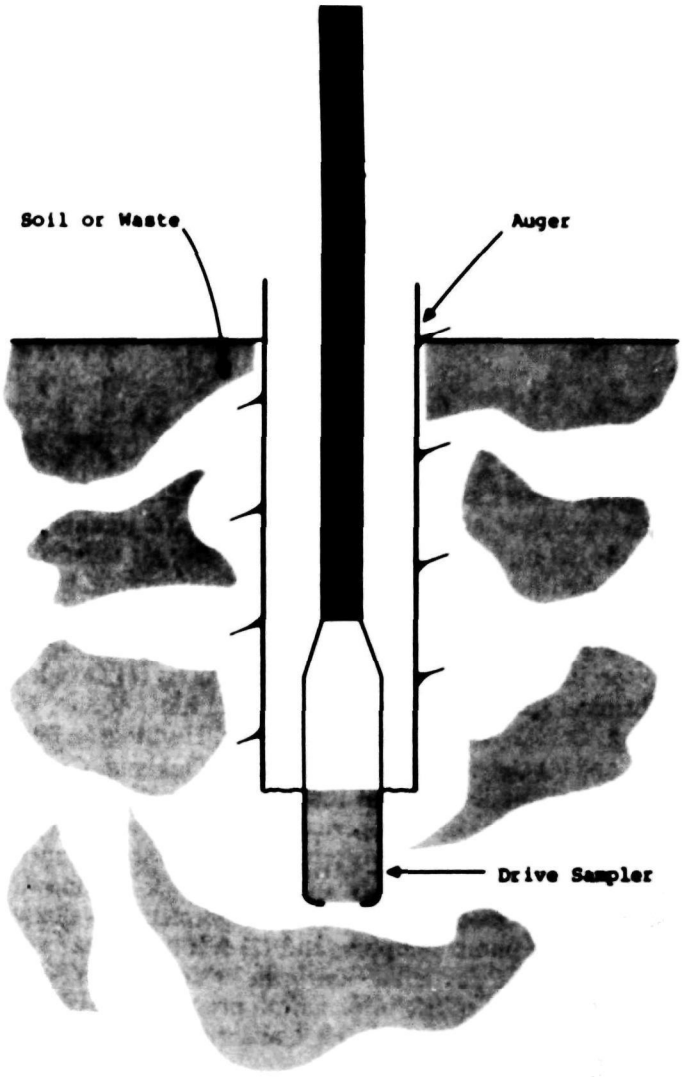

Figure 1.
Hollow Stem Auger with Drive Sampler.

Because of the flowable nature of the wastes, a light weight trailer mounted rig with large surface supports was necessary. The cleanliness of the split barrel sampler could not be maintained because of the use of the drilling fluid. The drilling fluid may also have penetrated the undisturbed waste material around the bore holes. These effects were controlled to a certain extent by discarding the top 1-2 in. of the sample. Any significant moisture in the sample was noted. The petroleum waste material was found to be relatively impermeable under the circumstances of the sampling.

Bucket Auger Drilling and Sampling

A bucket auger (Figure 3) is a cylindrical (12-18 in. diameter) bucket with a swing-open bottom. A set of

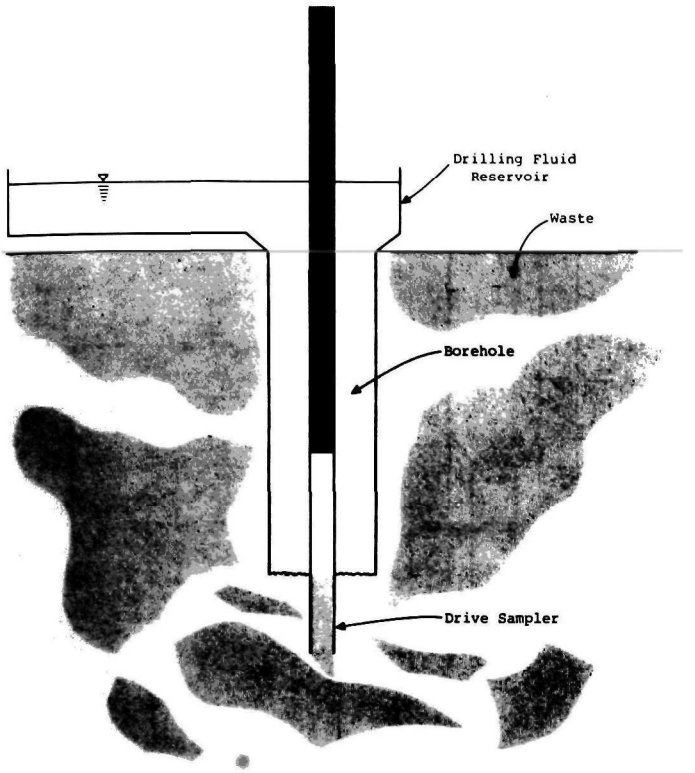

Figure 2.
Rotary Drilling with Drive Sampling.

Figure 3.
Bucket Auger.

angled teeth is fixed to the bottom for augering into the soil. The teeth guide the sample into the bucket as the bucket is rotated by a turntable. Depending on the length of the bucket, samples can be collected at 1 to 2 ft intervals. Once a sample is obtained, the bucket is withdrawn from the bore hole, swung out to the side and the sample is released onto the ground surface by opening the bottom. The large sample size generally allows taking several subsamples from each depth.

This technique was used at the Mola Development site with the primary objective of obtaining samples of the waste material deposited below the building demolition wastes and drilling muds. From previous drilling experience at the site, it was determined that other techniques were not adequate for penetrating the stubborn overburden and obtaining samples of the waste. With much effort, it was possible to remove the concrete rubble overburden and obtain depth specific samples of the solidified petroleum waste material.

In some cases, the waste was in a semi-solid or slurry form and it was not possible to obtain representative depth specific samples. A composite sample was taken of these borings and the bottom of the waste was roughly determined by the sandy stream bottom.

No attempt was made at decontaminating the auger between samples because of the time involved and the large sample size. Sloughing of the walls of the bore hole could not be adequately controlled. The rate of gas generation was significantly lower, here than at the McColl Site and the prevailing winds provided higher dilution such that gas control measures were not necessary during sampling.

Trenching

Trenching for purposes of locating and sampling buried hazardous waste materials usually entails the use of an extendable back-hoe with a fully enclosed operator compartment (Figure 4). The unknown nature of the buried material requires strict attention to the health and safety of the sampling personnel. It is critical that as much information as possible on the location and possible nature of the buried material be gathered before trenching is begun. A series of cross-trenches is usually dug to intersect the suspected burial area. The trench walls and diggings are logged and sampled using manual devices.

Investigation of historical records at Occidental revealed the existence and general locations of the burning and burial trenches. After marking the approximate locations, trenching began with the intention of locating the trenches more precisely and sampling their contents. The 3-4 ft of relatively uncontaminated overburden was placed in separate piles while the contaminated soil and wastes were placed on polyethylene sheeting.

A significant fraction of the wastes were found in the buried and saturated zone. The wastes consisted of partially full pesticide containers, empty drums and other solid wastes related to pesticide formulation. The volume of waste uncovered and the fact that much of the pesticides were leaking directly into the groundwater mandated a change of strategy.

The wastes were loaded into trucks for immediate disposal classified as extremely hazardous pesticide wastes without benefit of analytical results. Containers with residual pesticides were overpacked and empty containers were placed in dumpsters. Contaminated soil was sampled and analyzed prior to disposal.

Although circumstances in this case dictated that the exploration and removal process occur concurrently, it is generally more appropriate to separate these two. This allows time to develop as much information as possible to safely and properly remove the wastes without incurring undue risks to workers, the surrounding community, and causing further contamination of the soils and groundwater.

GROUNDWATER SAMPLING

Single Completion Wells with Submersible Pump and Packer

As shown (Figure 5), this technique involves using a submersible pump attached to an air inflatable rubber tube to obtain a representative groundwater sample. After positioning the pump/packer assembly at the desired depth, the packer is inflated to form a seal between the screened section and the rest of the water column. The system which also includes a Teflon ® tube for sampling is then flushed with 3-5 volumes (volume of the screened section) before a sample is taken. The sampling tube is not, however, shown in Figure 5.

Figure 4.
Trenching.

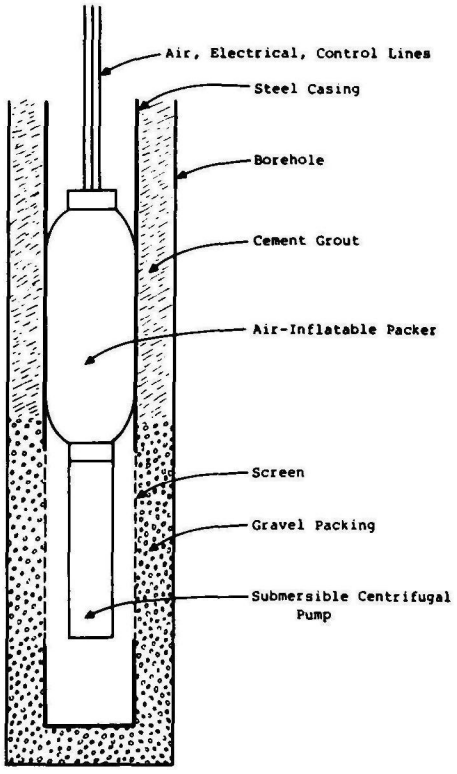

Figure 5.
Pump and Packer Assembly.

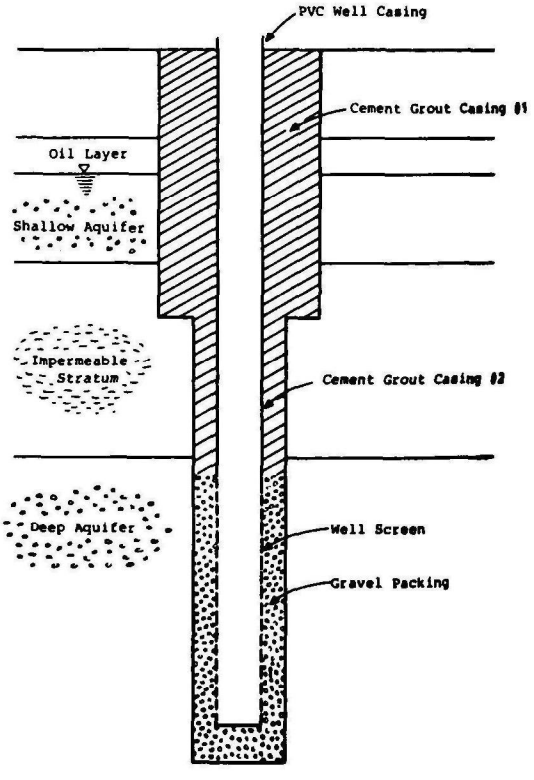

Figure 6.
Multi-Cased Well.

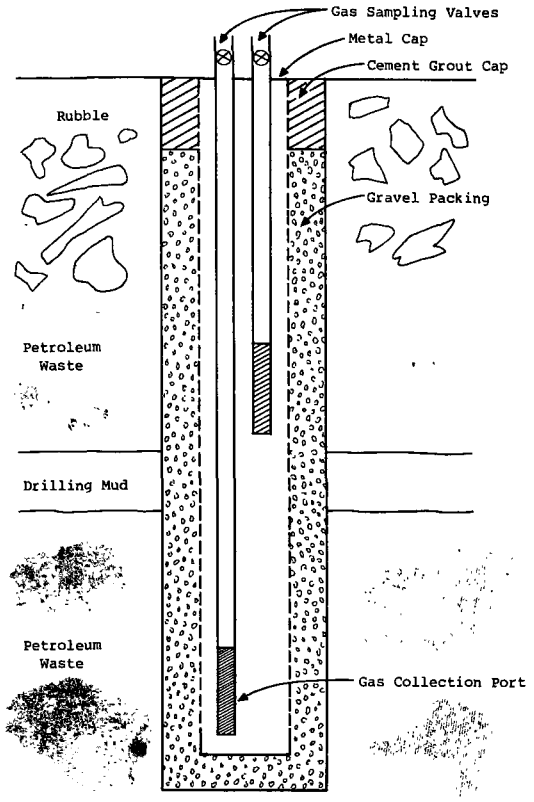

Figure 7.
Gas Sampling Well.

The permeability of the soils in the area, analytical data from surrounding wells, and the nature of the operations at Occidental's facility indicated that groundwater was contaminated with organics and inorganics to significant depths. Based on available hydrogeological and pilot well data, further sampling locations, each with three single completion wells at various depths down to approximately 200 ft were selected. This type of well construction allowed isolation of the most significant water bearing strata. The packer further isolated the specific zone of interest while limiting the amount of water flushed and controlling any mixing of stagnant water in the well column with water which is more representative of the aquifer.

The submersible centrifugal pump with relatively inert component parts allowed sampling for purgeable organics such as DBCP and EDB (1, 2-dibromoethane) along with other less volatile constituents. The depth of sampling and these volatile components prohibited the use of other sampling methods (bailing, vacuum pumps, and air lift pumps). The entire sampling assembly was flushed with distilled, deionized water between each location instead of providing dedicated tubing for each location to provide further control over the possibility of cross-contamination.

Multiple Cased Wells

This is more a method of well construction rather than of sampling (Figure 6). A large diameter boring is made through the upper, highly contaminated aquifer into the first impermeable zone. This boring can then be cased and grouted with cement or plugged with bentonite clay. A smaller boring is then made through the casing or the seal into the next aquifer where a single completion well is constructed.

Multiple cased wells were employed at the General Electric facility where the PCB contaminated oil layer on the water table threatened to cause contamination of the deeper aquifer during drilling. Representative depth specific soil samples were also obtained from zones below the water table aquifer using this drilling technique. Such an approach should be considered in all cases where the probability exists of contaminating to a significant extent previously uncontaminated zones.

AIR SAMPLING

Gas Well Installation and Sampling

The landfill gas sampling probes shown in Figure 7 are encased in a perforated metal casing and lowered into a bore hole. The annulus is packed with gravel and sealed with cement. All parts are constructed of steel or brass to minimize adsorption and desorption effects.

Gas collection parts are provided at two levels for characterizing gases at these levels and to provide for the possibility of inundating the deeper probe with leachates. Samples of the collected gases are obtained by pumping through various types of adsorbents (i.e., activated carbon, or Tenax ®, impingers with selective solutions or by filling Tedlar ® bags.

This approach was necessary at the Mola Development site to evaluate the rate of generation of the noxious gases, characterize them more fully and evaluate the potential for subsurface migration to the surrounding community. The information was also necessary to develop appropriate mitigation measures. These gas collection devices were installed in some of the borings made by the bucket auger and the well was allowed to equilibrate for several weeks. Composite gas samples representing the entire column were taken using Tenax ® adsorbent for organics and impingers for inorganic vapors. This method allowed extensive characterization of the gases generated on-site although it was not sufficient to fully evaluate the rate of gas generation for purposes of planning excavation.

CONCLUSIONS

Technology has generally been available for sampling at the sites discussed and other sites. Investigations at uncontrolled sites often require novel applications of these technologies.

Maintaining quality control is a key factor in any sampling method selected, especially when addressing low levels of highly toxic contaminants. However, compromises must be made in some cases when sampling waste material.

Care must be taken in any investigation that the act of sampling does not cause significant contamination of previously uncontaminated soils, aquifers or air space.

THE STRATIFIED SAMPLE THIEF— A DEVICE FOR SAMPLING UNKNOWN FLUIDS

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INTRODUCTION

The primary reason for the development of the stratified sample thief was the problem of sampling the fluids recovered by the oil spill recovery devices tested at the EPA OHMSETT test facility. The method used since the facility opened and continued until the 1980 test season was as follows:

- The test fluids were collected in containers on the auxiliary bridge during a test
- The container fluid level was measured to obtain total volume collected
- The free water was decanted from the bottom of the container
- The remaining fluid was remeasured
- The sample was mixed (emulsified) using an electric motor and propellor
- A small sample of the fluids was taken while mixing continued
- The sample was taken to the lab where it was centrifuged to determine the amount of water in the oil.

Some of the problems associated with this procedure were:

- The measuring, draining and remeasuring took time and produced more numbers that could be lost of misinterpreted
- The mixing caused severe emulsification that made the refurbishment of the oil for reuse difficult and expensive
- The plastic containers used for the recovered fluids were subject to damage and degradation by sunlight.

To eliminate some of these problems, many methods for sampling were discussed and/or tried including:

- Discrete sampling using a rotary table with tubing and a solenoid valve
- Discrete grab samples (this was similar to the rotary table except that all operations were manual).

The rotary table discrete sampler was less than satisfactory because:

- The fluid in the discharge line from a device could stratify and allow a non-representative sample to enter the tubing
- High viscosity fluids would not flow through the sampler tubing fast enough to fill the sample bottles in the time allowed for each discrete sample
- Debris sometimes plugged the tubing or solenoid valve
- In some test configurations, there was not enough pressure to allow sufficient flow in the sampler system
- The electrical system constantly failed due to corrosion and mechanical damage.

The manual discrete sampling was better from the mechanical/electrical standpoint but it had problems with stratification, low pressure, debris and high viscosity. Another disadvantage was the large amount of manpower required.

Some of the sampling methods discussed for possible use were:

- Vacuum bottles (similar to those used for blood sampling)
- Multiple valved tube
- Grain sampler tube
- Cork plugged tube (COLWASA).

These methods were all rejected because of anticipated problems such as:

- Cost
- Complexity
- Debris problems
- Viscosity effects
- Sealing
- Susceptibility to damage.

STRATIFIED SAMPLER DEVELOPMENT

A solution to the problems inherent with the other sampling devices or methods was finally arrived at after eliminating numerous other ideas. It is called a stratified sample thief.[1, 2, 3]

This sampler uses discs and wipers to hold the stratified liquids in position while the tube is slipped past them. (Figures 1 and 2.) The wipers keep the inside of the tube from carrying portions of the upper fluid down into other layers. They seal well enough so that the samplers can be carried to and stored in the laboratory horizontally.

This procedure allows the transfer of the sample from the sample thief to another container to be accomplished in the laboratory. This is done by clamping the sample thief vertically in a rack and removing the sheath.

Advantages

- Simplicity
- Inexpensive
- Ease of use
- Speed of operation
- Representative sample obtained (see Table I)

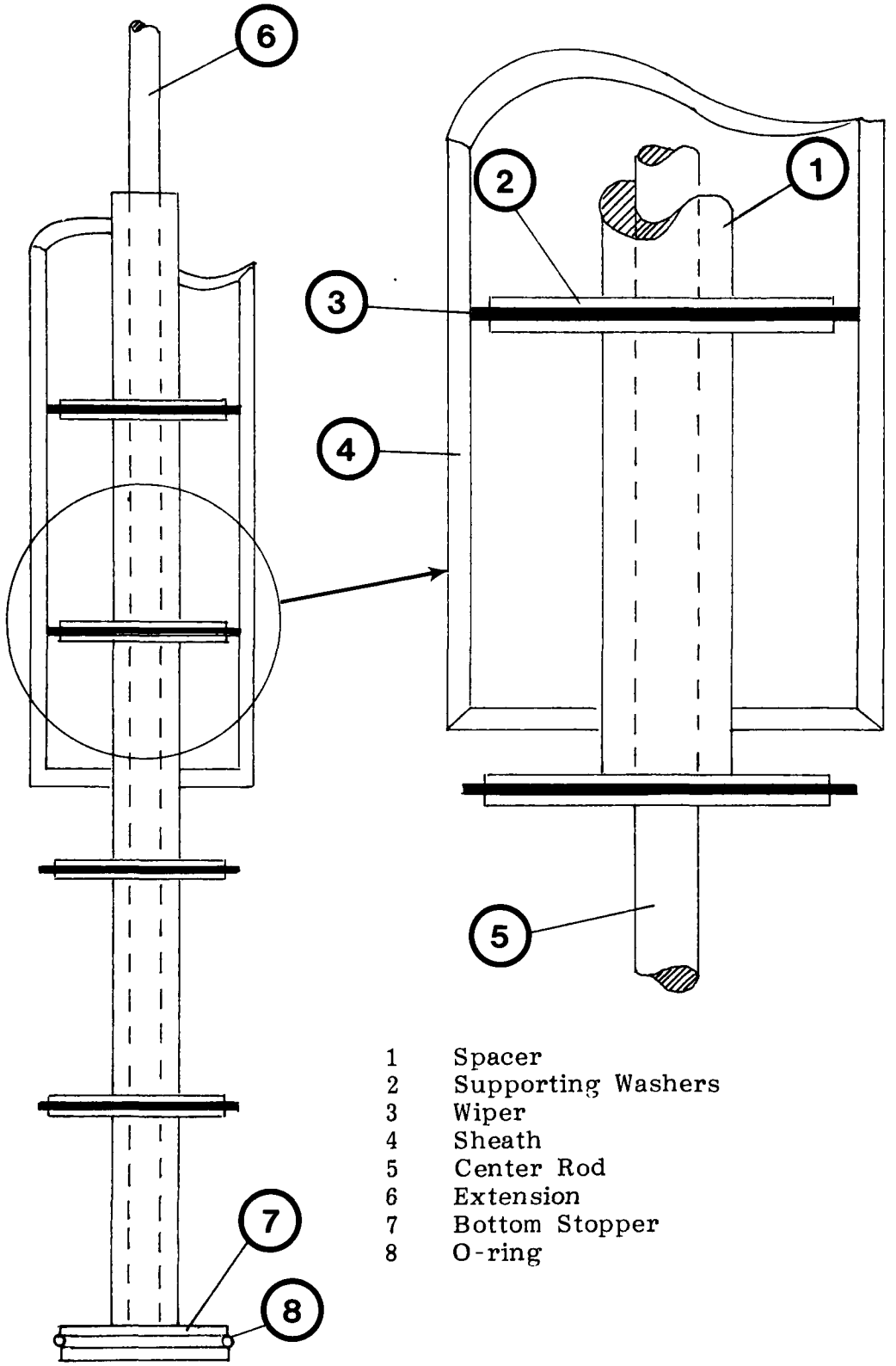

Figure 1.
Stratified Sample Thief Construction

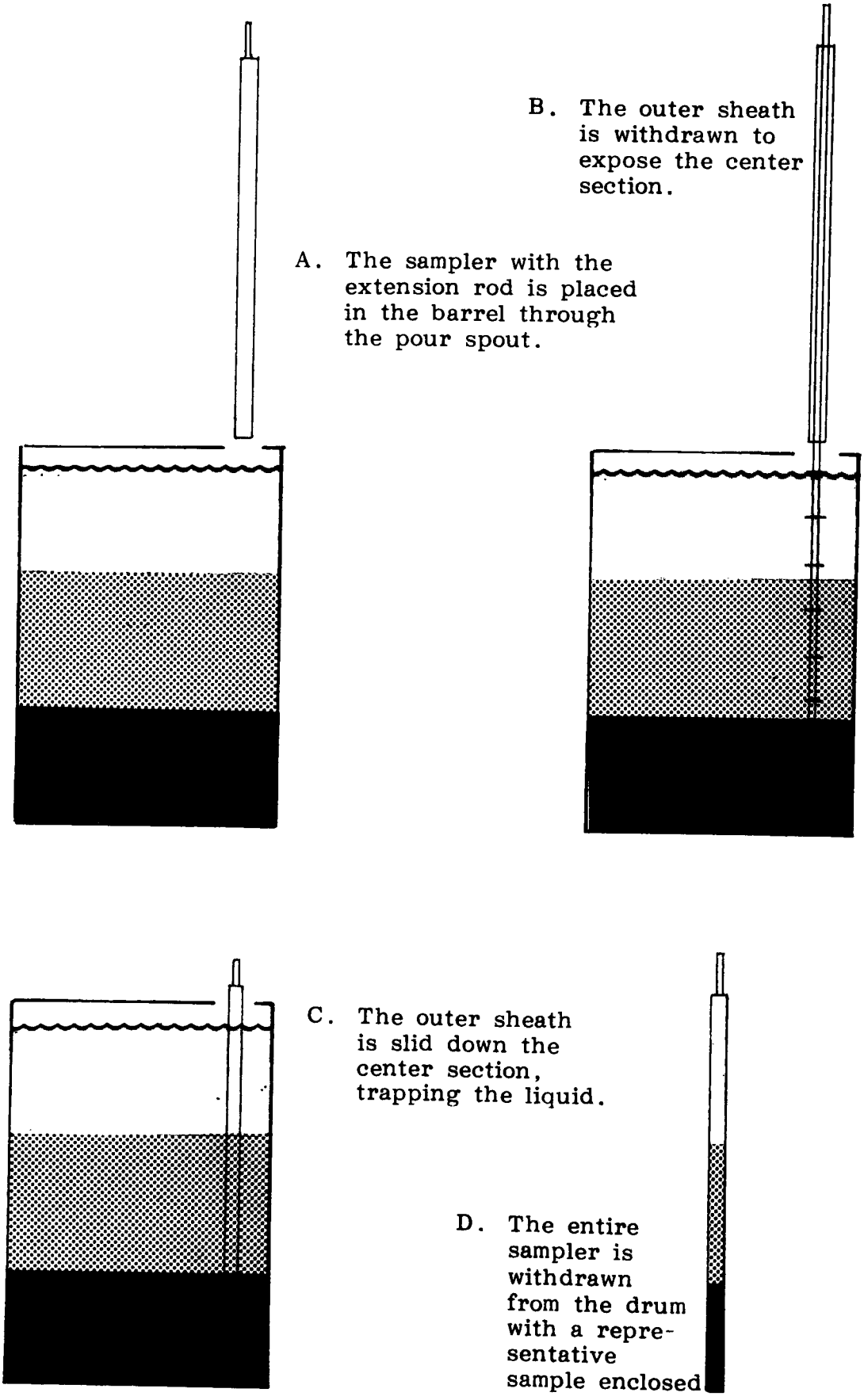

Figure 2.
Use of the stratified sampler

•Horizontal storage
•Useable by personnel wearing bulky safety gear
•Can be made in lengths to eight feet for deep containers.

Disadvantages

•Hard to clean
•Sheath material may be damaged by organic solvents (glass sheaths may be better)
•Use in low overhead area restricted by rod extension
•Bottom o-ring swells after repeated usage, requiring replacement.

COLWASA SAMPLER

This device is similar to the COLWASA[4] device, which is a tube with a cork or plug in the lower end which can be pulled into the lower end by a line or rod attached to the cork. The line or rod runs up through the inside of the tube and extends far enough out of the upper end of the tube so that it can be grasped. A sample is taken by lowering the assembly slowly into the fluid with the cork lowered so liquid can flow into the tube. When the assembly reaches the bottom of the fluid container, the line or rod is pulled up to seal the liquid inside the tube. On some models, a locking mechanism has been added to lock the rod in place.

The COLWASA sampler works well for homogeneous fluids or for stratified liquids of low viscosity. Stratified fluids with high viscosity can cause a problem due to the rather thick coating that can build up inside the tube. This coating can prevent the taking of representative samples. The stratified sample thief offers a solution to this problem.

The 2.22-cm (inside diameter) sampler was evaluated in 22 different tests in a 500-gal barrel of salt water with measured quantities of oil varying from 10 to 90 percent. The results of tests with the Johnson sampler and (for comparison) with grab samples taken after homogenizing barrel contents with an electric mixer are shown in Table I.

Table I.
Johnson Sampler Test Results on Oil/Water Samples

Test number	Actual Conc. (% Oil)	Johnson sampler (% Oil)	Grab sample (% Oil)
1	74.2	73.1	81.0
2	64.3	60.0	73.1
3	53.9	59.8	59.8
4	67.2	66.3	65.5
5	45.9	46.1	44.5
6	56.0	54.7	54.7
7	76.5	71.2	75.2
8	86.9	83.1	85.1
9	66.4	64.9	64.9
10	81.8	77.8	79.7
11	40.3	39.7	39.7
12	49.7	48.3	50.5
13	44.3	44.9	42.6
14	37.0	35.2	36.2
15	39.2	38.8	41.4
16	30.8	29.0	29.4
17	23.2	21.1	23.7
18	13.3	8.8	9.0
19	18.8	18.0	16.3
20	10.9	10.3	9.0
21	14.5	9.7	11.2
22	89.5	90.5	90.0

ACKNOWLEDGEMENT

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THE COMPLEMENTARY NATURE OF GEOPHYSICAL TECHNIQUES FOR MAPPING CHEMICAL WASTE DISPOSAL SITES: IMPULSE RADAR AND RESISTIVITY

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INTRODUCTION

Geophysical mapping at waste disposal sites has provided a direct comparison of results obtained from the application of two different geophysical techniques: (1) electrical resistivity (ER) and (2) electromagnetic impulse or ground penetrating radar (GPR). A correlation between data acquired by these two methods is reported in this paper. The two types of data can be used in a complementary manner since the radar signatures give geological meaning to the resistivity and the resistivity can be used to estimate radar system capabilities and predict the depth of penetration of the radar signals in the site geology.[1]

GROUND PENETRATING RADAR

The ground penetrating radar system, illustrated in block form in Figure 1, is composed of a transmitter, a receiver, an antenna (or antennas), an analog magnetic tape recorder and graphic display unit. The transmitter generates repetitive extremely short-time duration pulses which are radiated into the ground from a broadband antenna placed in close proximity and electromagnetically coupled to the ground. The radar operates as an echo sounding device. Electromagnetic pulses, reflected from targets or interfaces within the ground, are detected by the antenna, converted into voltage as a function of time waveforms in the receiver, and displayed on a graphic recorder.

As the antenna is scanned over the ground surface, a continuous profile of subsurface electromagnetic conditions is printed on the graphic recorder. The location and depth of subsurface targets are inferred from the graphic record. Depth of penetration and velocity of propagation in the ground are a function of the constitutive electromagnetic parameters of the soil. Maximum depth of penetration ranges from tens of centimeters to hundreds of meters.

The transmitter and high frequency receiving electronics are mounted in the antenna. This allows the use of several different antenna configurations operating at different frequencies with the same radar control unit and recording equipment. Even though each antenna configuration radiates a broad spectrum of frequencies, a particular antenna unit is designated by the center frequency

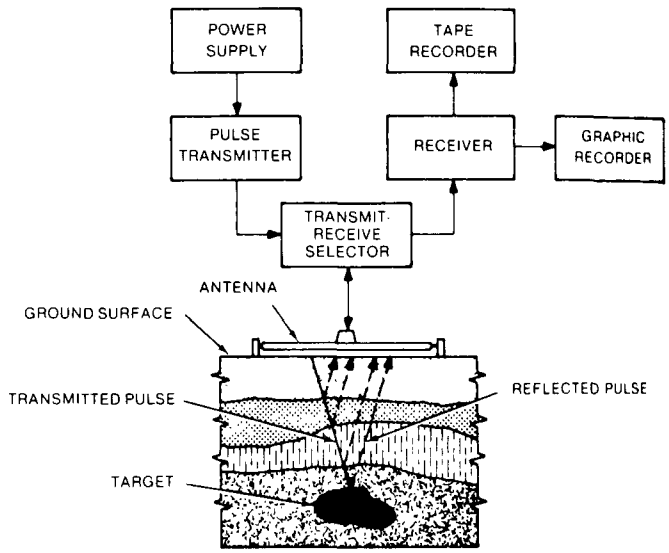

Figure 1.
Block Diagram of a Ground Penetrating Radar System

of its spectrum. Typical radar center frequencies vary between 10 and 1000 MHz.

The recording equipment and control unit are mounted in a van or other appropriate vehicle and the antenna is towed behind the vehicle. Data are recorded on magnetic tape and on the greyscale graphic recorder; the latter information being compressed dur to the high input data rate. After completion of a survey, the magnetic tape data are played back to generate full resolution hard copy for analysis.

An example of a typical transmitted and received pulse train is shown in Figure 2a while the graphic recorder display of the same is shown in Figure 2b. The dark bands occur at signal peaks, (both positive and negative), while the narrow white lines occur at the zero crossings between peaks. Areas to be surveyed are defined by driving stakes into the ground to establish a reference grid system. This grid is used as the coordinate system for the radar data and for any other geophysical surveys also undertaken. Positional information is accurate to within a few feet. Grass and weeds are usually mowed and brush cleared to ease actual travel over the surface.

Several preliminary scans are made at each site to calibrate the antennas with respect to the electromagnetic characteristics of the specific soils. In this way, each system configuration is optimized to provide the desired depth of penetration and/or resolution. In addition, the velocity of propagation of the EM signal and the dielectric constant of the soil are calculated by measuring the two-way travel time of the signal to objects at known depths or by a series of wide-angle reflection from an object or interface at an unknown depth.

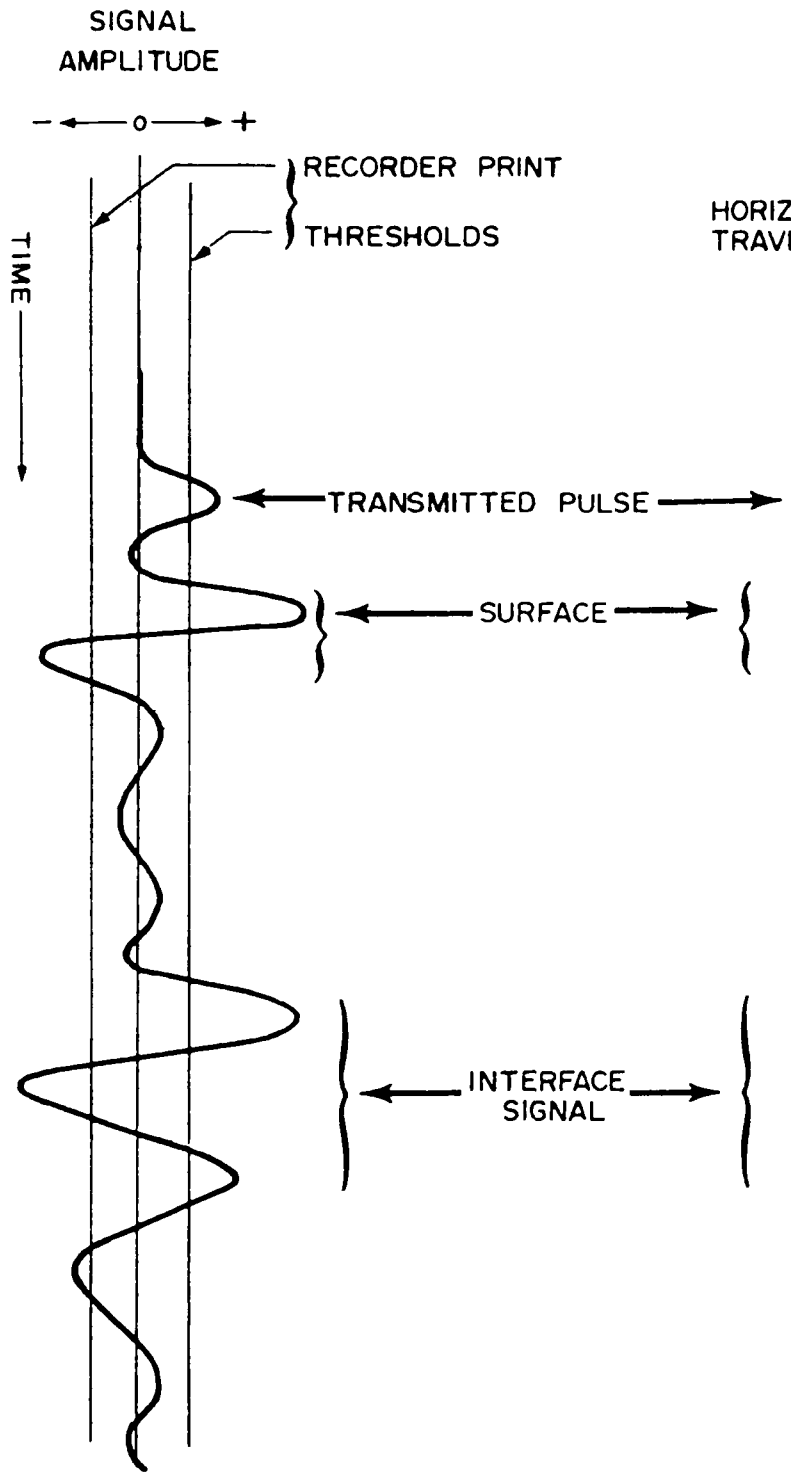

Figure 2a.
Sketch of a Single GPR Pulse and Reflections as Seen by the Receiver.

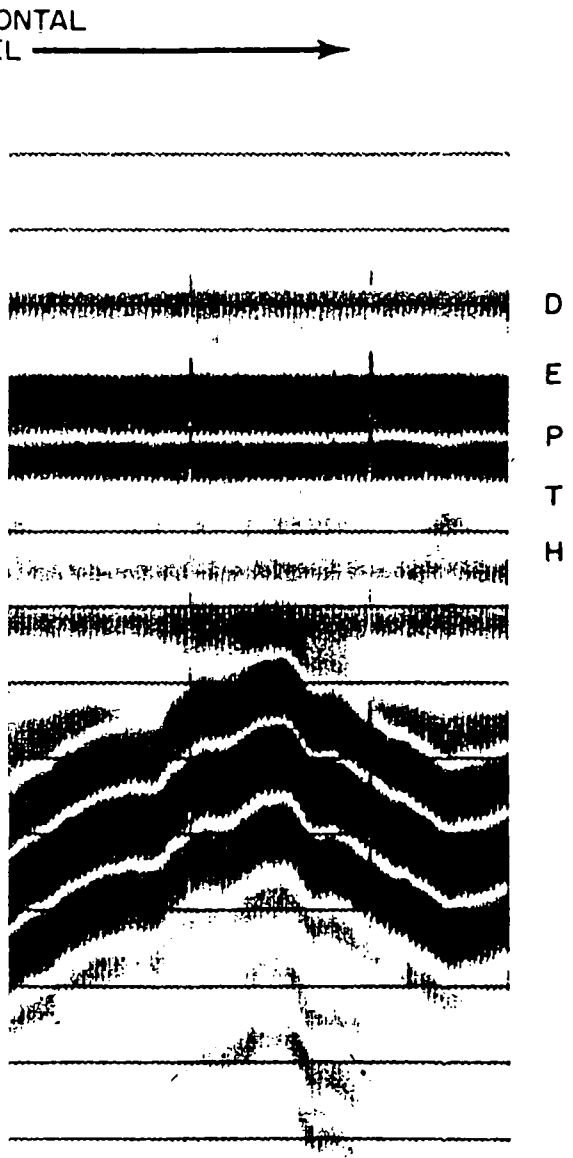

Figure 2b.
Example of Profile Information as Displayed by the Graphic Recorder.

RESISTIVITY

Earth resistivity surveys have been used for many years in exploration for groundwater and mineral deposits, and in the study of engineering properties of earth materials.[2] Equipment to measure apparent resistivity consists of a controlled source of electric current and a device for measuring the potential differences generated by the current passing through the earth.

Typically, four electrodes are used in resistivity measurements. The volume of a subsurface material influencing the resistivity measurement is controlled by the spacing and geometric arrangement of the electrodes. While any array of four or more electrode contacts can be used in studying earth resistivity, a relatively few electrode configurations have become accepted as standard arrays in practice. The most common electrode arrays used in the resistivity method are shown in Figure 3.

Many factors go into the choice of array configuration for a given problem. Susceptibility to geological noise, ease of array movement and the nature of the assumed structure are a few of the factors to be considered.

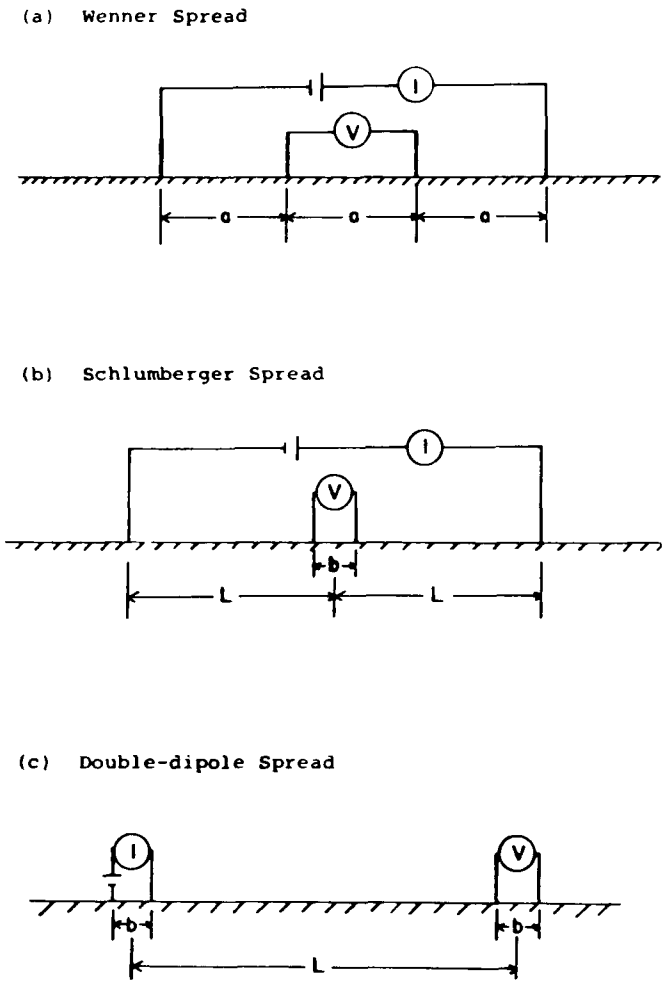

Figure 3.
Common Electrode Configurations for Resistivity Arrays

RADAR/RESISTIVITY CORRELATION

Examples of radar signatures obtained at a frequency of 120 MHz are shown in Figure 4, for "broken slag" and "clay" present at an uncontrolled chemical waste disposal site; the corresponding resistivity profile superimposed on the radar profile is also illustrated. Apparent resistivity is plotted downward in order that conductivity may be visualized as increasing upward. The effective depth of penetration is greater in "slag" with a corresponding lower conductivity and less in "clay" with a higher conductivity. Although conductivity is frequency dependent and the two methods are operating at frequencies differing about seven orders of magnitude, the relative effects of radar signal attenuation and measured d.c. conductivity (or resistivity) are shown to be similar when moving from one material to another.

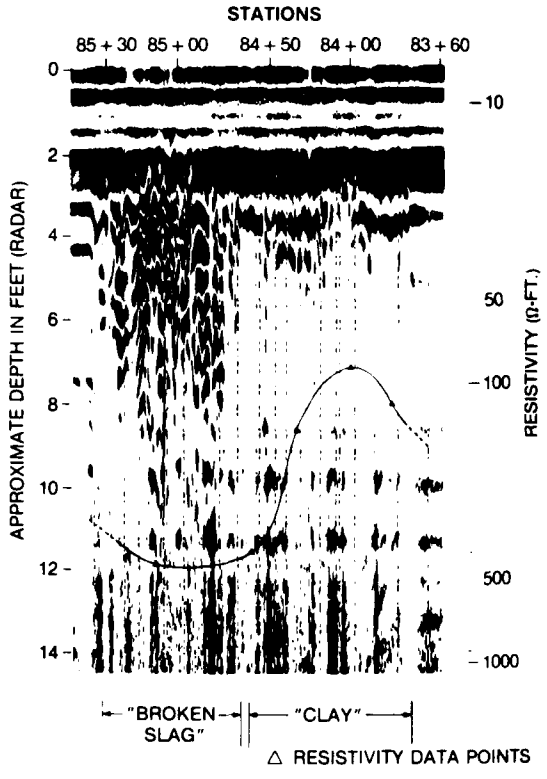

Figure 4.
Radar and Resistivity Profiles.
Radar Profile Shows Characteristic Signals of "Broken Slag" and "Clay".

The relationship between the radar depth of penetration and the d.c. conductivity (resistivity) is illustrated in Figure 5. Based on the radar range equation and a complex index of refraction soil model, the maximum depth of penetration of the radar system is calculated for frequencies of 10, 100, and 300 MHz.[3,4,5]

Also plotted in this figure are the radar penetration depths achieved at 120 MHz and d.c. conductivity (resistivity) measurements obtained at the chemical waste site illustrated in Figure 4. Considering the complexity of this

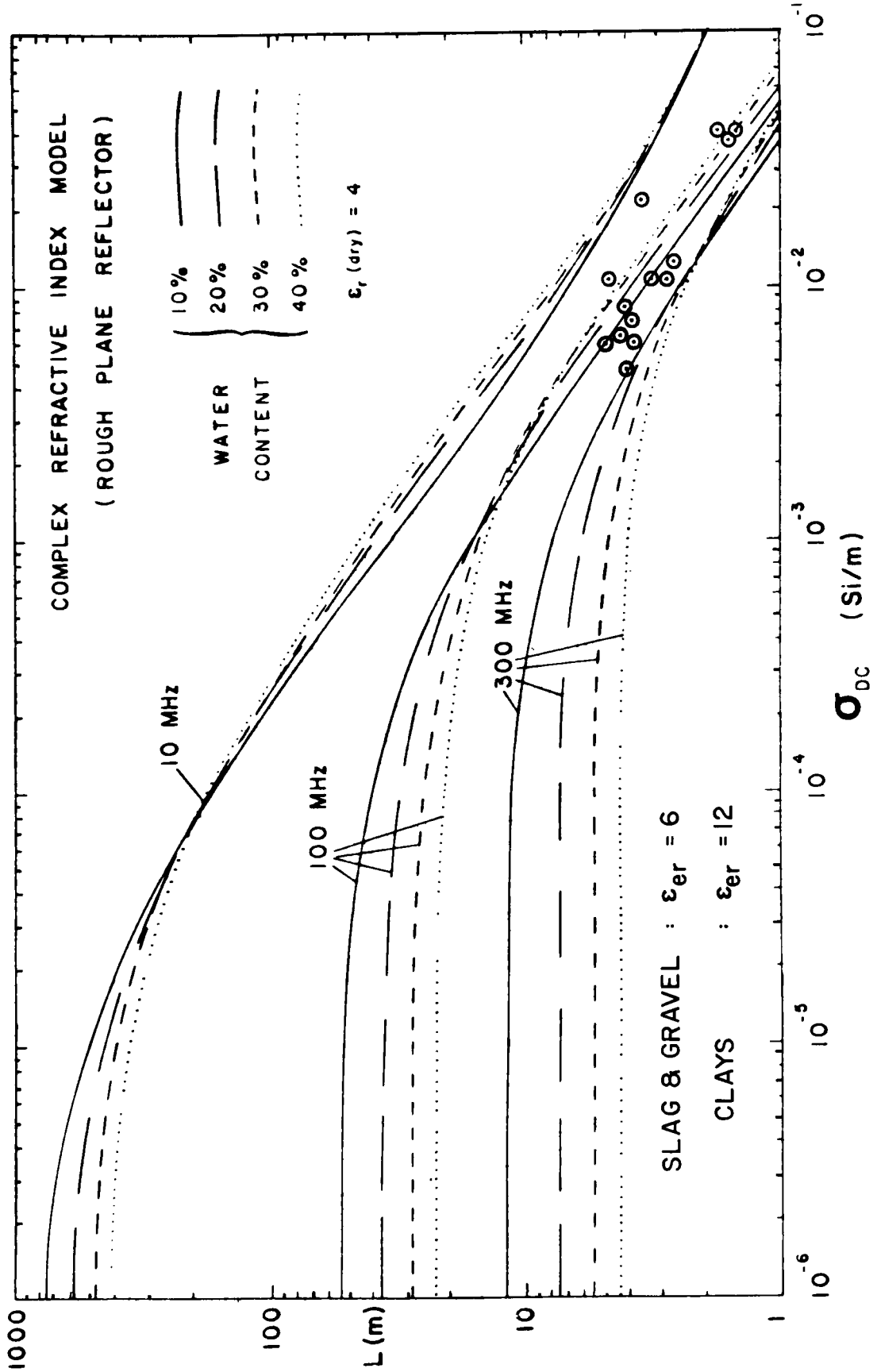

Figure 5.
Calculated Maximum Depth of Penetration as a Function of DC Condictivity at Three Frequencies and Various Soil Moisture Contents. Resistivity Measurements and Radar Ranges (120 MHz) Taken at a Chemical Waste Disposal Site.[1]

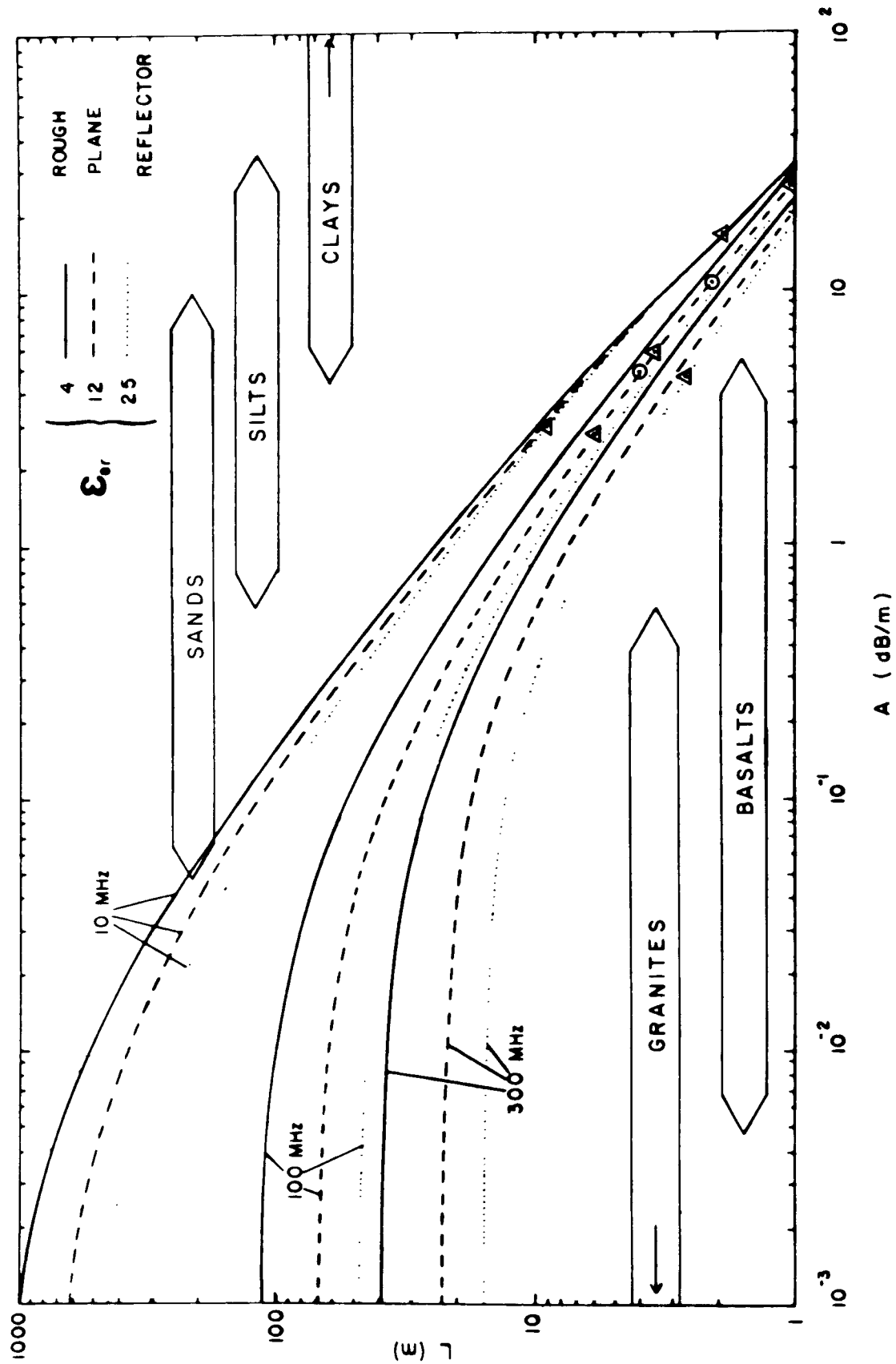

Figure 6.
Variation of Maximum Depth of Penetration (L) as a Function of Attenuation (A) for Different Frequencies and Dielectric Constants. Typical Ranges of Attenuation for Different Earth Materials Are Also Shown.[1]

Low-Level Nuclear Waste Disposal Sites: Chemical Waste Disposal Site:O

site and the extent of modeling involved, excellent agreement is obtained between the soil and radar models and the experimental data.

In mapping the substructure of a number of low-level nuclear waste disposal sites, Geo-Centers has had the opportunity to test the model comparing both the calculated and the measured depth of penetration and attenuation of the radar system. Such a correlation is illustrated in Figure 6 in which the depth of penetration and attenuation measured with radar frequencies between 10 and 300 MHz are compared with calculated values. The range of expected attenuation for a number of typical soils and rocks is also indicated on the figure. The data indicate that attenuations range from 2.5dB/m to 25dB/m for the soils encountered at the sites. The relationship of attenuation to depth of penetration encountered in the field surveys agrees well with that calculated using the model.[1]

In order to simulate a typical uncontrolled disposal site in New England and obtain radar signatures from an assortment of objects in known orientations and configurations and at known depths, a site was developed near Harvard, Massachusetts (about 25 miles west of Boston).[1] The site chosen was in an undisturbed portion of an active sand mining operation.

A trench 150 feet long and 20 feet wide was excavated to a depth of 10 feet, except for one 20 foot section, 20 feet deep, in a glacial outwash deposit of well-sorted, cross-bedded sand. Sixteen 55-gallon metal barrels, two plastic drums and a one meter cubic box were buried at the site.

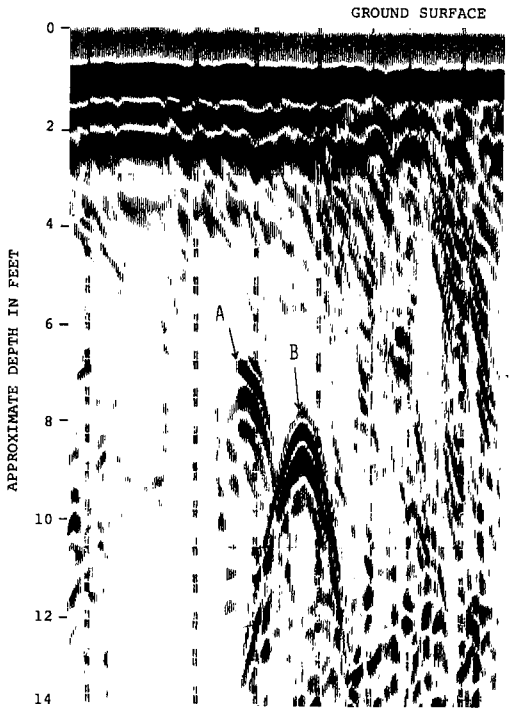

Figure 7.
Portion of a Radar Profile Taken at 300 MHz Over a Vertical Metal Barrel (A) and a Horizontal Metal Barrel (B) in a Trench 10 Feet Deep.

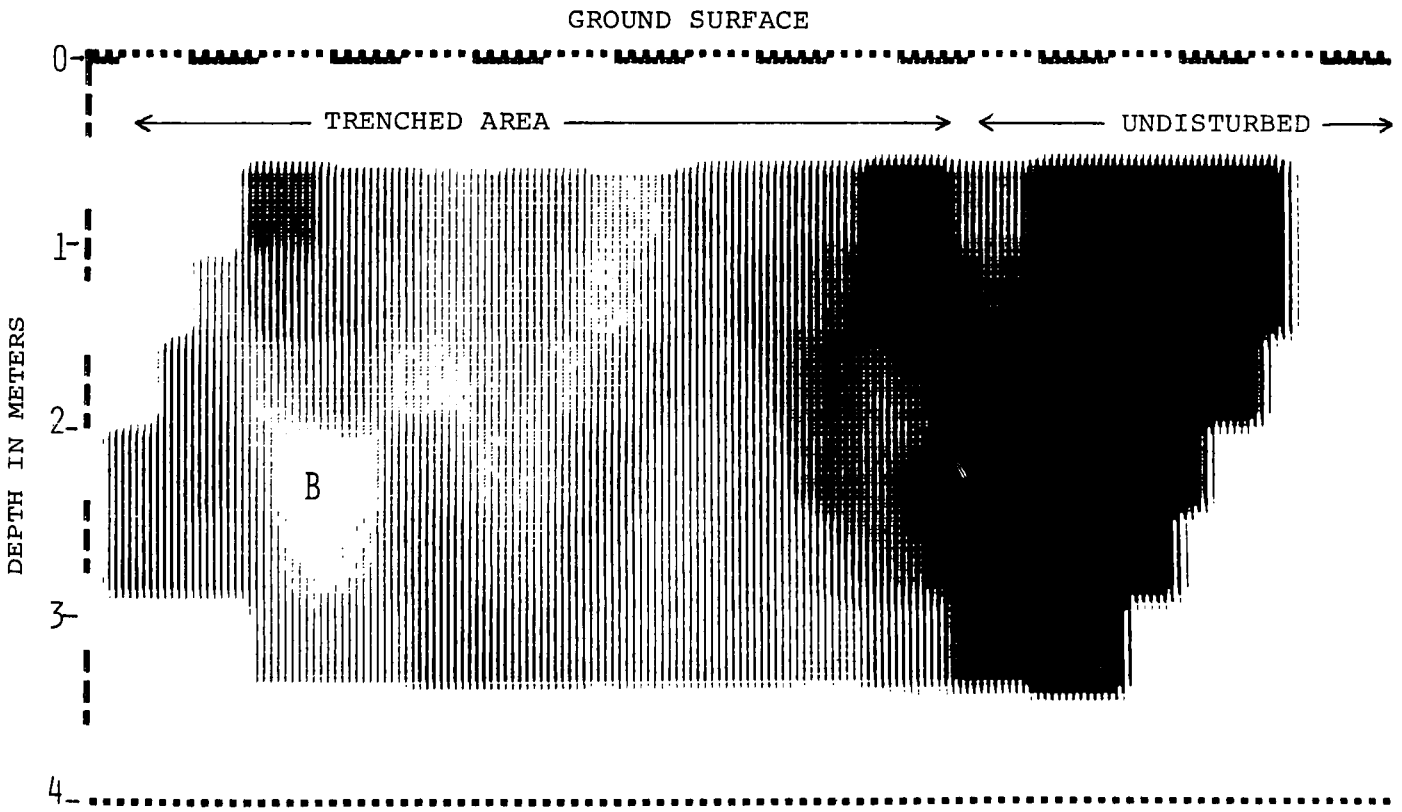

Figure 8.
Apparent Resistivity Pseudo-section Across Trench. Resistivity Values Range From 190 ohm-m at the Location of a Metal Barrel (White Area Indicated as "B") to 2400 ohm-m (Black). Horizontal Distance is 15 Meters.

The metal barrels were representative of typical objects found at waste disposal sites. The two plastic barrels and wooden box were representative of voids of different size and shape within the soil.

Comprehensive data were taken with three antenna systems at 10 MHz, 80 MHz and 300 MHz. Radar scans were made along the length of the trench at approximately five foot intervals. In addition, one scan perpendicular to the length of the trench and one diagonal scan were made over each of the targets at each frequency. Electrical resistivity data were obtained to supplement the radar data.

An example of a radar profile taken over two buried 55-gallon metal drums, one on its end (A) and one on its side (B) is given in Figure 7. All fifteen target configurations, both metallic and non-metallic, were detected with the radar. Resistivity data at this site are presented in Figure 8 as a computer plotted pseudo-section showing position across the trench and apparent depth. The resistivity values differ markedly between the disturbed area within the trench and the undisturbed geology. In addition, the effect of the presence of a metal barrel on the resistivity values is also demonstrated.

SUMMARY

A correlation has been found between the data obtained using ground penetrating radar and electrical resistivity. These two geophysical techniques provide complementary geophysical information.

Ground penetrating radar, coupled with ground-truth, can be used to give greater meaning to apparent resistivity values, both with respect to geological substructure identification and to target or object location and identification. Measurements of bulk soil resistivity can be used to predict the expected depth of penetration of the ground penetrating radar. Other geophysical techniques, such as induced electro-magnetism and induced polarization are expected to show similar correlations with ground penetrating radar.

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UTILIZATION AND ASSESSMENT OF A PULSED RF SYSTEM TO MONITOR SUBSURFACE LIQUIDS

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INTRODUCTION

Hazardous liquids infiltrating the ground from shallow or deep injections, storage lagoons, leaking containers, tank car spills, etc., often reach the groundwater table where they then flow downstream to open water, streams or wells. The necessity of locating and monitoring such seepage trajectories is of paramount importance. Obviously, this can be done by core borings and monitoring wells, but the economics of the situation begs for a more suitable and cost effective technique. It seems that one of a number of nondestructive testing (NDT) methods might be adopted for such monitoring. Candidate techniques, grouped according to their basic operating principle, are as follows:

- •Thermally Induced Methods
  - infrared
  - heat pulse
- •Elastic Wave Methods
  - seismic refraction
  - seismic reflection
  - ultrasonics
  - acoustic emission
  - sonar (active and passive)
- •Nuclear Methods
  - neutron
- •Electromagnetic Methods
  - resistivity
  - very low frequency
  - eddy current (metal detector)
  - pulsed radio frequency
  - continuous microwave
  - magnetometer
  - penetrating radiation

These methods have been reviewed as far as their overall applicability to hazardous materials problems,[1] and the electromagnetic methods have been categorized and compared in a unified manner for location of subsurface anomalies, mainly buried drums.[2] This paper is an extension of one of these electromagnetic methods, the pulsed radio frequency (RF) method, for the purpose of locating the water table in different soil types and over the complete seasonal change of one year. Water surface measurements via water observation pipes were also made so as to obtain "ground truth" information and thus provide an actual comparison.

OVERVIEW OF THE PULSED RF TECHNIQUE

A considerable amount of subsurface probing at shallow depths has been based on the transmitting of pulsed RF waves in the frequency range from about 1 MHz to 200 MHz. The transmitted pulse travels through the soil until it infringes upon an object or material with dissimilar electrical characteristics. Part of it is then reflected back to the ground surface where it is received and the time of

Table I.
Details of Pulsed Ratio Frequency (RF) Methods

Investigator(s)	Approx. Freq. Range (MHz)	Max. Depth (meters)	Major Application Area
Cook (4, 5)	1-100	225	locating faults, walls, holes
Rosetta (6)	100-200	15	locating faults, caverns, water, utilities
Morey (7)	100-200	15	locating faults, caverns, water, utilities
Dolphin, *et al.* (8)	15-50	40	locating rock cavities
Unterberger (9)	230	500	salt thickness measurement
Harrison (10)	35	2000	determining ice thickness
Rubin *et al.* (11)	100-200	10	detecting subway tunnels
Rubin and Fowler (12)	100-200	15	drilling guidance, subway tunnel monitoring, coal thickness
Benson and Glaccum (13, 14)	100-200	10	general subsurface probing, locate and follow pollutants in ground, detection of buried containers of industrial wastes
Sandness *et al.* (15)	100-200	10	general subsurface probing as described above
Alongi (16)	1,000	3	locating mines, pavement thickness, shallow voids, pipelines
Moffat and Puskar (17)	6,000	3	locating faults, joints, cavities, pipelines

travel is measured. The depth "d" to the interface is then calculated from d = (vt)/2 where "v" is the wave velocity (which is equal to $c/\sqrt{\varepsilon_r}$, where "c" is the velocity of light and "ε_r" is the relative dielectric constant of the material in which the wave is propagating) and "t" is the pulse travel time. The relative dielectric constant of numerous soils at different water contents has been evaluated by many investigators, including Okrasinski, *et al.*[3] As shown in Table I, this technique has been studied by many workers.

Additional systems of a similar type as just described are also available at a higher frequency range, i.e., above 1 GHz. These are also listed in Table I. They could, however, better be classified as microwave methods. The advantage of the higher frequency range is that a shorter wave length gives greater definition to the subsurface object. However, the attenuation of the waves is higher, resulting in lower penetration depths, see Lord, *et al.*[18]

The authors have been active in adapting the pulsed RF method to problems of interest in hazardous materials spills and incidents. Using a commercially available system which transmits RF pulses in the 100-300 MHz frequency range and presenting the received signal in a real time printout, a visual subsurface profile is developed. Strong return signals appear as the black areas, while weak (or no) return signals appear as white. Gray areas require appropriate interpretation. The particular system used in this study transmitted short (10^{-8} sec. long) pulses of carrier frequency about 120 MHz into the ground. Reflected patterns were recorded in real time printout as previously discussed. Maximum depth of penetration at the sites under investigation was approximately 6 meters. The specific goal was to reflect the RF pulses off the water table surface, thereby determining its depth under the widest possible set of conditions and circumstances.

DETAILS OF TEST SETUP AND SITE CONDITIONS

Each of the three sites selected for monitoring were unpaved and originally thought to be relatively homogeneous within the upper 3 m of interest. To guarantee the near-surface existence of the water table, each site began at a creek or river at one end of the traverse and proceeded inland. One site went from exposed creek to exposed creek. Shown in Figure 1 are photographs of the three sites with the water bodies visible in the background.

Wharton Site

The Wharton site extends from a 2 m deep cedar water creek onto the land for a distance of 100 m. The ground surface rises 3 m within this length. Nine water observation wells were placed in the ground, each deep enough to intercept the water table. The water observation wells were 2.5 cm diameter open ended pipes with removable surface caps to prevent damage or vandalism during time of non-use. The spacing varied from 3 m to 15 m.

Subsurface sampling from the site showed that the soil beneath the upper 15 cm was a poorly graded sand which contained a well defined water table, below which the soil was saturated and above which the soil was dry or partially saturated depending on the recent weather conditions. Physical properties of the soil are given in Table II. Geotechnical properties calculated from the date of Table II show an *in situ* porosity of 0.38 and a saturation of 9% for the soil above the water table.

Springfield Site

The Springfield site extends between two shallow freshwater creeks spaced 90 m apart. Between these two creeks the land surface rises approximately 1.5 m. The ground

(a) Wharton Site (b) Springfield Site (c) Penrose Site

Figure 1.
General Surface Conditions of Sites Being Monitored

Table II.
Physical Properties of Soils Encountered at Various Test Sites

Location and Stratum	Unit Weight PCF (g/cc)	Water Content %	Specific Gravity g/cc	Effective Size mm	Coef. of Uniformity	Liquid Limit	Plastic Limit	Plasticity Index	Classification*
Wharton Site									
Upper	111 (1.78)	2	2.68	0.25	18	N/A	N/A	N/A	SW-GP
Lower	105 (1.68)	2	2.68	0.10	5	N/A	N/A	N/A	SP
Springfield Site									
Upper	107 (1.72)	13	2.70	0.065	11	N/A	N/A	N/A	SW
Lower	125 (2.00)	23	2.67	N/A	N/A	56	36	20	OH
Penrose Site									
Riverside	-	-	-	0.19	130	N/A	N/A	N/A	GW/SW
Landside	108 (1.73)	29	2.20	0.15	20	51	51	0	MH

N/A = not applicable
*refers to Unified Soils Classification System

surface is an asphalt paved parking lot with a crushed stone base. Total pavement thickness is approximately 15 cm. Eleven water observation wells, of the type previously described, were placed along the traverse at intervals of 4 to 15 m.

Soil samples indicated two different soil types: The upper soil (i.e. beneath the asphalt/stone base pavement) is a well graded silty sand and the lower soil is an organic clay of high plasticity. Physical properties of the soils are given in Table II. Calculated values from these properties show the upper sand to have a porosity of 0.44 and percent saturation of 45%, while the lower clay has a porosity of 0.39 and is fully saturated.

Penrose Site

The Penrose site extends from the edge of a major river (brackish water) up a relatively sharp ridge to gradually upward sloping land. The traverse selected was 50 m long and four water observation pipes were placed along its length at spacings from 5 to 10 m. Soil samples indicated two different soil types: Closest to the river is a random fill consisting of cobbles, gravel and miscellaneous fines which was too coarse to obtain an undisturbed sample. Away from the river the soil abruptly changed due to past construction activity. The soil here was identified as a high plasticity silt whose physical properties are given in Table II. The resulting *in situ* properties of the landside silt were a porosity of 0.39 and a saturation of 100%, i.e., fully saturated. It was observed that the riverside random fill was also high in water content and obviously close to complete saturation.

TEST RESULTS

During the course of this 12 month study, 20 separate scans were taken of each test site. Temperatures ranged from summer high of 29 °C to winter lows of −6 °C. Surface conditions varied from dry, to wet, to snow covered and included varying amounts of frost penetration. Time of monitoring varied from morning, to noon, to late afternoon.

Actual water table elevations were taken by placing a stiff coaxial wire down the water observation pipe until it came into contact with the water within the pipe. The shielding of the wire was drawn back from the central lead about 2 mm so that a shorted condition existed until contact was made with the water surface within the pipe. The cable was connected to a voltmeter at the ground surface which clearly registered a completed circuit, hence the water surface. The length of wire was then measured to determine actual elevations from the top of the water observation pipes.

Pulsed RF traces of the various sites were made immediately after water table measurements. The entire process at each site took less than one hour, thus changes in water table elevation between the two sets of readings were not considered significant.

Wharton Site

A typical pulsed RF trace at the Wharton site is shown in Figure 2. As with all of the traces it appears as though the ground surface is level while, in reality, it rises from left (the creek) to right (landside). Also noted is a heavy black band immediately beneath the ground surface where no data can be obtained. This "main bang" effect is due to the interaction of the three pulses traveling directly across the transceiver. Its thickness depends upon the frequency of the pulses and varies from 20 to 40 cm.

Seen reasonably clearly on the trace is a separation from light (above) to dark (below), which indicates the location of the water table. Superimposed on the figure are the locations of the water surfaces within the water observation

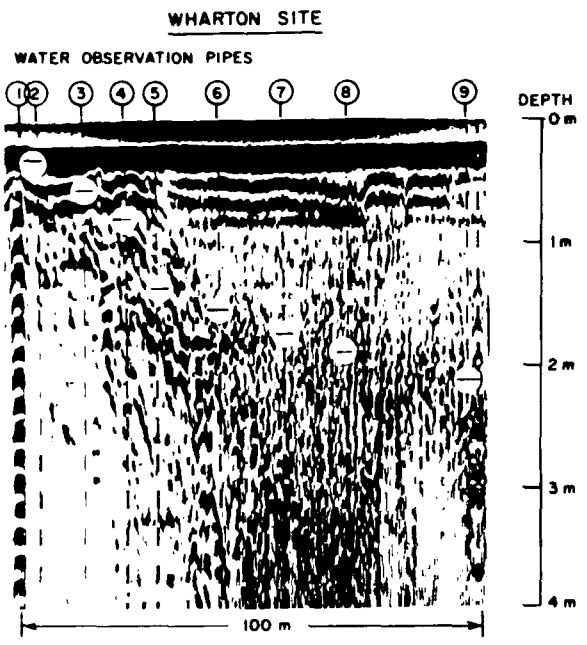

Figure 2.
Pulsed RF Survey of Wharton Site made on April 3, 1981 with actual water table elevations indicated by horizontal line in circle

pipes. Correlation has generally been good with accuracy of 14% during dry ground conditions and 27% during conditions of high surface moisture. This latter situation occurred usually during winter readings when the ground was frozen in the upper 20 to 50 cm. Interestingly, the ground surface having a snow or ice covering did not seriously influence the readings. Readings taken during different times of the day and temperatures above freezing did not appear to influence results.

Springfield Site

A typical pulsed RF trace of the Springfield site is shown in Figure 3. Here a very different situation is seen to occur where no correlation exists between the RF trace and the actual water table elevation. This is undoubtedly due to the capillary zone which draws moisture above the water table in fine grained soils. Since the degree of saturation in this zone is very high, e.g., completely saturated in the lower soil, no distinct boundary exists for the pulsed RF system to define a distinct water table elevation. However, within the water observation pipe, the capillary zone does not exist, thus the actual water table surface can be located.

What is dominant on the pulsed RF trace of Figure 3 is an undulating discontinuity showing two well defined areas. This discontinuity maps out the distinction between the upper granular soil and the lower fine grained soil. It was present in this exact location every time that a traverse was made. The only different noted from time to time was in contrast, which was probably due to varying performance of the printer.

Penrose Site

A typical pulsed RF trace of the Penrose site is given in Figure 4. As with the Springfield site, the capillary zone, with its high moisture content soils, completely masks out the presence of the actual water table as determined by the water observation pipes. What is clearly seen is that the soils on the left side (adjacent to the river) are very different than the soils on the right side (the inland soils).

Subsequent soil testing showed these two soil types to be very different from one another and placed in their respective locations during past construction activity. The boundary was always present, in the same location, with contrast being the only difference between various readings.

SUMMARY AND CONCLUSIONS

Of the many candidate techniques available to nondestructively test for subsurface water, as in seepage plume detection, the use of pulsed RF methods are likely methods. Indeed, the reflection from a well defined water table can lead to reasonable accuracy. Results of 12 months of testing show that the greatest accuracy, approximately 14%, is during dry summer weather where there is no surface moisture. The accuracy decreases to 27% during wet winter months when moisture is contained within the soil above the water table. These results, however, are only valid for sandy (or gravelly) soils which do not contain a capillary zone. This capillary zone which

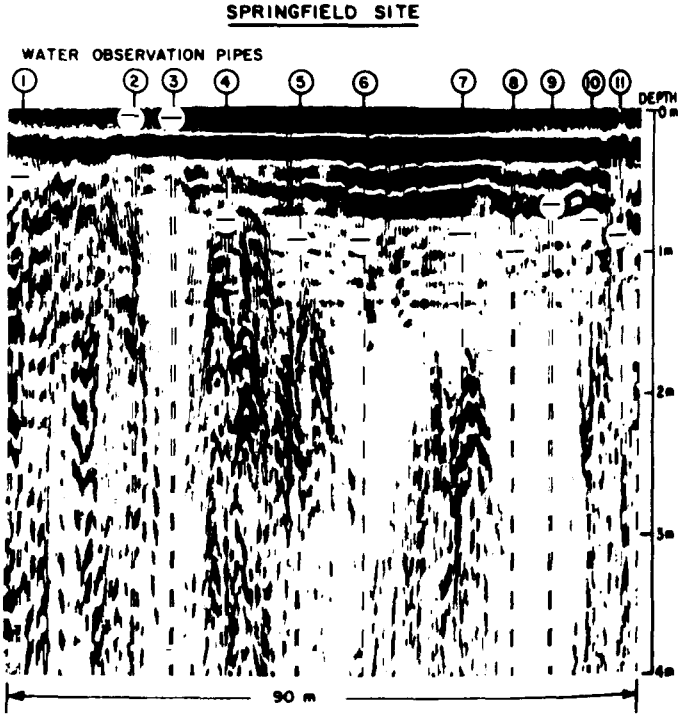

Figure 3.
Pulsed RF Survey of Springfield Site made on April 3, 1981 with actual water table elevations indicated by horizontal line in circle

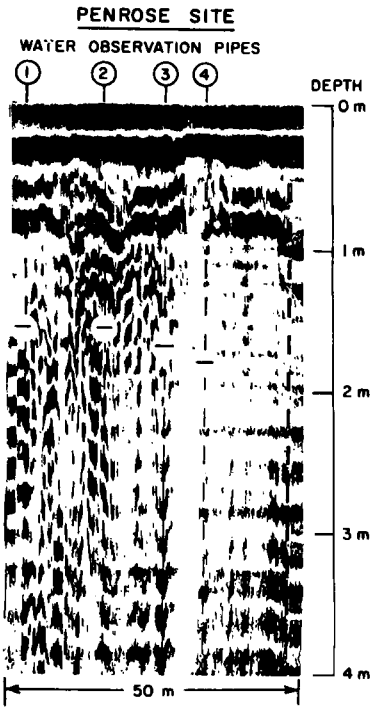

Figure 4.
Pulsed RF Survey of Penrose Site made on April 3, 1981 with actual water table elevations indicated by horizontal line in circle

varies in thickness above the water table is saturated, or nearly so, and has a theoretical height of:

$$h_c = \cos\alpha \frac{T_o}{\gamma_\omega} \frac{1}{d_v}$$

where

h_c = height of capillary rise

α = wetting angle of water to soil

T_o = surface tension force of water to soil

γ_ω = unit weight of water

d_v = average soil void diameter

Thus, height of capillary rise is inversely proportional to the average soil void diameter. Easily seen is that coarse grained soils (gravels, sand and their mixtures), with large particle sizes hence proportionately large void sizes, have very little capillary zones, e.g., the soils at the Wharton site.

This is not the case for the Springfield and Penrose sites, both of which had predominantly fine grained soils (silts, clays and their mixtures). At both of these sites the actual water table was not possible to locate and was completely dominated by stratigraphic changes in soil layers. Seen at the Springfield site was a undulating horizontal layering, while at the Wharton site the distinction was between two different soils placed beside one another.

In conclusion, the use of pulsed RF methods can be used in seepage detection in granular soils, but not in fine grained soils. This is not a particularly disastrous limitation because it is the granular soils which have high permeability, hence seepage problems are more acute in these soil types. For the fine grained soils a spill, or other incident involving liquids, will be contained relatively close to the spill location due to the much lower soil permeability. Thus, in its proper setting, pulsed RF methods can be used for groundwater monitoring and the related problem of spill detection.

ACKNOWLEDGEMENTS

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INTEGRATION OF REMOTE SENSING TECHNIQUES WITH DIRECT ENVIRONMENTAL SAMPLING FOR INVESTIGATING ABANDONED HAZARDOUS WASTE SITES

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INTRODUCTION

Abandoned hazardous waste sites present varying degrees of difficulty to investigators. For example, abandoned sites which are really extensive, rural (with hindering vegetation) or in areas of complex geology and hydrology, represent troublesome environments for investigation. Therefore, it is important to develop approaches for thorough, but rapid and cost-effective assessments of these difficult situations. In most cases, a well designed and executed investigative program will include remote sensing techniques in addition to direct measurement. Premature action to drill wells, collect and analyze various air, water and soil samples or perform excavations without careful planning and proper integration of available techniques may result in an unnecessary exposure to hazardous conditions and in an inaccurate or incomplete understanding of the total problem.

Remote sensing techniques may be used to provide reasonably accurate assessments of subsurface contamination, the location and extent of buried drums and other data needs for determining appropriate methods of abatement. However, not all the critical information can be obtained remotely, since each of the techniques has limitations, both theoretical and site-specific and consequently, direct sampling should be undertaken at every uncontrolled hazardous waste site.

To accomplish site investigations in the most efficient manner, a systematic approach is necessary to take advantage of the information that can be extracted from remote sensing methods. In addition, a systematic approach allows a reduction in the time and cost and an increase in the effectiveness of direct sampling.

In general, the following two objectives must be addressed by all investigations at uncontrolled hazardous waste sites:

1. Determination of the nature and extent of the problem and the resulting effects on public health (both actual and potential)
2. Determination of environmentally sound and cost-effective methods to effectively abate the problem (if abatement is deemed necessary).

The first activity of any investigation should be the identification of the specific data needed to meet each objective. After this has been accomplished, the various techniques available for data acquisition, both remote and direct, can be evaluated with regard to the type of information that can be obtained from each in relation to the specific conditions at the site.

Although not always the case, it may be reasonably assumed that remote sensing techniques should be used in advance of the more direct data acquisition methods of borings or excavations. This is not intended to imply, however, that all direct sampling should be held in abeyance. There have been numerous instances in which emergency action is dependent upon immediate results from air, water and soil sampling, and for such cases remote sensing techniques should be used secondarily.

The purpose, advantages and limitations of each of the four remote sensing methods discussed in this paper are summarized in Table I. This material should be consulted prior to the development of an investigatory program. Even though there are disadvantages inherent to each technique, proper sequencing and phased studies can potentially result in an overall optimized approach.

As the study progresses, preliminary conclusions will necessarily be modified and the nature of direct sampling activities will need to be evaluated continuously. Final conclusions should not be drawn solely from the results of remote sensing methods. Direct sample collection should be undertaken for all studies.

Because no single procedure would be appropriate for all site investigations, the conditions at an uncontrolled hazardous waste site in Coventry, Rhode Island will be used for the basis of development of systematic procedures with the expectation that some of the concepts can be applied elsewhere, as appropriate.

The sequence of activities discussed on the following pages represents the idealized case and may not necessarily have been followed in actual practice during an investigation performed by MITRE at the above site. This is due to the fact that one of the purposes of the site investigation was to evaluate the capabilities and limitations of the selected remote sensing methods. The exact

Table I.
Comparison of Remote Sensing Techniques

Technique	Purpose	Advantages	Limitations
Electrical Resistivity			
Lateral Profiling	• determine lateral extent of contaminated ground water • facilitate placement of monitoring wells and optimize their number • monitor changes in plume position and direction	• procedure less expensive than drilling • procedure more rapid than drilling • equipment light-weight, able to be hand carried • survey may be conducted in vegetated areas	• limited ability to detect non-conductive pollutants • technique unsuitable if no sharp contrast between contaminated and natural ground water • interpretation difficult if water table is deep • interpretation difficult if lateral variations in stratigraphy exist • interpretation difficult if radical changes in topography are not accounted for in choice of A-spacing • technique unsuitable in paved areas or areas of buried conductive objects
Depth Profiling	• indicate change in contamination with depth • establish vertical control in areas of complex stratigraphy	same as above	same as above
Seismic Refraction (Non-explosive Method)	• determine depth and topography of bedrock • determine depth of trench containing buried drums	• procedure less expensive and safer than coring or excavation • procedure more rapid than coring or excavation • survey may be conducted in vegetated areas	• technique unsuitable if no sharp velocity contrast between units of interest (e.g., trench containing buried drums and surrounding soil) • survey requires access road for vehicle • depth of penetration varies with strength of energy source • low velocity unit obscured by overlying high velocity units • interpretation difficult in regions of complex stratigraphy
Metal Detection	• locate areas of high metal content (e.g., buried drums)	• procedure less expensive and safer than excavation or radar • procedure more rapid than excavation or radar • equipment light-weight, able to be hand-carried • survey may be conducted in vegetated areas	• technique unsuitable for the detection of non-metallic objects • technique unsuitable for objects below five feet • technique unsuitable for determination of number or arrangement of buried objects
Ground-Penetrating Radar	• locate buried objects (e.g., buried drums) • provide qualitative information regarding drum density • detect interfaces between disturbed and undisturbed soil (e.g., bottom of trenches) • detect plumes of high chemical concentration	• procedure less expensive and safer than excavation • procedure more rapid than excavation • procedure deeper-penetrating than metal detection • procedure yields more information than metal detection • procedure may be used over paved areas	• technique unsuitable for vegetated areas • data requires sophisticated interpretation • underlying objects obscured by those above • survey requires access road for vehicle

investigating procedures, the results of the investigation, and an evaluation of options for abating the hazardous conditions there are found in two MITRE Corporation reports.[1,2] An evaluation of the remote sensing techniques themselves is the subject of a report by Cichowicz *et al.*

The following conditions existed at the Coventry site at the outset of the investigation:

- An unknown number of drums buried on a cleared seven-acre site; location of drum burial areas incompletely known
- An unknown quantity of unknown chemicals bulk-discharged into trenches on the site
- Surface discharge of chemicals at a swamp, 1200 feet away and 50 feet lower than the site
- Potential for groundwater to flow away from the site over an arc of approximately 270°, two-thirds of which was moderately vegetated, not including the swamp
- Subsurface material consisting of hard, boulder-studded glacial till amid numerous bedrock outcrops.

As was stated earlier, data should be collected during site investigations to achieve two general objectives: (1) understanding of the nature and extent of the problem and (2) determination of methods to abate the problem. Although these data needs may overlap in many instances, it

is helpful to keep them both in mind separately when planning an investigation. The integration of remote and direct sampling methods is therefore presented in the context of meeting these two separate goals.

DETERMINATION OF NATURE AND EXTENT OF PROBLEM

The following items had to be determined for a comprehensive understanding of the nature and extent of the problem at the Coventry site:

- Direction, rate, and extent of subsurface migration of contaminants
- Location of surface discharge areas of contaminated groundwater and the subsequent fate of the contaminants
- Identification of contaminants
- Location of areas of contaminated soil and buried drums and determination of the potential of this source of pollutants for long-term release.

An example of a systematic approach to achieve the above objectives is presented in Table II and the phasing of site activities is shown by Figure 1. In Figure 1 a two-phase monitoring-well installation and sampling program is shown. The purpose of a phased investigation is to obtain a preliminary understanding of the problem prior to final planning of all direct sampling in order to more effectively guide subsequent activities. Additionally, this figure shows that, in general, remote sensing precedes direct sampling in order to reduce the time and cost of the latter and to help ensure that the full extent of the situation is identified.

For buried drums, metal detection, rather than ground-penetrating radar should be used to locate the burial areas because of the relatively lower cost and greater portability of the former technique. However, radar has greater penetration and should be used in all areas where drums are suspected but not found by metal detection.

Limited excavation may then be required to gain information about the depth, condition and contents of the drums so that the concept of total drum excavation and chemical disposal can be evaluated with the other abatement alternatives. Limited excavation was considered feasible for the Coventry site since total drum excavation did not appear significantly more expensive than other abatement alternatives.

Surface water, groundwater and soil sampling are necessary for any hazardous waste site investigation. Monitoring wells are best located once the extent and direction of the plume have been determined by a resistivity survey. Monitoring wells should be placed at the following locations:

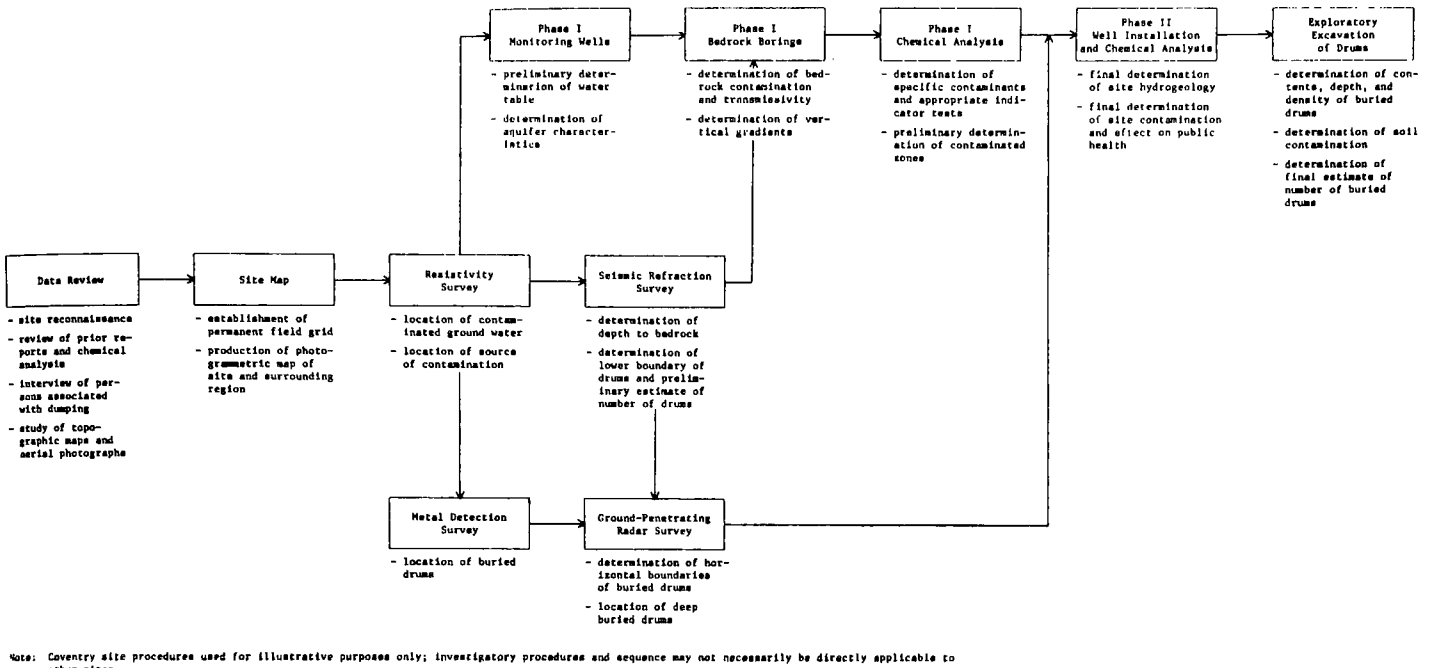
- Upgradient from the source of contamination (to monitor background conditions)
- Outside of the plume downgradient from the source of contamination (to verify the extent of the plume and to monitor its movement)
- Within the plume close to the source of contamination (to obtain samples before extensive dispersion, dilution or attenuation)
- Within the plume at the outer extent of contamination (to observe dispersion, dilution and attenuation).

Table II.
Systematic Approach to Determine Nature and Extent of Problem at Coventry Site

Objective	Data Needs	Investigatory Methods	Comments
1. Direction, Rate, and Extent of Subsurface Contaminants	• determine areal extent of contaminated ground water	• assess hydrogeologic and geologic settings of the site by reconnaissance and study of topographic maps, aerial photographs, and all existing data	• establish permanent field grid for use by all remote sensing surveys; grid locations can be transferred to site map by aerial photography or land survey
		• conduct vertical resistivity profiles in various locations to determine approximate depths of contamination	• choose wide enough A-spacing for lateral survey to minimize influence of variations of anticipated depth to ground water from ground surface
		• conduct lateral resistivity survey choosing A-spacing based on results of vertical resistivity profile	
		• install monitoring wells inside and outside of contaminated zones as defined by resistivity survey for confirmational purposes	
	• determine vertical extent of contaminated ground water	• conduct seismic refraction survey over contaminated area to determine depths to bedrock and vertical subsurface profiles	• use established field grid for seismic survey
			• use results of seismic refraction survey to select most economic locations for bedrock borings
		• install cluster wells consisting of borings screened in soil and in bedrock both inside and outside of contaminated zones	• determine whether vertical gradients exist and whether contaminants are present in bedrock fractures
			• install bedrock wells as a second-phase drilling effort and install any additionally-needed monitoring wells based upon first-phase results

Objective	Data Needs	Investigatory Methods	Comments
	• determine direction and rate of subsurface migration	• install minimum number of monitoring wells to define ground water flow; well locations should be based on results of resistivity survey and chemical analytical needs (see third objective in this table) • perform in-situ permeability tests in selected monitoring and bedrock wells	• because the ground surface contours at Coventry site indicate a potentially large arc of subsurface travel, wells at edge of contaminated zones were necessary to detail direction of outer fringe of pollutants • install cluster well upgradient of pollutant source to determine background conditions
2. Location of Surface Discharge Areas of Ground Water Contamination and Determination of Fate of Pollutants	• locate surface discharge areas	• reconnoiter site; locate discharge areas by sight and air quality measuring devices • use results of electrical resistivity and water table map to identify surface receptors of subsurface discharge	• use air quality measuring devices to determine areas of poor quality, indicating surface discharge points: also indicates areas requiring breathing protection devices
	• determine fate of pollutants	• conduct downstream sampling, including rate of flow of surface water • sample sediment and air around discharge area	• mass balances should be calculated for principal pollutants to determine ultimate dispersion mechanism(s) • upstream sampling necessary for background conditions • all water wells and surface waters used for potable water supplies within a mile radius should be precautionarily sampled
3. Chemical Identification of all Principal Contaminants	• determine principal contaminants	• analyze composite samples from selected wells and surface waters for priority pollutants • analyze selected wells and surface waters for selected compounds based upon priority pollutant analysis	• composites made up of wells close to source of pollutants and surface discharge areas: should limit each composite to only two adjacent wells
	• determine dispersion of contaminants	• select indicator analyses based upon priority pollutant screening: include general water quality tests (pH, conductivity, iron, chloride, TOC)	• indicator analysis provides relatively low cost method for non-specific monitoring of pollutant levels in monitoring well network
4. Location of Areas of Buried Drums and Contaminated Soil and Determination of Lifetime of Future Release of Chemicals	• locate areas of buried drums and contaminated soil	• reconnoiter site; search for areas of disturbed soil or vegetation, or areas of discolored soil • interview persons involved with dumping activities for information concerning location of trenches and method of operations • study previously taken aerial photographs to obtain historic information • use results of resistivity survey to locate source of contaminated ground water • conduct metal detection survey over all cleared or disturbed areas of site • conduct ground-penetrating radar survey in burial areas located by metal detection survey	• use established field grid for metal detection and ground-penetrating radar survey • metal detection used in advance of ground-penetrating radar because of lower cost and ease of use; however, radar has greater penetration and should be used in all areas where drums are suspected, but not found by metal detection
	• determine lifetime of future release of chemicals	• conduct seismic refraction survey over drum burial area to determine depth of drums • perform limited excavation of buried drums to determine: condition and contents of drums, density of drums, lower boundary of drums • sample soil in drum burial areas and bulk chemical discharge area; analyze extracted leachate for specific chemical compounds determined by priority pollutant screening	• effectiveness of seismic refraction method to determine lower boundary of buried drums remains subject to verification • drum excavation limited to data gathering only and should be terminated when sufficient information obtained; refer to Phase II project report (referenced in Section 1) for recommendations regarding excavation procedures • drum excavation should be conducted after all other site activities completed in order to minimize personnel on site

Note: Coventry site procedures used for illustrative purposes only; investigatory procedures and sequence may not necessarily be directly applicable to other sites.



Note: Coventry site procedures used for illustrative purposes only; investigatory procedures and sequence may not necessarily be directly applicable to other sites.

Figure 1.
Recommended Sequence of Activities at Coventry Site

The depth and topography of the bedrock should be defined, not only to evaluate certain abatement methods, but also to economically locate the deep borings that may be needed for bedrock sampling, permeability testing and water sampling. Seismic refraction is a very effective tool for providing remote information on the configuration of subsurface strata. Additionally, the results can be used to locate bedrock wells, the position of which will depend upon the objectives of the investigation. For example, some investigators may wish to install bedrock wells only to determine formation integrity as an acceptable base for certain abatement alternatives. Other investigators may be interested in locating bedrock wells to determine the presence of contaminants in specific regions or channels.

DETERMINATION OF METHODS TO ABATE THE PROBLEM

The data needs for selecting and determining the cost of abatement alternatives (Table III) are similar to those required for understanding the nature and extent of the problem at the Coventry site. However, the two objectives are best addressed separately, since the location for direct sampling and remote sensing may differ between the two, as may the use of the information obtained.

It is possible to use remote sensing techniques as a "negative screening" step in the evaluation of certain abatement options. An example of this concept is given in the case of evaluating source encapsulation as an abatement technique for the problem at Coventry. For encapsulation to be feasible it is necessary to have a low permeability base within a relatively shallow depth from the ground surface. Seismic refraction has the potential to determine whether the bedrock underlying the source of contamination should be ruled out (negative screen) or consideration as an acceptable base.

If, after a seismic refraction survey it is found that the bedrock is either too deep or too fractured to function as

Table III
Major Informational Needs for Implementation of Certain Abatement Activities at Coventry, Rhode Island

Alternative	Informational Needs
Removal of Buried Drums and Disposal of Chemicals	Drum Condition Drum Number Drum Contents Trench Location and Geometry
Encapsulation of Source	Drum Contents Imperviousness of Underlying Strata Level(s) of Contamination (soil and/or groundwater and/or bedrock) Trench Location and Geometry
Collection and Treatment of Leachate (trenches and/or wells)	Areal Extent of Contamination Type of Contamination Concentration of Contaminants Imperviousness of Underlying Strata Aquifer Characteristics
No Action Alternative	Drum Contents Drum Condition Level(s) of Contamination (soil and/or groundwater and/or bedrock) Type of Contamination

an effective base, then rock coring is unnecessary. The information obtained by this method is not sufficient, however, to prove that the bedrock is sufficiently sound for encapsulation without actual test borings and field-permeability tests.

There is one investigational method for estimation of the number of buried drums which is listed in Table II and not included in the discussion of the preceding section. The remote sensing technique of seismic refraction can determine the lower boundary of buried drums. The results of an exploratory excavation can be compared to the seismic profiles obtained at a particular location and if valid, the seismic profiles for all other buried drum areas may be used for drum number estimates. If there is no correlation found between the seismic profile and the excavation (of if an exploratory excavation is not desired), it is recommended that the maximum feasible excavation depth or depth to bedrock be used for the lower boundary of the buried drums.

ACKNOWLEDGEMENTS

The work on which this paper is based was supported under MITRE contracts with the U.S. Environmental Protection Agency, Solid and Hazardous Waste Research Division, and the State of Rhode Island, Department of Environmental Management. The encouragement and interest of Mr. Donald Sanning of the EPA is especially noted. The contributions to the site investigation of Mr. Paul Stoller and Dr. Harold Yaffe of MITRE and Ms. Nancy Cichowicz, formerly of MITRE and presently with ERT, Inc., are also acknowledged.

The actual results of the Coventry investigation are found in a paper by Yaffe *et al.*[4]

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SURVEY AND ANALYSIS OF PRESENT/POTENTIAL ENVIRONMENTAL IMPACT SITES IN WOBURN, MASSACHUSETTS

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INTRODUCTION

The U.S. Environmental Protection Agency, Region I, initiated a request through EPA Headquarters to the Environmental Photographic Interpretation Center (EPIC) for a survey and analysis of a heavily industrialized area (approximately 16 square miles) surrounding North Woburn, Massachusetts. The purpose of the study was to establish the ambient environmental condition of this area, where various industries have produced a high output of industrial and chemical products for more than a century. Many of these industries are alleged to have dumped or buried spent chemicals and by-products, which are a suspected source of endemic health effects in the vicinity.

Analysis of historical cartographic and photographic sources and current aerial imagery can supply continuous information to search efforts in the field, thus reducing the time anc cost of locating test sites, abandoned or unpermitted dumps, and areas of environmental damage. Through the utilization of imagery, sites can be located and analyzed in a matter or hours or days by a single analyst, as opposed to time-consuming ground searches by inspection crews themselves.

Currently, field tests are being scheduled to coincide with the receipt of incremental site assessments forwarded from EPIC upon completion.

Located north of Boston, Woburn is a town with a long history of industrial activity. Since the 1850's, industries have manufactured products which include: chemicals for textile, paper and leather processing; explosives, hide and bone glue and arsenic-based pesticides. The wastes from these products were frequently disposed of on grounds surrounding the factories. A tract of approximately 120 acres containing abandoned dump sites, building ruins, waste pits and a new industrial park is the main focus of an area-wide survey to determine the extent of present or potential environmental hazards and ambient environmental conditions.

Presently owned and controlled by prominent area developers, this tract is a valuable piece of commercial real estate. Its location in close proximity to I-93 and Route 128 resulted in a surge of expansive redevelopment creating the industrial facility known as Industri-Plex 128. Purchased in 1968, the tract has yielded vast amounts of industrial by-products during excavation for future commercial sites. Public attention was drawn to this area in the mid-1970's when hydrogen sulfide odors were emitted by rotting hides and animal wastes unearthed during construction. Complaints were made to the State of Massachusetts by residents of neighboring communities affected by the fumes. In a separate but coinciding incident, an EPA employee reported a possible case of illegal wetlands filling. Unpermitted, the filling was halted; subsequent testing by the EPA and the U.S. Army Corps of Engineers revealed concentrations of arsenic, hexavalent chromium and lead. Research into prior land use along this strip indicated past utilization for chemical waste disposal in ponds and lagoons, as well as for a dump site by various tanners and renderers.

Subsequent sampling of water throughout the Woburn area revealed two municipal wells in North Woburn to be contaminated with the solvent trichlorethylene (TCE), a suspected carcinogen. The source of the contamination by this compound is unknown.

Woburn has experienced a higher than normal rate of cancer, approximately 13% higher than Department of Health Statistics predicted, especially in a neighborhood known as Walnut Hill located less than a mile south of the industrialized corridor. Eight of fourteen reported cases of leukemia have occurred within a half-mile radius of one another in this small residential development.[1] As yet, no cause-and-effect correlations can be drawn for this occurrence.

AREAS OF CONCERN

Seven sites and surrounding areas, including the industrial park, were chosen for in-depth analysis of present and historical land use. Known industrial and commercial uses of these tracts include: the sites for tanneries and glue manufacture, chemical processing, and extraction and landfilling operations.

As of July 1981, sets of prints, overlay series and texts concerning the Woburn study area have been forwarded incrementally upon completion to Region I for use by EPA Massachusetts Department of Environmental Quality Engineering (DEQE) and the field inspection team (FIT).

The focus of critical concern from impact by uncontained wastes is the quality of surface and subsurface water in the study area. A review of historical aerial photography shows that major changes have occurred in surface water paths, wetlands and terrain throughout the Woburn area.

Although alteration of these features through excavation, filling, dredging or construction may re-route surface drainage or re-shape impoundments, subsurface water will often resume its flow in the original stream bed, along the path of least resistance. Fluid or viscous waste and leachate from buried contaminants will flow under gravity to groundwater levels and form plumes along the stream. These plumes may extend under many acres of ground if the source is unchecked.[2] Locating the point source of subsurface water contamination can be facilitated by examining historical land use in the drainage basin.

Slightly less critical, because of its more stationary nature, is soil contamination. Sites with possibly contaminated fill material can also be identified through historical imagery analysis.

In the realm of air quality, past and present offenders may be noted by the presence of vents, stacks, fans and similar exhaust structures.

METHODOLOGY

Use of Historical Cartographic Records

Since aerial imagery of the United States is scarce or non-existent prior to the late 1920's, land use before this period may be largely unrecorded. Human memory is subject to error; interviews with area residents on historic usage may yield conflicting data or place sites far from where they actually existed. In regions such as Woburn, it is apparent that many major alterations probably occurred between the inception of industrial land use in the 1800's and the first available photography in the 1930's. In order to assess past environmental influences, research was undertaken at the U.S. Library of Congress for plots, documents or cartographic records of properties which were recorded in the late 1800's or early 1900's.

In the Geography and Maps Division, the Sanborn Fire Insurance Maps[3] were the focus of attention. Developed to record safety precautions and hazards associated with structures in the towns, they provide valuable information on conditions in an area beginning in the 1800's.

Coverage of Woburn begins in 1888 and ends in a series of 1926 maps corrected by paste-ons in the 1930's and again in 1947. An example of the type and extent of information found on the maps is the Merrimac Chemical Company sheet. In 1888, Merrimac Chemical occupied a site in North Woburn adjacent to the railroad (Figure 1). Each structure is plotted, and the building contents or process described. At this time, the major compounds present were sulphur, lead, muriatic acid and alum. By 1904 (Figure 2), the number of buildings had increased and substances such as chloride of aluminum, bauxite and pyrite had been added to the inventory. Moving chronologically through the maps, it is possible to see the transition of Merrimac Chemical (1888) to include New England Manufacturing Company Chemical Works (1918) and its evolution into Consolidated Chemical Industries Co. Glue Plant (by the 1940's), along with details in process changes and on-site materials. The most recent transitions were revealed by aerial imagery. The site remains a functioning chemical process plant in 1963 (Figure 3), and is finally seen as a razed, abandoned site in 1980 (Figure 4).

An example of the value of these cartographic records in extreme land-use changes is depicted by the reproduction of a block in the town of Woburn in 1894 (Figure 5). This lot had been the site of a leather company since 1888. In 1904, it is recorded as American Hide and Leather Co. Factory H (closed); in 1918, the lot contains scattered residences and open ground. By 1926, the block contains many residential units. This block, as it appeared in 1963, is centered in Figure 6.

In a rough preview count, 14 of 48 selected sites traced through the maps became residential, commercial or vacant areas by the 1940's. Each of the 48 sites will be checked against the aerial imagery for 1938 and 1963 to determine the continued development of these historic industrial grounds.

The utilization of Sanborn Maps in hazardous waste studies is also being pioneered in a current project for Stroudsburg, Pa. Concerned with contamination from no apparent sources, Sanborn Maps checked for the years 1905, 1912, 1923, 1930 and 1950 disclosed the location of a coaltar injection well and two storage tanks which no longer exist. No previous knowledge of the location of these features was apparent in the region.

Use of Historical Aerial Photography

In order to accomplish a comprehensive, detailed data base on locations of present and former excavation and fill sites, streams, bogs, wetlands and impoundments, as well as industrial locations, a survey utilizing historical and current aerial photography was undertaken. Historical black-and-white imagery was obtained for December 1938, April 1963 and April 1978, from the U.S. Geological Survey and the National Archives. Current true-color imagery was obtained in November 1980 under contract by EPIC.

The photo frames were chosen at the scale of 1:24,000 for the historical, and obtained at 1:10,000 for the color. Each of the seven primary areas of concern was plotted on overlays to USGS quadrangle maps (scale 1:24,000) and analyzed from the imagery for both minute and massive alterations which may have occurred over the 42-year span. With the location illustrated on the map overlays, the specific details of site variation were plotted on clear mylar overlays to enlarged photos of each year of coverage per site. The scale of the enlargements varied from site to site. An example of drastic change, illustrating the type of details found, is evident in Figures 7 and 8. In 1938, (Figure 7) large lagoons and trenches for liquid waste run along the western boundary of the plant property. This same section in 1963 (Figure 8) is the site of additional plant structures, an access road and a filled lot with only a single narrow trench visible. The surrounding locale has experienced development and the addition of major transportation routes.

In order to obtain and evaluate information such as this from aerial imagery, film transparencies are backlit on a standard Richards light table and examined in stereo through optics capable of magnification up to 30x. A

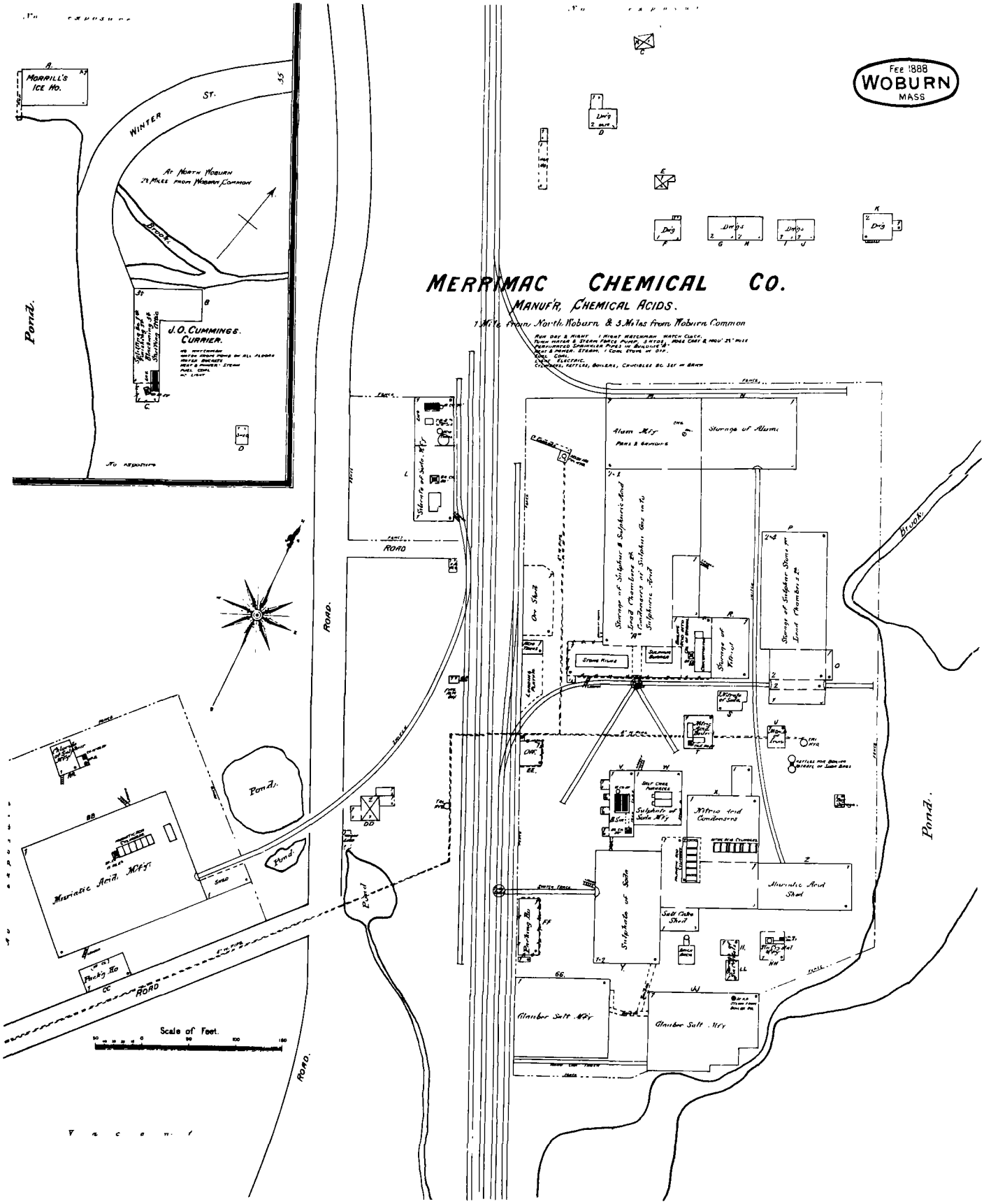

Figure 1.
Merrimac Chemical, Sanborn Maps, 1888

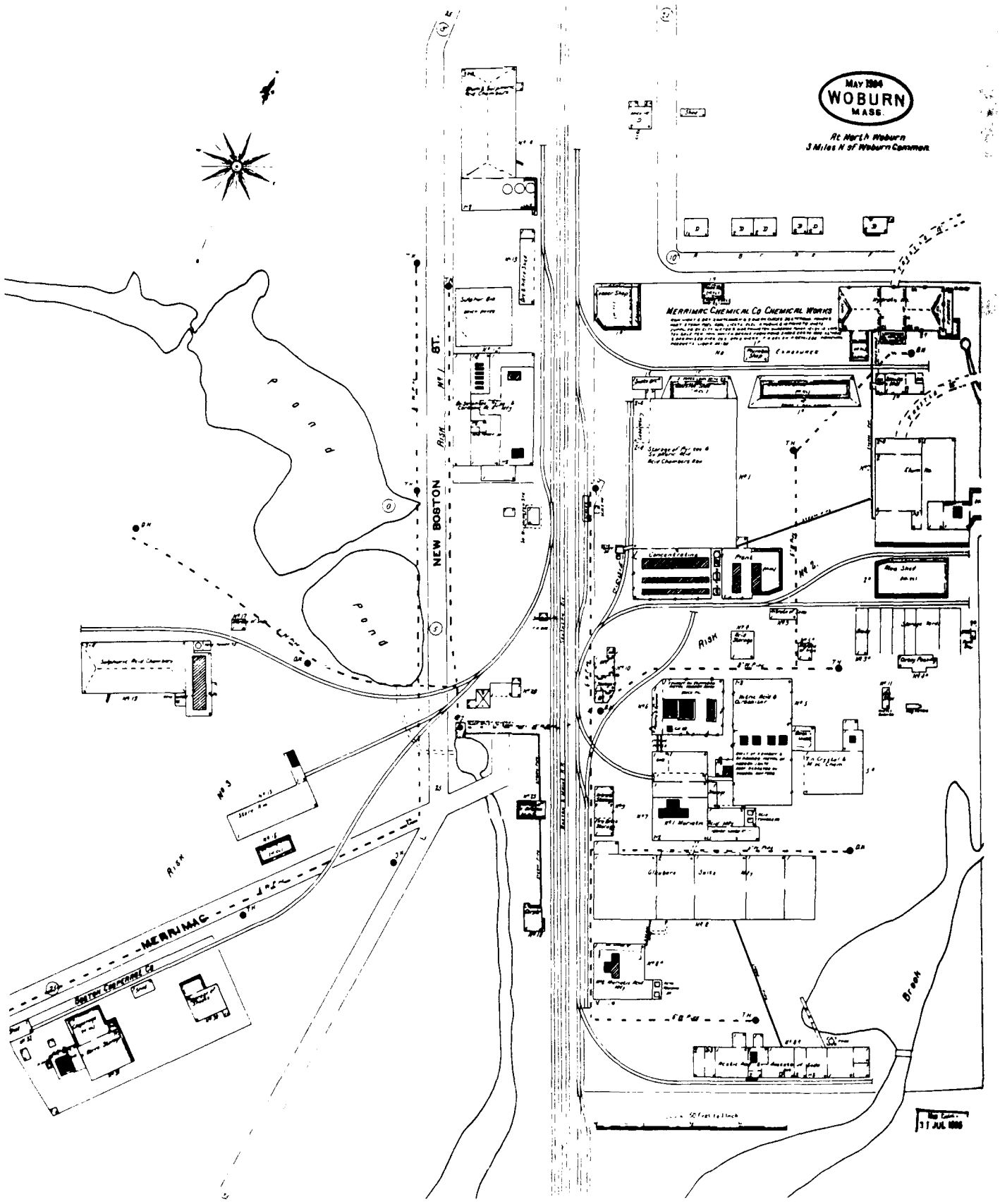

Figure 2.
Merrimac Chemical, Sanborn Maps, 1904

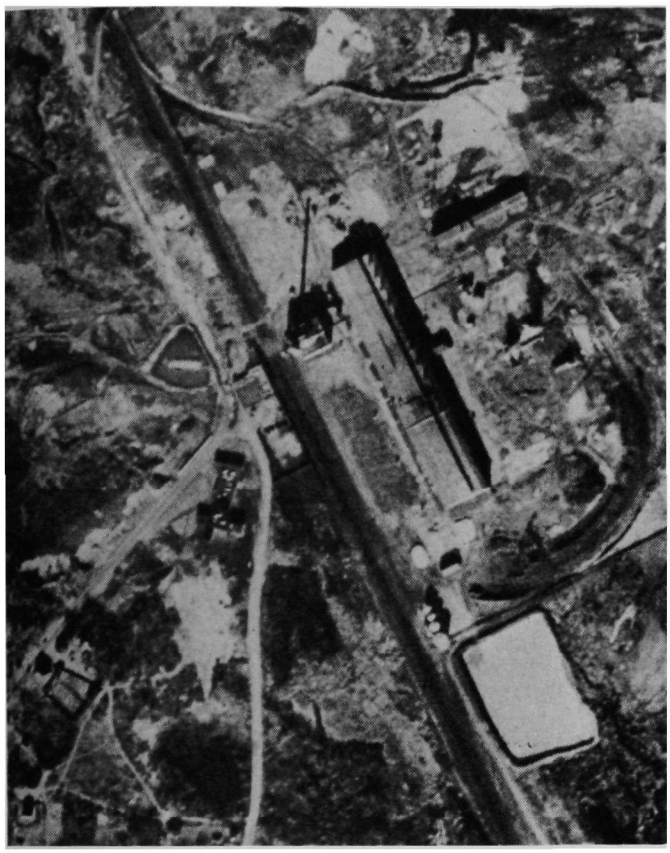

Figure 3.
Old Merrimac Chemical Site, 1963

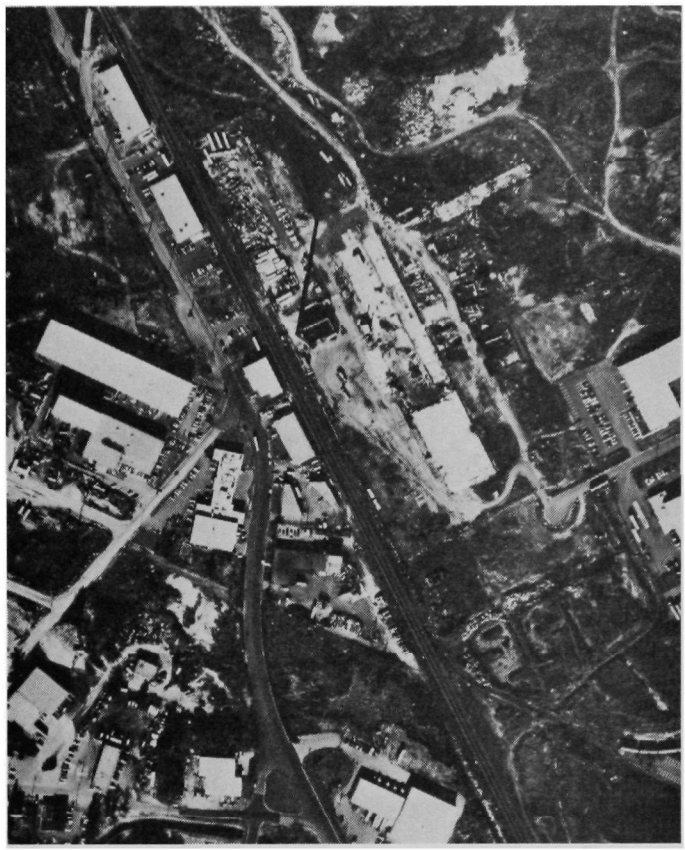

Figure 4.
Old Merrimac Chemical Site, 1980

trained analyst examines each site for details concerning terrain, structures, ground disturbance, impacted drainage, discarded material, land use of the locale and "signatures"* of other elements of environmental influence. In general, examination of terrain features, structures, drainage and land use is fairly straightforward; the detection of drums, rubble, offal or evidence of underground structures requires close scrutiny and reliance on surrounding information for detection. All pertinent information regarding the site is recorded on the overlays for location; a corresponding text contains details and conditions of all possible past and present impact points.

In cases of confirmed or suspected waste disposal or other pertinent environmental factors, comparisons will be made by engineers in the region against local hydrologic, geological and air, studies to determine possible cause-and-effect correlations, the extent of any effects, and other related factors. From this information, fields checks will be performed on soil and water quality. At EPIC, when the photographic analyses have been performed, a computer system is utilized to locate and chart the exact location of sites to guide field sampling efforts. EPIC's Imagery Analysis System (IAS), designed by Calma, is capable of rectifying photo-to-map scales in order to plot points directly from imagery to a standard map. The system is also able to determine the exact geocoordinates for an individual site or set of points and to compute the area of a chosen feature. Using this information, the field inspection team can quickly and effectively locate precise points from which to extract samples.

In addition to the site-by-site analysis, a survey of the entire Woburn study area was performed to locate any dumps, impoundments, fill mounds, extractions, industries or junkyards in each year of imagery coverage. The sites were located numerically on a series of clear overlays to USGS 1:24,000 quadrangle maps, and a brief description, by site, for each year was included in an inventory list (Figure 9). The transformation of a site from a hillside farm in 1938 to an extraction site and back to a filled meadow by 1980 can thus be quickly surveyed. A survey is also being performed at 10-year intervals from the Sanborn Maps of the study area between 1888 and 1947.

To accompany the site survey, two additional series of overlays were developed to illustrate historical to present drainage transformation and land-use patterns. Included on the drainage overlays were streams, bogs, wetlands, natural lakes and ponds, and man-made features including dams, industrial lagoons and impoundments. This series can provide much needed data on original water courses in sections of disturbed drainage. When used in

*The term "signature" is used to describe a particular pattern, shape, tone or color which consistently indicates the presence of an object, material, etc. on aerial imagery, even though the object itself may be indistinguishable.

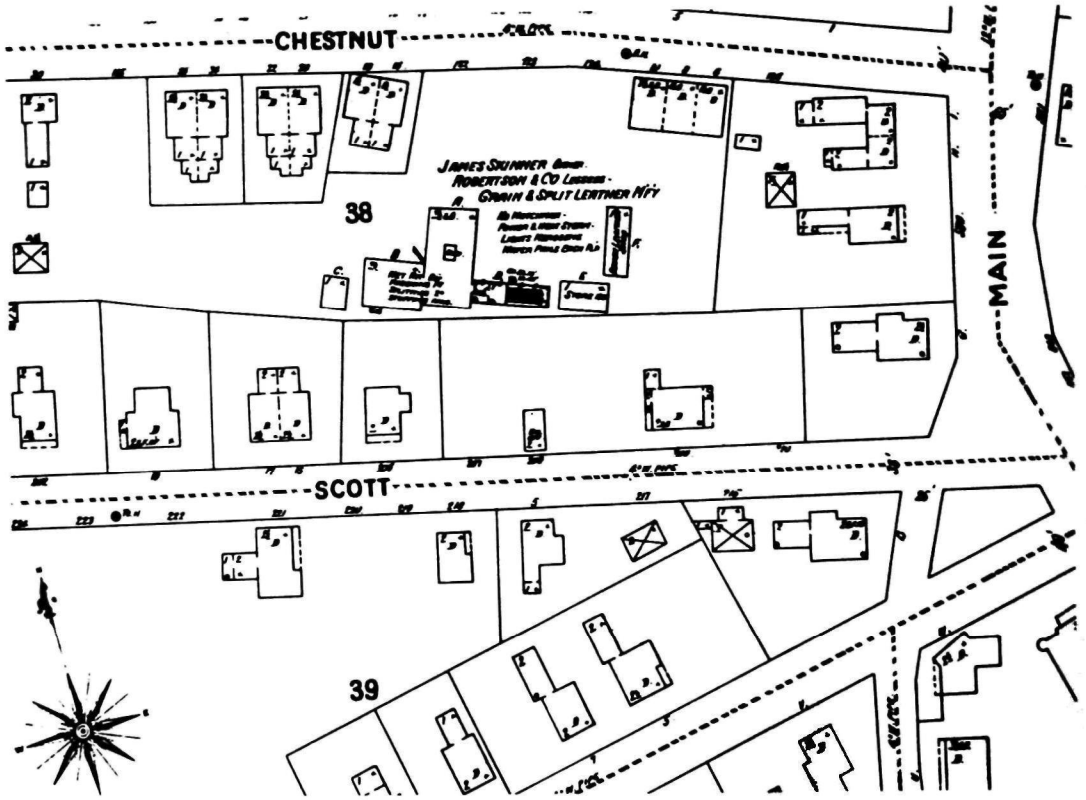

Figure 5.
Block of Chestnut and Scott Streets
Sanborn Maps, 1894

Figure 6.
Block of Chestnut and Scott Street, 1963

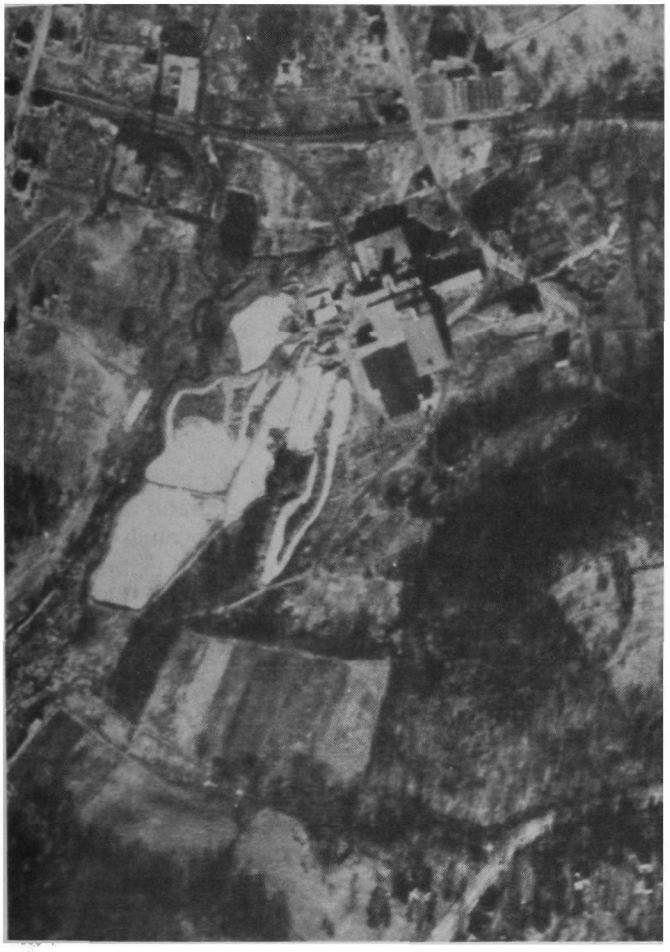

Figure 7.
Waste Lagoons; Industrial Site, 1938

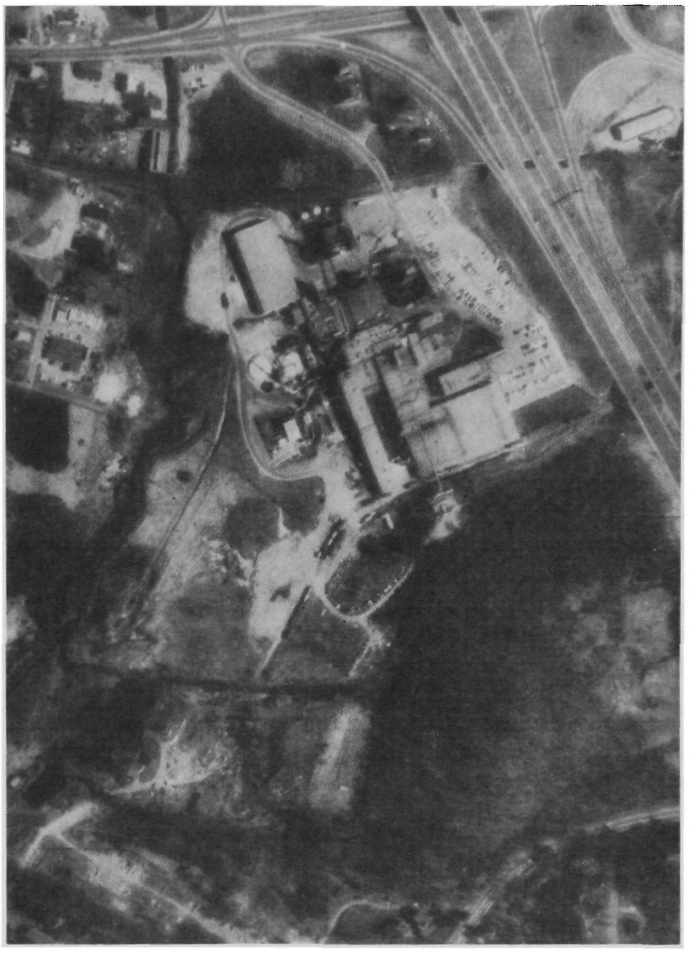

Figure 8.
Waste Trench; Industrial Site, 1963

conjunction with the site overlays, possible point sources of subsurface water impaction may be located, and abatement procedures formulated.

The land-use series employed a system of mapping land usage categorized down to Level III, modified from the USGS Land Use Classification System.[4] For example, Category 2 in this system covers agricultural land use; at Level III, sub-categories are determined and broken out for crops (211), pasture (212), fallow (213) and orchards (22). The drainage series and the land-use series together can show historical patterns of agricultural run-off, possible paths of industrial waste or leachate flows, and locations of liquid dump sites. Findings such as these can assist in evaluating deposits of contaminants not associated with present land usage and drainage tendencies.

Site 1—
1938: Agricultural use; barn, residence
1963: Extraction site
1978: Extraction site
1980: Filled, revegatated meadow

Site 2—
1938: Agricultural field
1963: Auto junkyard
1978: Construction site
1980: Residential development

Figure 9.
Sample inventory list for site comparison

VERIFICATION OF FINDINGS

Upon the completion of the analyses of the seven specific sites and at mid-point in the area-wide site inventory, a ground-truthing meeting was held by the imagery analyst and representatives of the Massachusetts DEQE and EPA Region I office. The comparison of data obtained from the four sets of imagery at EPIC and information researched by the DEQE (including different sets of aerial imagery and historical information on zoning uses of some properties) confirmed a high level of accuracy. Field inspection of several sites also yielded confirmation of suspected historic use not found on the present color imagery. An example of this occurred during an inspection of a tannery site. Historical imagery revealed plumes of sludge assumed to be chromium wastes along a slope at the rear of the property. The 1980 color imagery showed only natural-toned earth in this section. From the ground at close range, however, a very light tone of pale yellow was observed emerging in several places. Pale and

bright yellow tones are sometimes indicative of chromate leachates.

In another case, historic analysis showed "soft" mounds of waste, which appeared to be hides, on the lot of a plant. Although the dumping of hides was not reported or suspected at this site, a walk through the abandoned site turned up several scraps of old hide in a historically filled area. Some information given to the state representative by local residents who recalled past dump sites and industrial uses also indicates a correlation with information gained from the imagery. The results of samples gathered by the field inspection team will determine the accuracy of selecting sites by imagery analysis.

ASSESSMENT OF MODE OF ANALYSIS

The procedure of site and area analysis via remote sensing is an effective, time-saving and economical method for determining environmental conditions in both the past and the present. Although it has been employed in Woburn as a locating device, imagery analysis is extremely useful in monitoring control and clean-up operations and in emergency response for assessing areas of immediate danger.

The utilization of historical imagery for a current national concern emphasizes the importance of maintaining imagery obtained in the past. It is invaluable for research in this mode; it does not describe what may have been but shows what actually existed at a given time and place.

The use of historic cartographic records such as the Sanborn maps, unprecedented in hazardous waste assessment, also illustrates the necessity for preserving historical records. The existence of such a detailed record of materials and industrial site locations long before the hazards of chemical wastes were realized has contributed much information on potential impact sites where no immediate signs of danger may otherwise have been noted.

CONCLUSIONS

To date, the impact of uncontrolled hazardous wastes upon Woburn has not been as spectacular nor as immediately devastating as at Love Canal although the essence of the situation is the same. It is the intent of those involved in the aerial analysis of the area to provide data which may prevent damage from dormant wastes, and aid in the control and clean-up of sites known to be a problem.

In combination, historical imagery and cartographic references can supply information for all areas in the United States where past land usage may pose a potential threat to the quality of the environment, as has already occurred in the vicinity of the town of Woburn, Massachusetts, in Memphis, Tennessee, and at the Love Canal, in New York.

As proven by studies already completed, this methodology is fast, effective, low in cost and it has a high rate of accuracy when tested in the field. It is hoped that utilization of this technology will become more widespread as cities throughout the United States examine the potential dangers of unsound, past environmental practices.

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PLANTS AS BIOINDICATORS OF ENVIRONMENTAL POLLUTION

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INTRODUCTION

Plant morphological and cuticular features have been used for over a century in the interpretation of taxonomic, paleobotanical, and phylogenetic relationships. However, their use in the understanding of ecological data is fairly recent. In addition, plant cuticular features have recently been found to be extremely useful in establishing relationships between environmental pollution and various taxa.

In view of the presence of acid rain and other pollutants throughout the world, the use of plants as bioindicators of environmental pollution in various habitats is an extremely significant contribution to the understanding of our ecosystems. With detailed studies on a wide variety of plant taxa, it is possible to suggest a specific relationship between environmental pollution and a plant taxon affected by it.

Numerous studies have revealed the detrimental effects of environmental pollution on plants under natural and controlled conditions. Scheffer and Hedgcock's study[6] of the forests of the Northwestern United States revealed the characteristic effects of sulfur dioxide injury on leaves. Solberg and Adams[9] reported that fluoride and sulfur dioxide destroyed the spongy mesophyll and the lower leaf epidermis of plants. This was followed by chloroplast distortion, and palisade and upper leaf epidermis damage. Chamberlain[1] observed that dirt, smoke, and the gases of a large city were fatal to conifers, especially *Pinus banksiana*. The plants illustrated chlorosis and necrosis. Pyatt[5] investigated lichens as possible indicators of air pollution in a steel-producing town in Wales and discovered that generally the lichen flora decreased in number of species present with increasing proximity of the source of pollution.

Although several studies[2,4] indicate the effects of environmental pollution on the gross morphological features of plants, relatively little work has been done to determine the relationship between environmental pollution and the cuticular features of plant leaves. Preliminary studies on the subject[7,8] indicate the usefulness of leaf cuticular features as indicators of environmental pollution in some plant taxa. The purpose of the present study was to determine the gross morphological and leaf cuticular variations in American sycamore and their possible relationship to environmental pollution. The present study is, therefore, a continuation of a comprehensive project involving plants as indicators of environmental pollution.

METHODS

American sycamore *(Platanus occidentalis)* is one of the largest trees in the eastern deciduous forest of the United States. It may grow to fifty meters in height and trunks may be as large as four meters in diameter. The sycamore family *(Platanaceae)* is composed of a single genus *(Platanus)* of about seven species occurring in the Northern Hemisphere. The tree is characterized by broadly ovate leaves which are 3-5 lobed. The bark of sycamore tree is deciduous and is in the form of broad, thin brittle plates. Sycamore grows well in rich soil such as bottom-lands. The wood of sycamore tree is utilized for many specialized products such as boxes, crates, and furniture. Due to the fungal disease caused by *Gnomia veneta* that often invades sycamore trees, planting of the tree is currently not advised[3].

Four populations (A, B, C, D) of sycamore tree were collected from different sites exhibiting varying degrees of environmental pollution (Table I). Populations A and B

Table I.
Distribution and Habitat Features of Sycamore Populations in Northwest Tennessee, Middle Tennessee, and Northern Missouri, U.S.A.

Pop'n	Location	Rel. Pol'n Level	Source
A	Reelfoot Lake, Tenn.	+	agricultural operations
B	Overton Park, Memphis, Tenn.	+	automobiles
C	Nashville, Tenn.	+ + +	automobiles industry
D	St. Louis, Mo.	+ + + +	automobiles, heavy industry

*+ + + +, highest level; +, lowest level.

were collected respectively in the semi-protected, semi-wooded vicinity of Reelfoot Lake and Overton Park in Tennessee.

Reelfoot Lake represents an extremely small, rural community in northwest Tennessee with a minimum level of pollution. Although the Overton Park area is in the city of Memphis, the tree samples were collected from a wooded, semi-protected microhabitat unlike the polluted macrohabitat of Memphis.

Populations C and D were collected from Nashville, Tennessee and St. Louis, Missouri respectively, where automobile traffic was an obvious source of environmental pollution. The tree samples comprising populations C and D were taken from the industrialized downtown areas of Nashville and St. Louis, respectively. In both of these large metropolitan areas, environmental pollution has resulted from industrialization and urbanization.

Each tree population sample consisted of 20 leaves collected at random from sycamore trees. These leaf samples were collected in mid-autumn to ensure their maturity at the time of collection. Gross morphological features were recorded and analyzed for the four populations (Table II).

Table II.
Gross Morphological Characteristics* of Platanus Occidentalis

Pattern	Population A	B	C	D
Leaf length (cm)	22.5 ± 3.48	22.0 ± 2.12	14.7 ± 2.46	8.5 ± 1.68
Leaf width (cm)	24.3 ± 3.87	22.6 ± 1.84	15.2 ± 2.01	9.0 ± 1.68
Petiole length (cm)	7.6 ± 1.04	7.5 ± 0.87	6.5 ± 1.23	1.2 ± 0.63
Internodal distance (cm)	6.9 ± 1.48	6.0 ± 1.01	5.1 ± 0.92	2.9 ± 0.78
Length: width ratio	0.9	1.0	1.0	0.9

*The values represent means of 20 measurements ± standard deviation.

Cuticular impressions of the upper and lower leaf surfaces were prepared by applying Duco® cement to the washed and air dried leaves[10]. A small portion from the central area of the leaf imprints was used to make cuticular slides for the adaxial and abaxial leaf surfaces of each population. Cuticular features of these four populations were analyzed by selecting at random 20 fields ($n = 20$) *from* each microscope slide. The microscopic analysis was performed using a 40x objective and 10x oculars.

RESULTS

No stomata occurred on the upper epidermis, as is generally the case in woody dicots. The number of undulations in the epidermal cells were counted only on the lower leaf surface since the undulations were not easily discernible on the upper epidermis. The statistical analysis of the data is given in Table III.

Populations A and B growing in relatively less polluted habitats had longer leaves (22.5 and 22.0 cm) compared to the leaf lengths (14.7 and 8.5 cm) in populations C and D respectively. The latter populations exhibited a high degree of environmental pollution in their habitats.

Leaf width measurements for populations A and B were also higher (24.3 and 22.6 cm) than for populations C and D (15.2 and 9.0 cm), respectively. Petioled length and internodal distance were also greater in plant populations of less polluted habitats. The mean length-width ratio in all the populations studied showed a very insignificant variation (0.9-1.0) and can be regarded as constant for the taxon under investigation. It is quite apparent from the measurements of the gross morphological features of the four sycamore populations, that polluted environmental conditions had an adverse effect on the growth of the plant.

Stomata were absent on the upper epidermis of sycamore leaves, as is the case in many woody dicotyledons. The trichome frequency was slightly higher on the upper leaf surface as compared to the lower leaf surface. The highest stomatal frequencies of 30.2 and 29.2 per unit area (0.152 mm^2) were found in populations A and B. These two populations illustrated a minimum level of environmental pollution. The leaves of sycamore tree seem to have low stomatal frequency (26.1 and 23.3) in polluted areas, an adaptation which may be of ecotypic significance in regulating the limited and controlled entry of harmful gaseous pollutants into the plant tissues, especially when the tree grows in a polluted area.

Trichome frequency values of 3.3 and 3.5 for the upper leaf surfaces of populations C and D respectively were the highest. These two populations were exposed to the highest levels of environmental pollution. Populations A and B, however, had fewer trichomes. All of the trichomes were unicellular and the majority of the trichomes were found along the veins rather than the lamina.

The trichome shape was variable. Most of the trichomes were star-shaped with 5-6 rays radiating from the case of the trichome. These star-shaped trichomes were prominent on the midvein of sycamore leaves. Also, several simple pointed trichomes were noted in each population. Populations C and D possessed the longest trichomes (106.7 and 110.0μm), respectively. It seems quite apparent that longer and more numerous trichomes were associated with a high degree of environmental pollution. These modifications or adaptations in sycamore may be of ecotypic or even evolutionary significance. A pubescent leaf surface may act as an insulator in a polluted environment. Leaf hairs are also known to be of value in shading the living cells and thus reducing the temperature of the leaf tissues.

The size of the largest and smallest stomata on the lower leaf surface in all the populations sampled showed little variation. The smallest stomatal size ranged from 7.6μm to 8.3 μm while the largest size ranged from 12.7μm to 14.3μm. Because of this relatively insignificant variation in the size of the two extremes within populations,

Table III.
Leaf Cuticular Characteristics* of Populations of Platanus occidentalis

Pattern		Population A	B	C	D
Stomatal frequency†		30.2 ± 1.12	29.2 ± 2.91	26.1 ± 2.46	23.3 ± 1.11
Stomatal length (um)					
Largest stoma		12.9 ± 0.89	12.8 ± 0.67	12.7 ± 0.89	14.3 ± 1.11
Smallest stoma		7.6 ± 0.89	7.6 ± 0.45	7.9 ± 0.89	8.3 ± 0.45
Trichome density++	U	1.3 ± 0.45	2.1 ± 0.45	3.3 ± 0.62	3.5 ± 0.89
	L	0.8 ± 0.78	1.7 ± 0.82	2.7 ± 0.89	2.9 ± 0.76
Trichome length (um)					
Longest trichome	U	90.3 ± 4.47	91.1 ± 5.59	106.7 ± 3.21	110.0 ± 4.47
	L	89.4 ± 1.41	90.2 ± 1.22	100.9 ± 2.41	104.2 ± 2.42
Shortest trichome	U	40.9 ± 2.12	56.3 ± 4.47	62.7 ± 4.47	80.0 ± 1.01
	L	39.2 ± 2.11	53.2 ± 2.23	60.2 ± 2.82	76.4 ± 1.84
Epidermal cell undulations** (number)		3.5 ± 0.89	3.6 ± 0.78	3.1 ± 0.89	3.2 ± 0.68
Subsidiary cell complex (number)		3-4	3-4	3-4	3-4

*The values represent means of 20 measurements ± standard deviation.
**Mean epidermal cell undulations = undulations of the lower surface of leaves.
†Mean stomatal frequency = stomata of the lower surface of leaves observed through a 40x objective and 10x oculars (field area = 0.152 mm²). U = upper surface of leaf; L = lower surface of leaf.
++per unit area (0.152 mm²).

it may be suggested that the stomatal size range remains fairly uniform in sycamore.

A count of the number of undulations in the epidermal cells reveals that environmental pollution had no significant effect on this cuticular feature. In all four sycamore populations, the mean value for the number of undulations ranged from 3.1 to 3.6. The subsidiary cell complex remained constant, with 3-4 cells adjacent to the guard cells. The constancy of the subsidiary cell complex in all the populations sampled may be of taxonomic significance for the taxon.

CONCLUSIONS

The study points out leaf cuticular and gross morphological variations in American sycamore as evidenced by modification in leaf length, leaf width, petiole length, internodal distance, stomatal frequency, and trichome density in the four populations studied. Stomatal frequency was low in the highly polluted habitats. The data suggest that high trichome frequency may be correlated with assumed high environmental pollution.

The number of undulations in the epidermal cells as well as the stomatal size ranges were not affected by environmental pollution to any significant degree. Leaf length-width ratio and the subsidiary cell complex remained the same in all the populations. The latter is no doubt a species trait and hence of taxonomic significance. Similar results have been found in other plant taxa studied by the author. With detailed investigations on additional herbaceous and woody plants growing in polluted habitats, it may be possible to suggest a more precise correlation between plants and environmental pollution and hence their use as indicators of environmental pollution.

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RATIONALE FOR DETERMINING PRIORITIES AND EXTENT OF CLEANUP OF UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act of 1980, PL 96-510, requires revision of the National Contingency Plan with a section known as the National Hazardous Substance Response-Plan and requires that the plan establish procedures and standards for responding to releases of hazardous substances, pollutants, and contaminants. One aspect of this new plan is defined as:

"105 (3) methods and criteria for determining the appropriate extent of removal, remedy, and other measures as required by this Act."

In this paper the authors attempt to develop a rationale for determining "appropriate extent of removal" for uncontrolled hazardous waste sites. This involves three types of decisions:

- **Determination of Cleanup Priorities**—To what area or areas to direct the cleanup effort when time or resources are limited and/or the affected area is too extensive to clean up the entire release.

- **Evaluation of Alternative Cleanup Methods and Selection of Optimum Methods**—Once the priority cleanup areas have been selected, (a) to evaluate cleanup alternatives considering availability and cost of manpower and equipment, effectiveness and speed of deployment, effect on the environment and other applicable parameters; and (b) to select the optimum method or combination of methods for the priority cleanup operations.

- **Determination of Extent of Cleanup (How Clean Is Clean)**—Once the optimum cleanup methods have been selected, how far and how long should cleanup proceed? The desirable "extent of removal" depends on (a) reaching acceptably low levels of residuals, (b) the (usually rising) cost of removal per unit mass of contaminant as lower and lower contamination levels are achieved, (c) environmental impact of cleaning methods themselves; and other suitable parameters.

The authors deal, in order, with these three questions and provide decision-making methodologies in these areas to assist those charged with directing cleanup operations. However, "removal" (which is primarily concerned with cleanup) as addressed here excludes the initial response to a hazardous substance release usually designated as first-response actions, which protect human populations against immediate dangers such as fires, explosions, and ingestion of toxic materials. Likewise excluded are subsequent remedial actions that stabilize the environment after removal.

HAZARDOUS SUBSTANCES

The CERCLA legislation, in Section 101 (14), designates the substances covered by the Act. More than 600 chemical compounds and elements are now listed while the exact number is still being decided. The physical behavior of hazardous substances (HS) on release can be classified into 11 categories, (Table I), including releases into water, into air and onto land. The principal distinguishing characteristics are density, vapor pressure, and reactivity.

The hazards they present are categorized and coded in Table II, and are mainly in the areas of toxicity and combustibility. Figure 1 is a typical page from an alphabetical computation which lists the hundreds of substances by Chemical Abstract Service (CAS) number, the physical behavior categories of Table I, and the hazardous effects coded in Table II. This provides an initial guide to the physical nature and danger of any known hazardous substance.

CLEANUP PRIORITIES

Even though first response actions have concentrated primarily on safeguarding the human population, the hazards to humans are still the paramount consideration even in the removal phase. This is the key issue in responding to hazardous substance incidents, in contrast to oil spills where normally no human lives are endangered. Therefore, oil spill response procedures are of limited use in this discussion.

The proposed cleanup priority decision methodology follows the flow chart of Figure 2. Inputs based on the hazardous substance release, the first response actions,

Table I.
Physical Behavior of Hazardous Substances on Release

Water Spill

1. Liquids and solids dissolving in water (solubles)
2. As above, but hazardous gases/vapors result
3. Insoluble substances lighter than water (floaters)
4. As above, but hazardous gases/vapors result
5. Insoluble substances heavier than water (sinkers)
6. As above, but hazardous gases/vapors result
7. Liquids or solids that react with water

Land Spill

8. Liquids or solids that are self-reactive
9. Compressed gas that could be released
10. Liquids or solids below their boiling/evaporation point
11. As above, but hazardous gases/vapors result

Air Spill

2. Hazardous gases/vapors from solubles/water
4. Hazardous gases/vapors from floaters/water
6. Hazardous gases/vapors from sinkers/water
8. Self-reactive liquids or solids
9. Compressed gases expanding
11. Hazardous gases/vapors from slow evaporators

Table II.
Hazardous Effects Categories and Codes

a	toxicity data not available
b	combustible with ignition source (low vapor pressure)
c	potentially toxic combustion/reaction products
d	*Highly toxic* combustion/reaction products
e	*Do not drink* contaminated water
E	*Explosion hazard*
f	*Do not inhale* toxic vapor/dust
g	*Readily flammable* (high vapor pressure)
h	*Corrosive*
T	*Toxicity hazard*
( )	Parentheses indicate a lower hazard or property value

Note: Italicized and capitalized letters indicate serious hazards.

climatic conditions and the nature of the affected or threatened environmental constituents are entered into the Hazardous Substance Incident Profile Form from which long- and short-term damage estimates are derived. This form is dependent on the time and date and may be filled out at different times during the cleanup action. The form serves as a record of the overall event and its consequences.

The generalized environmental response priorities are shown on Table III. Normally, the priorities are to guard against, in order, human, animal, ecological, socioeconomic and social impacts. Also affected constituents should be protected before threatened constituents. Priorities, however, may be changed if special circumstances indicate that the situation requires it.

A numerical Vulnerability Rating System was developed to establish cleanup priorities among environmental constituents. This is illustrated in the worksheet of Figure 3. There are six additive vulnerability parameters, with a maximum possible score of 100. Parameters 1 through 3 are hazardous substance-related while parameters 4 through 6 are constituent-related. Further, there are three subtractive constituent-related parameters (numbers 7 through 9) indicative of the background contamination level and assimilative capacity and any self-cleaning ability.

The numerical ratings are guides to cleanup priorities (higher vulnerability ratings mean higher cleanup priority) subject to two considerations: the priorities among classes of constituents (axiom 1 on Table III), i.e., whether they are in the order A, B, C, etc. as shown on Figure 3; and the priority of affected constituents over threatened constituents (axion 2 on Table III). The judgment of the user must make the final priority assignment.

SELECTION OF CLEANUP TECHNIQUES

The number of hazardous substances cleanup strategies that can be applied to different situations is almost limitless due to the complexity of the parameters involved. Hazardous substances themselves possess a va-

Table III.
Generalized Environmental Response Priorities

Axiom 1: Normally protect environmental constituents in the following order of priority:

a. Human populations and habitats—human impact
   - Cleanup crews
   - General population

b. Fauna—animal/ecological impact
   - Marine
   - Land
   - Birds, etc.

c. Flora—ecological impact
   - Forests
   - Food crops
   - Other crops
   - Marshes
   - Marine, etc.

d. Property—socioeconomic impact
   - Industry
   - Business
   - Municipal
   - Fisheries, etc.

e. Aesthetic and recreational areas—social impact
   - Parks
   - Beaches
   - Wilderness
   - Water use and sports areas, etc.

Axiom 2: Protect affected areas before threatened areas.

Axiom 3: Use judgment and common sense in applying Axioms 1 and 2.

COMPOUND	WATER SPILL 1 Dissolves	2 Hazardous Vapor	3 Floats	4 Hazardous Vapor	5 Sinks	6 Hazardous Vapor	7 Reactive	LAND SPILL 8 Reactive	9 Compressed Gas	10 Slow Evaporation	11 Hazardous Vapor	NOTES
Acenaphthene (83-32-9)	(X)				X							b, c, e, f
Acenaphthylene (208-96-8)	(X)		X									b, c, e, f
Acetaldehyde (75-07-0)	X	E,T	X	E,T						X	E,T	f, g
Acetic acid (64-19-7)	X	T			X	T				X	T	skin, eye hazard, f, g, h
Acetic anhydride (108-24-7)	(X)	E,T			X	E,T				X	E,T	skin, eye hazard, f, g, h
Acetone cyanohydrin (75-86-5)	X	T	X	T						X	T	poison (cyanide), d, e, f
Acetyl bromide (506-96-7)	X	T			X	T	X	X		X	T	violent reaction with water, eye hazard, skin burns, irritant, f, g, h
Acetyl chloride (75-36-5)	X	T			X	T	X	X		X	T	
Acrolein (107-02-8)	X	E,T	X	E,T						X	E,T	skin, eye hazard, e, f, g
Acrylonitrile (107-13-1)	X	E,T	X	E,T						X	E,T	Poison (cyanide), can explode d,e,f,g
Adipic acid (124-04-9)	(X)				X							b, f, irritant
Aldrin (309-00-2)												skin poison, b, c, e, f
Allyl alcohol (107-18-6)	X	E,T	X	E,T						X	E,T	eye hazard, f, g
Allyl chloride (107-05-1)	(X)	E,T	X	E,T						X	E,T	eye hazard, skin poison, f, g
Aluminum sulfate (10043-01-3)	X				X							
Ammonia (7664-41-7)	X	T							X			f, h, choking gas
Ammonium acetate (631-61-8)	X				X							
Ammonium benzoate (1863-63-4)	X				X							e, f
Ammonium bicarbonate (1066-33-7)	X				X							
Ammonium bifluoride (1341-49-7)	X				X							etches glass, e, f, h
Ammonium bisulfite (10192-30-0)	X				X							sulfur dioxide formed with acids, f
Ammonium carbamate (1111-78-0)	X				X							
Ammonium carbonate (506-87-6)	X				X							
Ammonium chloride (12125-02-9)	X				X							
Ammonium chromate (7788-98-9)	X				X							e, f
Ammonium citrate, dibasic(3012-65-5)	X				X							
Ammonium dichromate (7789-09-5)	X				X							oxidant, e, f, g, h
Ammonium fluoborate (13826-83-0)	X				X							e, f, h
Ammonium fluoride (12125-01-8)	X				X							etches glass e, f, h
Ammonium hydroxide (1336-21-6)	X	T			(X)					X	T	f, h

Figure 1.
Typical Page From a Listing of Hazardous Substances

riety of physical, chemical and toxicological combinations so as to make a fairly standard cleanup and treatment methodology, such as for oil spills, not appropriate or applicable. It is therefore impractical to attempt to develop a specific cleanup methodology for each hazardous substance and spill situation combination. Instead, an attempt is made to present for each hazardous substance physical behavior release class (Table I) a variety of spill treatment techniques that may be useful in cleaning up hazardous substances falling within a particular class.

The treatment techniques, which are listed in Table IV, fall under the classifications of mechanical, chemical, and sorbents, gels and foam methods. The treatment techniques are geared toward both containment and removal actions and include the following cleanup strategies:

(1) Dilution and dispersion into the environment
(2) In-situ treatment
(3) Offsite treatment and disposal
(4) Treatment on site in an offstream treatment system

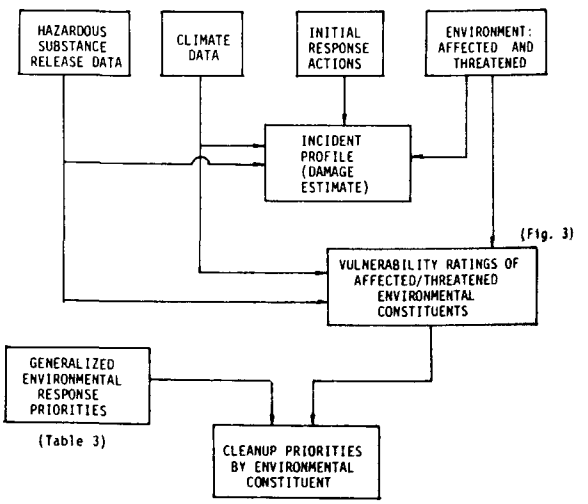

Figure 2.
Cleanup Priority Decision Flow Chart

Table IV.
Hazardous Substances Cleanup Techniques

Method	Use/Application	Advantages	Disadvantages
A. MECHANICAL TECHNIQUES			
1. Dispersion	Employ water jet, mechanical mixer, aerator, etc. to promote dilution. Should be used where adequate dilution can be attained.	Inexpensive, easily implemented	Pollution may be spread over a larger area
2. Dilution (Water)	Consider water use classification, and the ability for natural or forced dilution.	Inexpensive and timely	Pollution may be spread over a larger area.
3. Dilution (Air)	Use blower equipment to introduce clean air to lower hazardous substance vapors to less than TLV or lower flammability limit. Use in calm and sheltered areas.	Can direct air away from populated areas	Pollution may be spread over a larger area. Need large-capacity blowers.
4. Booms	Need deployment device. Use in fairly calm waters.	Can be used over a larger area. Many varieties.	Cannot be used in rough or rapidly rapidly moving water.
5. Weirs	Need a weir and boat. Use in calm, large waterbody.	Easily used.	Cannot be used in rough water. Not always available.
6. Spill Herding	Apply chemical herder to protect shore or other facilities.	Useful in rough water.	Not easily obtainable; not 100% effective.
7. Dredging	Uses in hazardous substances spills is largely untested.	Can effectively remove pollutants.	Equipment not readily available; potential for environmental damage; generation of large amounts of contaminated material.
8. Burial	Use *only* as a temporary measure to retard spread of spill until recovery, or when spill substance is harmless.	Easily implemented.	Not an environmentally sound practice.
9. Dikes (Earth)	Create barrier with bulldozer or earthmoving equipment.	Material on site; common equipment.	Composition of soil may not be suitable (possible leakage).
10. Dikes (Foamed Polyurethane)	Need trained personnel to construct on hard, dry surfaces.	Can hold up to several feet of water.	Equipment hard to obtain; leaks on wet ground.
11. Trenches	Construct with bulldozer or earthmoving equipment.	Construct with common equipment.	Move large amounts of material; highly permeable soil may not contain spill.
12. Diversion	Use earthmoving equipment to divert channel and sandbags, dikes, etc. to block entrance of pollution.	Separates contamination.	Large amounts of earth must be moved. Clear area and proper soil conditions required.
13. Dam (Underflow)	Create dam and underflow drain in relatively small stream.	Simple to construct.	Can only be used in small streams.
14. Mist Knockdown	Use fine mist spray to suppress water-soluble low-lying hazardous vapors.	Reduces air pollution potential.	Can create a water pollution problem, runoff must be contained.
15. Vacuum Skimmer	Use vacuum tank to generate draining force for removing small spills.	Easily used.	Equipment not always obtain-spills only.
B. CHEMICAL TECHNIQUES			
1. Neutralization	Apply acid or base in powder or slurry form.	Effective in restoring pH to proper range.	Added chemicals may be a threat to the environment. Difficulty in determining correct amount of chemical addition.

2. Precipitation	Add chemicals to clarify or precipitate out soluble substances.	Can be performed in situ or in field treatment unit.	Ultimate reaction, including particulate matter formed, may pose a new threat to environment.
3. Chelation	Chalating agents are added to water to bind (and deactivate) metal ions.	Effective in removing spilled metal ions.	Misapplication of treatment may cause environmental damage. Essential metal nutrients may be inadvertently removed.
C. SORBENTS, GELS AND FOAMS			
1. Activated Carbon	Implement treatment by (1) dragging AC-filled bag through water, (2) passing water through AC beds or columns, or (3) employing mobile treatment unit. Used mostly for organics.	Most universal sorbent; readily available.	Costly if carbon is not regenerated.
2. Polyurethane Foam	Apply via foam-laden belts or shredded foam broadcast over the spill to absorb pollutants.	Can be squeezed and reused.	Bulky and difficult to transport.
3. Ion Exchange	Water must be pumped through bed or column used mostly for acid, base, metal, or toxic salt spills.	Effective removal method for specific pollutants	A large amount of equipment must be deployed. Resins must be regenerated.
4. Gelling Agent	Adds gels through dispersion device to reduce viscosity (and immobilize) spill.	Effective containment method; can reduce vapors.	Practical use for small volumes only; difficult to obtain; creates a disposal problem; heat may be generated in the reaction.

Environmental Constituents / Vulnerability Parameters		A. Human Populations and Habitats								B. Fauna						C. Flora						D. Property						E. Aesthetic and Recreational Areas					
1. Susceptibility to this HS via pathways of:		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	B_1	B_2	B_3	B_4	B_5	B_6	C_1	C_2	C_3	C_4	C_5	C_6	D_1	D_2	D_3	D_4	D_5	D_6	E_1	E_2	E_3	E_4	E_5	E_6
a. Air	(0-4)																																
b. Surface Water	(0-4)																																
c. Groundwater	(0-4)																																
d. Land Surface	(0-4)																																
e. Subsurface	(0-4)																																
2. Proximity to Release Pt.	(0-12)																																
3. Contamination Vector	(0-12)																																
4. Population/Size/Extent	(0-16)																																
5. Intrinsic Values																																	
a. Water Quality	(0-4)																																
b. Air Quality	(0-4)																																
c. Food Chain	(0-4)																																
d. Ecological	(0-4)																																
e. Economic	(0-4)																																
f. Aesthetic	(0-4)																																
g. Recreational	(0-4)																																
6. Time Restrictions	(0-12)																																
INTERIM TOTALS (100 MAX)																																	
SUBTRACT (for this HS):																																	
7. Assimilative Capacity	(0-12)																																
8. Self-Cleaning Ability	(0-12																																
9. Background HS Level	(0-12)																																
RATING TOTALS																																	

Figure 3.
Vulnerability Ratings of Environmental Constituents

Table V.
Hazardous Substances Cleanup Selections

Physical Behavior Class (From Table I)	Potential Cleanup Alternatives (From Table IV)
1. Liquids and Solids Dissolving in Water (Solubles)	A.1 A.2 A.12 B.1 B.2 B.3 C.1 C.3
2. As Above, but Hazardous Gases/Vapors Result	As above, but add A.3 A.14 C.2 C.4
3. Insoluble Substances Lighter Than Water (Floaters)	A.1 A.2 A.4 A.5 A.6 A.12 A.13 A.15 C.2 C.4
4. As Above, but Hazardous Gases/Vapors Result	As above, but add A.3 A.14
5. Insoluble Substances Heavier Than Water (Sinkers)	A.7
6. As Above, but Hazardous Gases/Vapors Result	As above, but add A.3 A.14
7. Liquids or Solids that React with Water	A.1 A.2 A.3 A.4 A.5 A.6 A.7 A.12 A.13 A.14 A.15 B.1 B.2 B.3 C.1 C.2 C.3 C.4
8. Liquids or Solids that are Self-Reactive	A.3 A.8 A.9 A.10 A.11 A.14 A.15 B.1 C.2 C.4
9. Compressed Gas that Could be Released	A.3 A.8 A.9 A.10 A.11 A.14 A.15 B.1
10. Liquids or Solids Below Their Boiling/Evaporation Point	A.8 A.9 A.10 A.11 A.15 B.1 C.2 C.4
11. As Above, but Hazardous Gases/Vapors Result	As above, but add A.3 A.14

The potential cleanup alternatives that may be applicable, depending on the particular substance spilled and spill situation, for each physical behavior class are listed in Table V. Figure 1 will aid in determining into which physical behavior class a particular hazardous substance falls.

Once the potential cleanup alternative (or combination of alternatives) is selected, several options will probably be able to be eliminated for favored due to obvious limiting factors such as available equipment, manpower, financial resources, etc. Also, the spill cleanup advantages/disadvantages listed in Table IV should be seriously considered. If no cleanup selection is feasible or if significant environmental damage will result from cleanup actions, no action at all may be the appropriate response.

DETERMINATION OF ALTERNATIVE CLEANUP TECHNIQUE COSTS

After a potential spill cleanup technique or combination of techniques has been chosen, costs for each selection can be determined from past experience, on-scene advisors, cleanup contractors or any other references at hand. The costs to be included, where applicable, are:

- Labor
- Capital or rental costs
- Material and supplies
- Packaging and transportation
- Ultimate disposal

Daily cleanup costs ($/day) for each cleanup technique can be computed by adding the appropriate cost components.

For each cleanup technique or techniques for which a daily cleanup cost ($/day) was calculated, an attempt can be made to try and obtain an estimate of the amount of hazardous substance each cleanup technique is capable of extracting on a mass per day (lb/day) basis. This parameter in most cases cannot be easily identified. Therefore, estimates of extraction performances should be made from past experiences of the OSCs or their advisors, from cleanup contractors, or from cleanup equipment manufacturers' data.

Unit cost ($/lb) is defined as the amount of dollars required to extract one pound of hazardous substance. This can be calculated by dividing the daily cleanup cost rate ($/day) by the extraction performance rate (lbs/day). Alternative cleanup techniques can now be compared on a unit cost basis to get an indication of relative economic merit.

DETERMINATION OF MOST EFFECTIVE CLEANUP TECHNIQUE

In many spill situations, it may not be realistic to choose cleanup techniques solely on a unit cost ($/lb) basis. Alternative cleanup techniques can be ranked on a unit cost basis but the listing priority should be qualified with certain cleanup effectiveness criteria that will be affected by the peculiarities of a specific spill situation and may outweigh any cost considerations. The cleanup effectiveness criteria include:

- •Completeness of removal—Can the desired or required cleanness levels or standards be attained?
- •Rate of removal—Can the substance(s) be cleaned up in time to protect critical habitats or reduce evacuation times, etc?
- •Logistics—Can the techniques be easily deployed? Necessary equipment? Is it available?
- •Operational requirements—What levels of labor, skill, etc., are required? Is it affected by weather?
- •Environmental impact—Will the environment be adversely affected?
- •Personnel protection—Will response personnel be unduly subjected to hazards?
- •Disposal problems—Will large amounts of wastes be generated? Will this result in transportation and ultimate disposal problems?

After consideration of the preceding cleanup effectiveness criteria, the cleanup technique priority list can be reordered to obtain the effective cleanup strategy for a particular hazardous substance incident.

EXTENT OF CLEANUP (HOW CLEAN IS CLEAN?)

Based on the results of the two previous sections, a specific strategy will have been selected to clean up the environmental constituents having the highest priorities. This strategy will consist of one or more cleanup actions at the same time, followed sequentially by other actions. For instance, simultaneous mechanical and chemical techniques may be used to extract and treat the hazardous substance at the incident site, followed by transportation

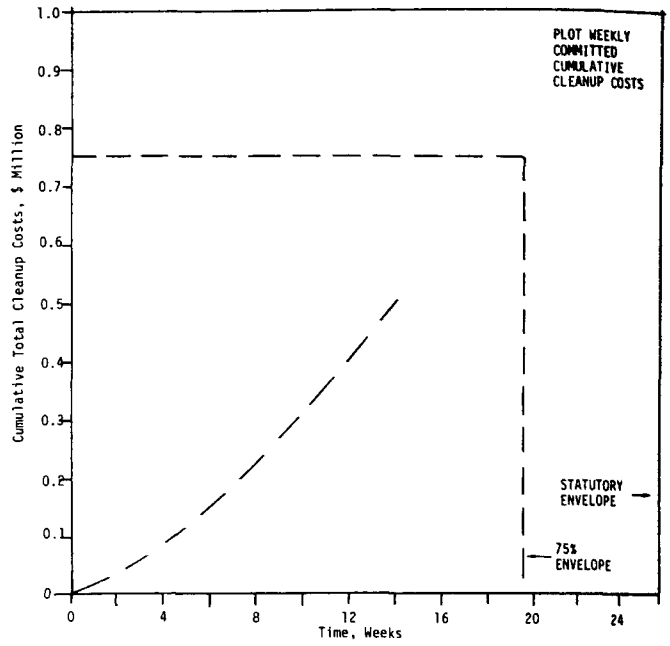

Figure 4.
Control Graph for Cleanup Time and Cost

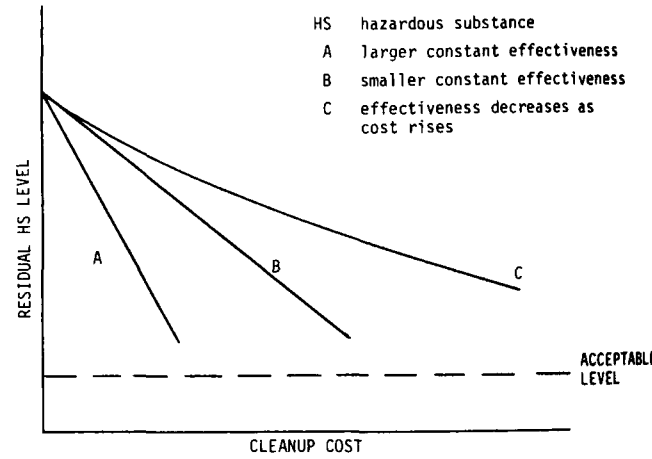

Figure 5.
Cleanup Effectiveness Curves

Table VI.
Factors Influencing Extent of Cleanup

1. Acceptably low final contamination levels
2. Change in effectiveness of cleanup techniques as contamination levels decrease
3. Change in incremental cleanup costs as contamination levels decrease
4. Environmental impact of cleanup techniques themselves
5. Effect of simultaneous vs. sequential cleanup of different environmental constituents
6. Overall and ultimate environmental consequences—assimilative capacity of environment
7. Public awareness and political pressures
8. Budget and time constraints (Superfund: $1 million and 6 months)

of the extracted hazardous matter to another location for disposal. These various techniques may be combined in simultaneous/sequential/intermittent ways, as needed.

During the removal or cleanup phase one must initially project and later keep track of three main parameters:

- Daily cost of individual cleanup techniques and of the total cleanup effort, including cost of measurements in item 3 below
- Daily amount of hazardous substance extracted
- Daily or periodic change in the hazardous substance residual contamination level in the environmental constituents affected by the incident, based on standardized meaningful measurements

The factors influencing the extent of cleanup during the removal phase are listed in Table VI. Unfortunately, all factors, except budget and time constraints which are dictated by outside considerations, are difficult to pin down.

Clearly, the basic goal of the cleanup operation is to reduce the level of toxic substances to an environmentally safe level, i.e., a level that does not present a hazard to human health or welfare, including water supplies and crops. Unfortunately, there are virtually no quantitative guidelines concerning acceptable residual levels of toxic substances for spill cleanup operations. Many of the metals whose salts are considered hazardous occur naturally in soils at low concentrations and are important trace elements in the biosphere. As a basic guideline, ideal cleanup operations should reduce the levels of toxic substances back to the natural levels found in the general area of the spill.

In certain cases, specific numbers for "safe" levels of contaminants are given in various regulations, particularly for drinking water and substances regulated under the Clean Air Act.

Although quantitative guidelines for cleanup standards have not yet been established, it is possible to go through the list of toxic substances and identify those that will require extensive cleanup because they present severe environmental hazards. Thus polychlorinated biphenyls, polynuclear armomatic compounds, various halogenated aromatic and aliphatic hydrocarbons, nitrosoamines and certain heavy metal salts of mercury, beryllium, and cadmium, among others, would merit special attention.

From a general consideration of the chemical, physical, and toxicological properties of the toxic substances listed, it is possible to perform a crude stratification into substances that are likely to present long-term environmental hazards and require extensive cleanup and substances with higher vapor pressures or greater chemical reactivity that present a relatively lower long-term environmental hazard and may require less extensive cleanup. A tentative stratification scheme along those lines involving four groups

Date: _____

		ENVIRONMENTAL CONSTITUENTS							
COST PARAMETERS (CP)		A.							
1. CLEANUP LABOR	(0-3)								
2. EQUIPMENT	(0-3)								
3. SUPPLIES & CHEMICALS (including fuels, lubes, power)	(0-3)								
4. CLEANUP IMPACT (allow for persistence and assimilative capacity)	(0-3)								
5. AREA USE INTERFERENCE (due to continued cleanup)	(0-3)								
TOTALS	ΣCP:								
BENEFIT PARAMETERS (BP)									
6. ECONOMIC (normalization of income from area)	(0-3)								
7. ENVIRONMENTAL (protection of ecosystems and habitats)	(0-3)								
8. AESTHETIC (preservation of visual quality & scenery)	(0-3)								
9. RECREATIONAL (normalization of indoor & outdoor areas)	(0-3)								
10. PUBLIC (normalization of public access & use)	(0-3)								
TOTALS	ΣBP:								
X ΣBP ΣCP:									
CONTINUE CLEANUP? YES/NO:									
(YES IF X>>0. NO IF X<<0. GET MORE FACTS IF X IS BETWEEN +3 AND -3)									

Figure 6.
Cost/Benefit Analysis of Incremental Cleanup

of inorganic and seven groups or organic compounds is presented in Table VII.

The factors listed in Table VI can be condensed into three indicators for use in deciding the extent of removal, or, "How Clean is Clean?"

- Ability to approach or reach acceptable residual contamination levels

Table VII.
Classification Scheme for Long-Term Environmental Hazards of Inorganic and Organic Compounds

PART 1: INORGANIC MATERIALS

GROUP I1: Inorganic metal salts likely to require extensive cleanup. Long-term environmental hazards. Drinking water hazards. Likely to bioaccumulate.

GROUP I2: Inorganic nonmetal compounds likely to require extensive cleanup. Long-term environmental hazards. Drinking water hazards. Likely to bioaccumulate.

GROUP I3: Inorganic metal salts presenting long-term environmental hazards, but likely to require less extensive cleanup than Group I1.

GROUP I4: Inorganic materials less likely to present long-term environmental hazards requiring extensive cleanup operations. May present severe short-term toxic or explosion hazards.

PART 2: ORGANIC MATERIALS

GROUP 01: Pesticides, likely to present long-term environmental hazards, drinking water hazards and bioaccumulation hazards. Extensive cleanup operations likely to be required.

GROUP 02: Nitrosoamines: Highly potent carcinogens, severe drinking water hazard, although long-term biodegradation likely. Extensive cleanup operations likely to be required.

GROUP 03: Polynuclear aromatics (PNAs): Potent carcinogens, low volatility, long-term environmental hazard, water and bioaccumulation hazards. Likely to require extensive cleanup.

GROUP 04: Halogenated hydrocarbons and related compounds: Known or likely carcinogens, probable bioaccumulation, dkrinking water hazards, likely to require extensive cleanup.

GROUP 05: Aromatic phenols, amines, nitro derivatives and related compounds: Known or likely carcinogens, probable bioaccumulation, drinking water hazard. Biodegradation possible, may present less long-term hazard than Groups 01 through 04.

GROUP 06: Amines, nitroles, aromatics and other compounds presenting environmental hazards, known or suspected carcinogens, drinking water hazards, but more reactive or volatile than previous groups and less likely to present long-term environmental hazards.

GROUP 07: Hydrocarbons, acids, esters and other compounds that are volatile or reactive enough to be biodegradable. Present lower long-term hazards and less likely to require extensive cleanup. May present severe short-term explosion or toxic vapor hazard.

- Comparison of costs versus benefits of incremental cleanup as a test of whether to continue cleanup
- Time and/or total cleanup cost limitations

Cost Benefit Analysis

It is desirable to reach acceptable residual contamination levels in the contaminated environmental constituents and prevent threatened constituents from being affected. Further, cleanup costs should not exceed the benefits that they provide. Lastly, time and/or total cleanup cost limitations, statutory or otherwise, should not be exceeded. In principle, all three conditions should be satisfied simultaneously. In practice, the connection between increasing costs, decreasing contamination levels, and increasing benefits can be tracked on an elapsed time basis. If all three conditions cannot be satisfied, then a compromise must be reached. The procedure detailed below is designed to furnish the user the needed data to make a decision.

First, daily cleanup costs and cumulative committed weekly cleanup costs are charted, for instance on a graph like Figure 4. This gives the overall picture for removal costs. Two rectangular envelopes are pre-drawn on this graph: the Superfund statutory limitation of $1 million and 6 months, and (in dashed lines) the envelope at 75% of these amounts for advance planning and control purposes.

Next, a plot of effectiveness of cleanup should be made. This is a plot of Residual HS Level vs Total Cleanup Cost, separate curves and acceptable residual level lines being drawn for each pathway or environmental constituent, like Figure 5. If the cleanup effectiveness is constant over the cleanup period, then the curve becomes an inclined straight line, showing that equal increments in cost produce equal decrements in contamination level. If the decrements become smaller while cost increments stay the same, i.e., the curve becomes flatter, then the cleanup effectiveness for the particular pathway drops as lower contamination levels are reached.

Third, make a Cost Benefit Analysis of Incremental Cleanup as shown in Figure 6 which is a form on which both cost parameters and benefit parameters are rated for the environmental constituents that are benefitting from cleanup. This analysis is similar to the one used in another study.[1] If the benefit score exceeds the cost score, then it is useful to continue cleanup; if the difference is 3 points or less, more facts are needed for a decision; and if the cost score exceeds the benefit score, then cleanup should be stopped. The analysis should be repeated at later times to see if the situation has changed.

To make the decision on How Clean is Clean, or when to stop cleanup, at different points in time:

- Determine if the residual HS contamination is at the acceptable level for the constituents of interest (Figure 5)
- Make the cost/benefit analysis whether or not to continue cleanup for the constituents of interest (Figure 6)
- Determine if the total cleanup costs are within the specified cost-time envelope (Figure 4)

If the residual contamination is at the acceptable level within the specified cost-time envelope, cleanup obviously should be stopped. If the acceptable level has not been reached, but the costs of continuing outweigh the benefits,

though time and funds remain, then a closer look must be taken as to the impact of a nonacceptable residual level. If funds and time run out before an acceptable level is reached and the cost/benefit analysis indicates that cleanup should continue, strong consideration should be given to continuing cleanup as part of remedial action. The user of this rationale must find a solution which is environmentally, economically, and legally acceptable. Often a compromise is the only possible way.

CONCLUSIONS

This study was prepared to assist on-scene decision-making personnel during removal activities following accidental releases of hazardous substances, as required by Public Law 96-510, or CERCLA. Decisions to be made are on cleanup priorities (what to clean up first?), on the selection of cleanup techniques (how to do it?), and on the extent of removal (how clean is clean?). The section on Cleanup Priorities contains forms on which to record the hazardous substance incident profile, and to work out the vulnerability ratings of all the environmental constituents affected or threatened by the incident. From these the cleanup priorities by environmental constituents are derived. The section on Selection of Cleanup Techniques lists various mechanical, chemical and biological techniques and indicates how choices should be made in particular cases. The section on Extent of Cleanup (How Clean is Clean?) contains forms and graphs on which to enter projected and actual cleanup costs, the progress in cleanup as evidenced by decreasing residual hazardous substance levels, and cost-benefit analyses of incremental cleanup actions. The user derives the environmental, economic, and legal decision indicators that must be combined to determine the appropriate extent of cleanup.

ACKNOWLEDGMENTS

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HAZARDOUS SUBSTANCE RESPONSE MANAGEMENT MODEL

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INTRODUCTION

The Environmental Protection Agency (EPA) is now using on an interim basis a Hazardous Substance Response Model as a management tool to lead governmental project managers through the activities related to cleaning uncontrolled releases of hazardous substances. Response funds are available primarily from the Comprehensive Environmental Response Compensation and Liability Act of 1980, P.O. 96-510 ("CERCLA" or "Superfund"). Superfund was enacted on December 11, 1980 and establishes broad Federal authority to respond to releases or threats of releases of hazardous substances, pollutants or contaminants from vessels and facilities. The Federal and State governments under the Act may take response actions whenever there is a release or a substantial threat of a release which may endanger public health or welfare or the environment. The Model presents in Flow Chart form (Figure 1) a suggested master network of activities designed to orchestrate a cleanup project in a manner that approximates the process of response currently being used on an interim basis by the EPA. The Model, in its completed form, is currently being developed and will include management-related activities, community relations, government/agency coordination, contractor procurement, contractor monitoring and technical decision-making.

The goals of the Model are: (1) to describe the activities necessary to manage cleanup of an uncontrolled hazardous waste site; and (2) to present this information in a form that is easy to understand, and which will assist those responsible for the day-to-day management of a project. In short, it is comprehensive in scope and designed for practical use. The Model is a vehicle incorporating the requirements of CERCLA with the experience of the people who are well-versed in evaluating, planning and cleaning releases.

The use of a management model provides the following benefits:

Information Transfer

The model allows new projects to benefit from past experience and to conform to CERCLA requirements by identifying the critical decisions in the project which must be made before succeeding activities can begin. Additionally, it provides a checklist of items which should be considered (but not necessarily performed, depending upon the circumstances of the specific project), thus ensuring that important components of the cleanup are not overlooked.

Funding Decisions

The model organizes cleanup operations into discrete phases with funding and decision points between each phase. Therefore, the performance of a project and the justifications for continuation come under pre-established review by the funding authorities. This allows project tracking on a large scale and improved cost estimation because of sharper definition and limitation of subsequent activities.

Goal-Oriented Sequencing of Activities

The model arranges all site responses into activities which accomplish the immediate needs of protecting the public health while providing support for the development of permanent remedial measures. Use of the model helps to avoid unnecessary or counterproductive activities (and their associated cost) and serves to ensure that necessary activities or data collection are not overlooked.

Public Support and Participation

The model serves to facilitate public support and participation by laying out in advance the purposes and limitations of each operational phase. In this way, project managers avoid generating unrealistic expectations.

Project Continuity

The use of the model will define the role of State and Federal decision makers and thereby ensure that the continuity of a project is not lost if there is a changeover in personnel. An additional benefit arises from the standardization of projects and provision of program consistency.

PHASES OF RESPONSE

There are two general types of removal response—immediate removal and planned removal. An immediate removal may be taken when action must be taken within hours or days to prevent significant harm to human life or health, or the environment. This is the type of response which has been traditionally undertaken for oil and hazardous substance removal. Planned removals are taken to stabilize releases where several weeks or months are available to identify responsible parties, plan the response and conduct procurement procedures. Planned removals bridge the gap between immediate response (which must occur within hours or days) and remedial response (which can take a year or more to institute).

Phase I—Discovery and Notification

Sites requiring response are identified in several ways. First, owners and operators of inactive hazardous waste sites were required to notify EPA by June 9, 1981. Second, the general public can inform the National Response Center or the EPA of potentially hazardous sites. EPA is also using aerial photography to identify potential sites.

Phase II—Preliminary Assessment

Based on the available information, preliminary site assessments can be conducted immediately or deferred to be included as part of an area-wide search.

The purpose of the preliminary assessment is to:

- identify the source and general nature of hazardous substances;
- estimate the potential of the threat;
- initially determine whether potential responsible parties will undertake site evaluation and response activities;
- determine whether immediate measures are required.

To make these determinations, the site manager evaluates previous disposal practices, information from generators, aerial and other photographs, and literature searches. Personal interviews are useful at this phase. A perimeter inspection may be needed to determine the potential for releases. Finally, an on-site inspection may be performed if the release may present an immediate threat to public health and if sophisticated safety equipment is not needed.

Phase III—Immediate Removal

Immediate removal actions can be initiated at any time during response to address acute situations. These are situations where response actions must begin within hours or days to mitigate fire or explosion hazards, to protect drinking water supplies, or otherwise to prevent or mitigate harm to human life or health or to the environment.

Immediate removal actions should be conducted by the responsible party. Only if the responsible party is not immediately available or cannot rapidly respond, can CERCLA funds be used.

By statute, immediate removal actions should be completed within six months and with less than $1 million. However, if acute harm still threatens the environment or public health, immediate removal actions may continue until the situation is stabilized.

Phase IV—Evaluation and Determination of Appropriate Response

To determine the nature and extent of the release and the priority of the site for response, greater emphasis is given to on-site sampling and analysis, especially when there is an apparent risk to public health or environment. Activities during this phase should include:

- assessing amount, types and location of hazardous materials

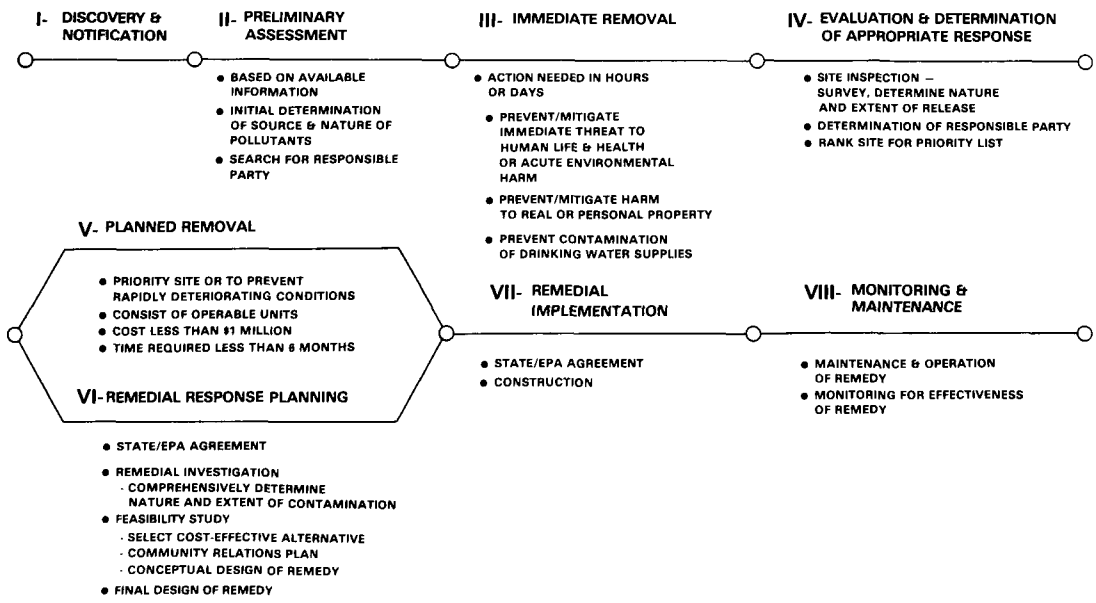

Figure 1.
Phases of Response

•determining or documenting immediate threats to the public or the environment
•reviewing records
•determining sampling protocols for any subsequent remedial investigations

The search for responsibile parties will continue through:
•search of local records
•interviews with local persons
•review of waste disposal records and labels.

If a responsible party does not exist, cannot be identified, will not act in a timely fashion, or is likely to be "judgment-proof" for all or a significant portion of the costs of the release, the site is considered for further fund-financed removal or remedial response.

At this point a decision is made to proceed with a planned removal and/or remedial response depending upon the need for action (as determined by the immediacy of the threat and the site priority ranking). The conditions under which these alternatives are selected and characteristic activities of each are described in detail below.

Phase V—Planned Removal

A planned removal action is taken in response to a release of hazardous substances which, while requiring some near-term actions to stabilize a threat to public health or the environment, does not require immediate removal actions. Such a situation allows some technical planning to more carefully select appropriate response activities.

Restrictions are placed on planned removal activities in order to conserve fund monies. All planned removals must consist of operable units, that is, self-contained components which will achieve some interim level of release mitigation or elimination without relying on future response actions. Further, planned removals can be taken only at priority sites or in situations where they are necessary to prevent rapidly deteriorating conditions. Finally, to the extent practicable, planned removal actions should conform to the cost-effective analysis required for full remedial activities.

Phase VI—Remedial Response Planning

Remedial actions are most appropriate for long-term and costly cleanups. The first step of remedial response planning is the remedial investigation. The purpose of the remedial investigation is to determine comprehensively the extent and nature of the problem and to support the development of alternative measures. Typical remedial investigations include:
•geophysical and hydro-geological investigations
•soil sampling and analysis
•hazardous waste characterization
•groundwater, surface water and air monitoring.

The second step in remedial response planning is the feasibility study. The feasibility study uses the results of the remedial investigation to develop and evaluate alternative remedies, assess the environmental affects of the release and alternative remedies, determine the cost-effective remedial action, and prepare a conceptual design of the approved action. A typical feasibility study includes:
•definition of response objectives and criteria
•laboratory studies
•development and evaluation of alternative remedial actions
•environmental assessment
•selection of an alternative
•conceptual design.

The selected remedial measure should meet public health and environment requirements. If the resulting remedies are more expensive than a predetermined cost guideline, then other remedies, including non-cleanup alternatives, shall be developed and evaluated.

The third activity in remedial response planning is the remedial design. In this step the approved remedial action will be clearly defined for implementation. A typical remedial design may consist of the following elements:
•site response plan
•relocation plan
•engineering drawings and specifications
•contract documents.

During the remedial planning process and before Phase VII, several technical, institutional and legal requirements must be met by the States. The State must show that it will be able to contribute its share of the remedial response planning and implementation costs, as well as future operations and maintenance costs. The State must also identify any required off-site disposal facilities required. Agreements between the State and EPA are signed prior to initiating Phase VI, VII and VIII actions. These agreements set forth the State's and EPA's responsibilities, define the scope of the project, and specify funding. When the State assumes the lead and funds are transferred to the State, a cooperative agreement is prepared. A less formal state agreement (or memo of understanding) is signed when EPA maintains the contractual lead.

Phase VII—Remedial Implementation

Several preparatory activities are necessary before construction begins. Final permits must be obtained and funding authorization is required from the State and EPA. The State must also demonstrate its ability to assume the responsibility for Phase VIII activities.

Remedial implementation—particularly for large projects—may be segmented. Each segment must be an operable unit and would remedy or mitigate at least part of the problem caused by the uncontrolled site. Project segmentation allows the EPA Fund Manager to preserve the size of the Fund and to balance response actions across more sites.

Phase VIII—Monitoring and Maintenance

After the remedial action has been completed, the States monitor the effectiveness of the response and provide any operation and maintenance necessary for the continued effectiveness of the permanent remedy.

Elements of Phase VIII can include:
•operation of treatment and collection systems
•reports of monitoring and maintenance program
•documentation of the determination that the substantial danger has been successfully reduced to design criteria.

SURFACE SEALING TO MINIMIZE LEACHATE GENERATION AT UNCONTROLLED HAZARDOUS WASTE SITES

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INTRODUCTION

Many existing technologies, such as those currently being used for construction, hydrologic investigation, wastewater treatment, spill cleanup and chemical sampling and analysis, can be applied to uncontrolled hazardous waste sites. The minimization of surface infiltration will, in almost all cases, be an integral part of the remedial steps at those sites where the waste has been buried and the cost of removal is prohibitive.

Minimizing surface infiltration typically consists of regrading, diverting surface water runoff and preventing or eliminating infiltration. The effectiveness of surface sealing depends upon the contribution of surface infiltration to the total problem at the site. From a cost effectiveness standpoint and ease of applicability, minimizing surface infiltration poses marked advantages over other types of remedial action unit operations.

The Solid and Hazardous Waste Research Division of EPA has been involved either directly, through actual EPA funding or indirectly through technically supported efforts at several sites where minimizing surface infiltration has been implemented. Two of those sites are discussed in this paper.

WINDHAM, CONNECTICUT

After a site selection process that involved consideration of over 400 sites, Windham, Connecticut, was selected for remedial work in 1977. The Windham, Connecticut, landfill is located in east central Connecticut, is approximately 25 acres in size and consists of two sections (Figure 1).

The landfill is located in an area of sand and gravel immediately adjacent to the City of Willimantic water supply reservoir. The eastern (old) half of the site is approximately 10 acres with its lower portion in the groundwater. The western (new) landfill is approximately 15 acres and is above the groundwater. The site was operated from approximately 1945 to 1978.

A series of monitoring points emplaced through and around the site defined the area of groundwater contamination and its movement with time (Figure 2). The monitoring system would also be useful in determining the effectiveness of the remedial action after it was implemented. This monitoring network included:

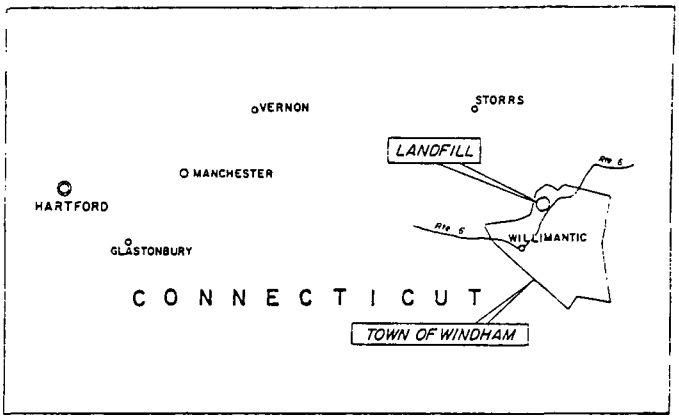

Figure 1.
Location of the Windham Landfill, Windham, Connecticut, from Approximately 1945 to 1978

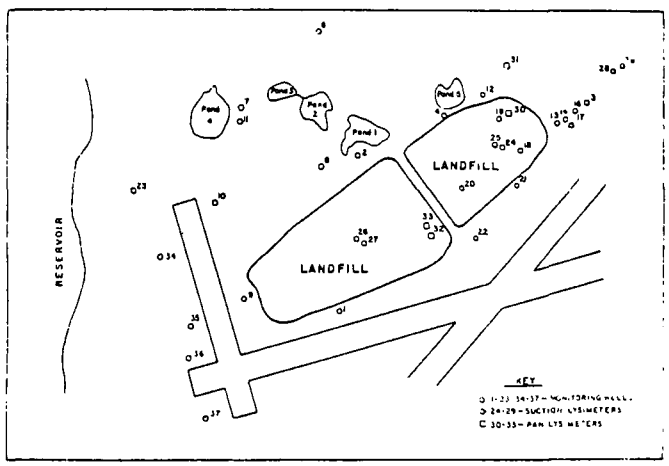

Figure 2.
Location of Monitoring Points at the Windham Landfill, Windham, Connecticut

(1) Suction and pan lysimeters in the refuse above the water table and in the surrounding soils to determine moisture infiltration
(2) The emplacement of piezometers into the water table below and around the landfill to determine the quantity and quality of leachate being generated and its movement through the subsurface

(3) The establishment of surface water sampling points
(4) The placement of suction lysimeters to obtain leachate in the refuse above the water table
(5) The implementation of a bimonthly sampling program to determine changes in the geometry of the pollutional plume with time

Between February and June 1979, wells, ponds and lysimeters were sampled on a monthly basis to determine water quality. The water levels in the wells and ponds were measured weekly and the volume of water collected in the pan lysimeters was measured.

The leachate, of moderate strength, was generated by the old fill whereas leachate of somewhat higher strength was generated by the newer portion of the landfill. Leachate degraded the groundwater down-gradient of the fill. There was a significant contrast between the background water quality measured upgradient of the site and that of contaminated groundwater found down-gradient of the landfill.

An analysis of the results of the weekly monitoring of groundwater and surface water elevations and daily precipitation data verified significant infiltration was taking place into the landfill. As much as 85% of the water passing through the refuse was derived from infiltration of precipitation.

The mass loadings to the Windham Reservoir from the disposal site prior to any remedial action are shown in Table I.

Table I.
Mass Loading of the Windham Reservoir by the Windham Landfill*
(Before Surface Sealing)

Constituent	Old Landfill mg/l	Old Landfill lb/day	New Landfill mg/l	New Landfill lb/day	Total Load lb/day	Total Load lb/year
TOC (total org. carbon)	242	54	663	127	181	661,000
Total Ions**	4,212	948	8,736	1677	2,625	958,000
Sodium	85	19	580	111	130	47,600
Chloride	80	18	510	98	116	42,300
Iron	61.3	14	270	52	66	24,000
Manganese	4.5	1	3.5	0.7	1.7	615
Hydraulic Load	15,000 gal/day ground water		23,000 gal/day ground water			

*Based on chemical analyses for March 79 for MP #24 and MP #26; background concentration for all constituents negligible (MP #28)
**Specific Conductance x 1.56 = Total Ions

Remedial actions proposed to abate and prevent pollution from the landfill included:

- Regrading of the landfill to maximize surface water runoff and minimize infiltration
- The placement of a 20-mil PVC top seal
- Covering the top seal with approximately 18 inches of final cover
- Revegetation (see Figure 3).

The remedial actions were designed to be passive to insure minimum future maintenance. From the late summer to the early winter of 1979, these remedial actions were implemented at the site and final revegetation was accomplished in the spring of 1979.

Beginning in the fall of 1979, with the installation of the seal, bimonthly sampling was instituted at selected monitoring points. Results of the sampling showed that the impact of the site on the groundwater has been mitigated between November 1979 and March 1981. The current mass loadings subsequent to the surface sealing, as well as, the reductions achieved to date are presented in Table II.

Table II.
Mass Loading of the Windham Reservoir by the Windham Landfill*
(After Surface Sealing)

Constituent	Old Landfill mg/l	Old Landfill lb/day	New Landfill mg/l	New Landfill lb/day	Total Load lb/day	Total Load lb/year	Total % Reduction
TOC	43.3	4.33	3.6	0	4.33	1580.45	99.76
Total Ions**	2808	280.61	7800	0	280.61	102422.65	89.31
Sodium	32.2	3.22	290	0	3.22	1175.30	97.53
Chloride	73	7.30	312	0	7.30	2664.5	83.70
Iron	14.1	1.41	51.2	0	1.41	514.65	97.78
Manganese	0.20	0.02	0.11	0	0.02	7.3	98.81
Hydraulic Load:	12,000 gal/day ground water		(no ground water)				Average = 94%

*Based on latest chemical analyses for each monitoring Point (March 1981 for MP #24 and May 1981 for MP #26).
**Specific Conductance x 1.56 = Total Ions.

CHARLES CITY, IOWA

This site was a chemical waste disposal dump from 1952 to 1977 by a manufacturer of feed additives and veterinary pharmaceuticals for the poultry industry. It is located in the floodplain of the Cedar River (Figure 4).

Since 1977, detailed studies undertaken there revealed that the site contains over three million cubic feet of waste material containing 28 priority pollutants. It lies over a major water supply aquifer for municipal and rural areas of northeastern Iowa. The following are calculated estimates of some of the major compounds present:

Estimate of the Major Chemical Components Contained in The LaBounty Dump Site, Charles City, Ia.

Chemical	Amount lb.
Arsenic	6,044,000
1, 1, 2-Trichloroethane	70,000
Nitrobenzene	280,000
Orthonitroaniline	1,500,000
Phenol	27,000

Early in 1979, the Solid and Hazardous Waste Research Division (SHWRD) was requested by both the Office of Solid Waste (OSW) and EPA, Region VII, Kansas City, to implement some form of remedial action research at the site. To date, ORD effort at this site has consisted primarily of providing guidance on the placement of effective monitoring system, assisting in the development of final closure plans, which included a capping operation and conducting an on site waste sampling study to ascertain the feasibility of *in situ* stabilization. If the capping operation (clay) does not sufficiently reduce the discharge of contaminates to the Cedar River, the overall closure plan calls for the construction of an upgradient cut-off wall to reduce or eliminate horizontal groundwater flows into the refuse mass.

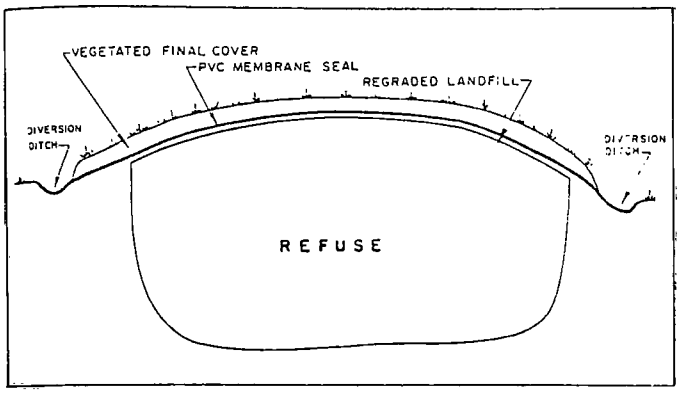

Figure 3.
Typical Section Through the Windham Landfill

Between 10/2/79 and 10/9/80, an elaborate monitoring system was used to quantitate the discharge of three primary/indicator contaminates from the site to the Cedar River (Table III).

The surface infiltration minimization plan for the 13.3 acre area of the Charles City Site consisted of a two foot thick clay cap, ground cover, erosion control at the site toe, storm sewer rerouting, surface runoff controls and post installation monitoring. The capping was completed in November 1980. Monitoring data taken to determine its effectiveness are presented in Table IV.

A comparison of the calculated LaBounty load contribution to the Cedar River before and after the capping operation is contained in Table V.

The wide range of concentrations for the contaminants before and after sealing makes it difficult to conclusively say whether or not the capping operation was effective.

An alternative conceptual approach was evaluated by the National Enforcement Investigation Center in Denver, Colorado. In this analysis, the investigators made a basic assumption that near-site and on-site rainfall are the primary driving forces for producing leachate. By this method, anomalies in correlated data might indicate effects of other possible derived forces such as upward leakage from the Cedar Valley aquifer or bank recharge from the Cedar River.

The analysis suggested that shortly after a rain, a leachate pulse forms and begins moving toward the Cedar River. The pulse is characterized by a higher flow volume

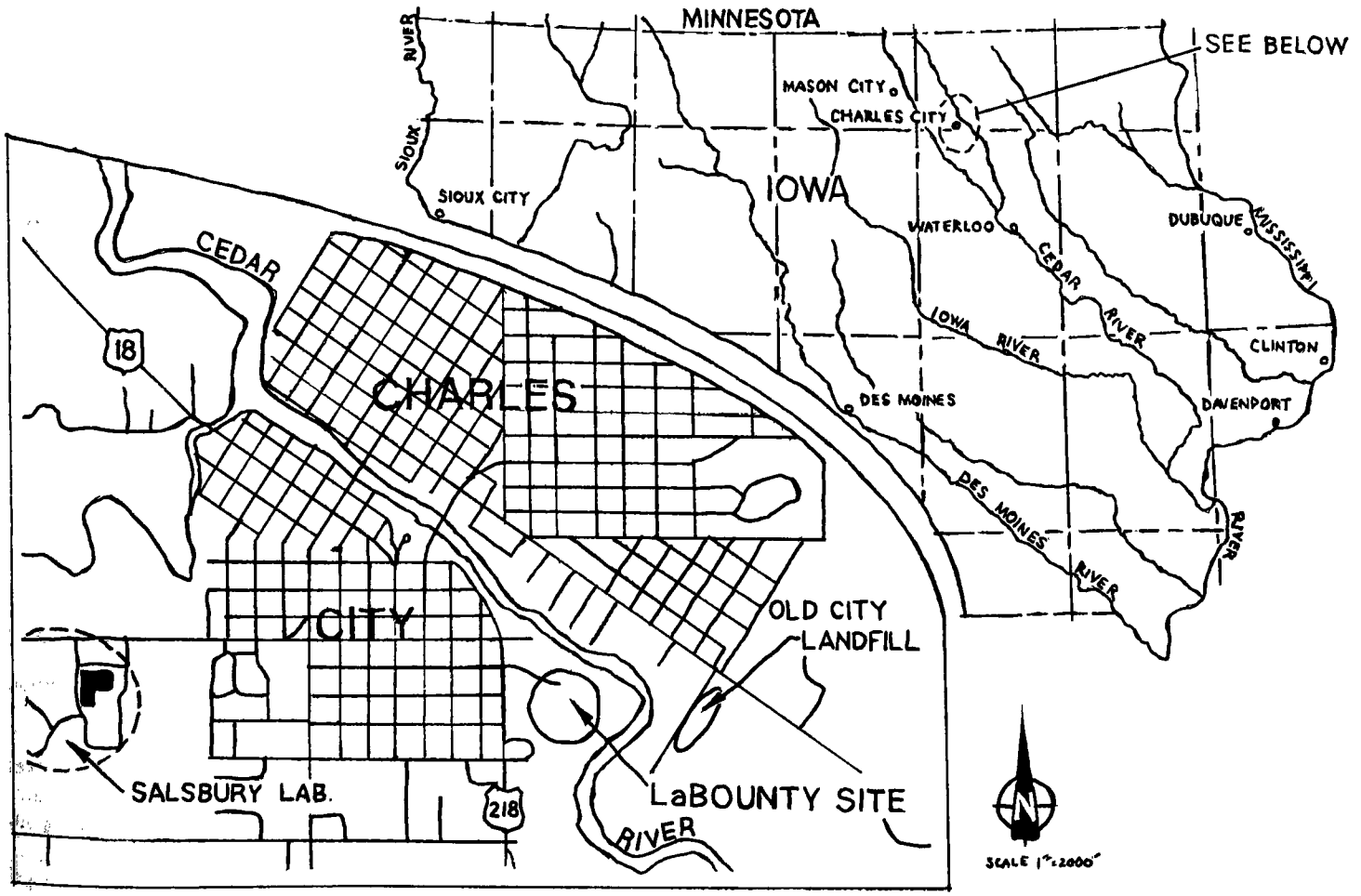

Figure 4.
Site Location, LaBounty Disposal Site

Table III.
LaBounty Disposal Site
Cedar River Monitoring
(Before Surface Sealing)

	STATION 11						STATION 12						CALCULATED LABOUNTY CONTRIBUTION		
	Arsenic		ONA		1,1,2-TCE		Arsenic		ONA		1,1,2-TCE		Arsenic	ONA	1,1,2-TCE
Day-Yr	Conc.	Load	Conc.	Load	Conc.	Load	Conc.	Load	Conc.	Load	Conc.	Load	Load	Load	Load
10/2/79	2.40	4.7	0.29	0.6	6.1	12.0	20.9	40.8	5.3	10.3	12	23.4	36.1	9.7	11.4
1/14/79	<2.00	<9.5	12.	56.8	5.4	25.6	9.2	43.6	29	137	8.0	37.9	34.1-43.6	80.2	12.3
2/13/79	4.30	7.2	0.32	0.5	9.3	15.7	43.4	73.1	7.1	12.0	23.3	39.3	65.9	11.5	23.6
4/16/80	6.4	24.7	0.049	0.19	<5	19.3	15.5	59.9	3.66	14.1	6	23.21	35.2	13.9	3.9-23.2
5/08/80	7.4	13.5	0.14	0.25	<5	9.1	33.5	60.9	4.0	7.2	8.0	14.5	47.4	7.05	5.4-14.5
6/13/80	4.2	15.0	0.158	0.56	<5	<17.8	33.8	21.	7.42	26.5	11	39.3	106	25.9	21.5-39.3
7/11/80	8.2	24.1	0.07	0.21	<5	<14.7	25.0	73.4	6.74	19.8	9.0	26.4	49.3	19.6	11.7-26.4
8/7/80	4.1	6.2	0.07	0.11	<5	<7.6	29.2	44.6	2.40	3.68	8.0	12.2	38.4	3.55	4.6-12.2
9/10/80	4.0	18.4	0.07	0.32	<5	<23	26.0	120	2.49	11.5	7.0	32.3	102	11.2	9.3-32.3
10/9/80	<2	6.47	0.14	0.45	<5	<16.2	13.0	42.1	3.3	11	<5	<16.2	35.6	10.6	0-16.2

Note: Conc. PPb
Load lb/day

*Measured flow at Station 11 used in loading calculations

Table IV.
LaBounty Disposal Site
Cedar River Monitoring
(After Surface Sealing)

	STATION 11						STATION 12						CALCULATED LABOUNTY CONTRIBUTION		
	Arsenic		ONA		1,1,2-TCE		Arsenic		ONA		1,1,2-TCE		Arsenic	ONA	1,1,2-TCE
Day-Yr	Conc.	Load	Conc.	Load	Conc.	Load	Conc.	Load	Conc.	Load	Conc.	Load	Load	Load	Load
11/6/80	6.	17.0	0.10	0.28	5.	14	16.	45.2	2.0	5.7	8.0	23.	28.2	5.42	9.0
12/12/80	<2.0	<2.89	0.06	0.09	9.0	13	25	36.1	2.2	3.2	14	20	33.2-36.1	3.11	7.0
1/12/81	3	4.2	0.19	0.27	<5.0	<7.1	37	52.2	2.7	3.8	9.0	13	48.0	3.53	5.9-13
2/10/81	4	11.2	0.21	0.59	9	25	27	75.4	1.7	4.7	10	28	64.2	4.11	3.0
5/8/81	4	23.5	0.6	.35	<5.0	<29	18	106	1.2	7.0	5.0	29	82.5	6.65	0.0-29
6/3/81	4	14.7	0.5	.18	<5.0	<18	17	62.7	1.1	4.1	5.0	18	48.0	3.92	0.0-18

Note: Conc. PPB
Load lb/day

and elevated pollutant concentrations. About eight months after the rain, the pulse reaches the Cedar River and results in increased pollutant loadings. The analysis also indicated that the clay cap installed over the site during the late summer, early fall of 1980, will reduce leachate by eliminating recharge to highly concentrated waste deposits within the site. The reduction was estimated to be quite significant; however, monitoring data are necessary to accurately define cap effectiveness.

Another alternative approach that was used to indicate the potential effectiveness to the remedial action was based upon moisture infiltration before and after capping. It was estimated that prior to remedial action, at least 20 in. of infiltration per year occurred. The volume of infiltration prior to capping was calculated as follows:

$$Q = 20 \times 13.3 \times 0.52 \times 1440 = 19{,}918 \text{ gal/day}$$

After capping the rate of infiltration through the site was reduced to less than 4 in. per year. This is a conservative estimate because under saturated conditions and unit gradient, a clay cap having a permeability equal to or less than 1×10^{-6} cm/sec would allow only 1.2 in. of water flow per year. In the field, under unsaturated conditions, flow would be less. Based on the above permeability after capping, infiltration is calculated to be

Table V.
Loadings to Cedar River from LaBounty
Before and After Capping

Before LaBounty Contribution			After LaBounty Contribution		
Arsenic Load	ONA Load	1,1,2-TCE Load	Arsenic Load	ONA Load	1,1,2-TCE Load
36.1	9.7	11.4	28.2	5.42	9.0
34.1-43.6	80.2	12.3	33.2-36.1	3.11	7.0
65.9	11.5	23.6	48.0	3.53	5.0-13
35.2	13.9	3.9-23.2	64.2	4.11	3.0
47.4	7.05	5.4-14.5	82.5	6.65	0.0-2.9
106	25.9	21.5-39	48.0	3.92	0.0-18
49.3	19.6	11.7-26.4			
38.4	3.55	4.6-12.2			
102	11.2	9.3-32.3			
35.6	10.6	0-16.1			

$$Q = 4 \times 13.3 \times 0.052 \times 1{,}440 = 3{,}984 \text{ gal/day}$$

The net effect of the site capping should be to reduce infiltration through the site by 80%. As a result mass loadings/migration due to infiltration will be reduced by 80%.

CONCLUSIONS

A synthetic capping remedial action at Windham, Connecticut under rather ideal hydrological conditions lead to an overall 94.0% reduction of the mass loadings between March 1979 and March 1981.

In a complex hydrologic situation 6 months of post remedial action monitoring is inadequate to determine effectiveness. Conceptual approaches to predicting the effectiveness of capping operation even in complex hydrologic settings, are available, but the verification of the extent of their accuracy remains to be proven.

ACKNOWLEDGEMENTS

Steven W. Sisk, Hydrologist, EPA, Office of Enforcement, National Enforcement Investigation Center, Denver, Colorado, for his contribution "Hypothetical Assessment of Rainfall Effects on Leachate Production at the LaBounty Site, Charles City, Iowa."

APPLYING TECHNIQUES FOR SOLIDIFICATION AND TRANSPORTATION OF RADIOACTIVE WASTES TO HAZARDOUS WASTES

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INTRODUCTION

The equipment discussed in this paper was originally developed in response to the needs of the nuclear power industry for processing and transporting radioactive wastes. Prior to 1979, liquid wastes, primarily in the form of boric acid and miscellaneous chemical drains, could be transported for burial in their liquid state. In mid-1979, the licenses for the three burial sites were revised to prohibit acceptance of liquid wastes. Utilities whose plants did not contain systems capable of solidifying liquid wastes were faced with a crucial decision. They could cut back on the volume of liquid wastes being generated and treat them with deep bed demineralizers or they could hire an outside firm to come onto the site and, with portable equipment, solidify the liquids prior to shipment. For many utilities, the first option was not feasible due to the large quantities of ion exchange resins that would be required to treat the liquid wastes involved.

Both mobile processing equipment, and equipment that is permanently installed on-site are discussed in this paper. The transportation equipment was designed and built to conform to specific requirements pertaining to radioactive wastes. The purpose of the following discussion is to identify how these types of equipment could be modified and used to accommodate hazardous chemical wastes.

SOLIDIFICATION OF LOW-LEVEL RADIOACTIVE WASTES

As stated previously, the solidification of low-level radioactive wastes can either be handled with mobile equipment, leased and operated by a company that specializes in this work or the equipment can be purchased and installed for operation by a utility. Numerous current suppliers exist for both mobile solidification services and supply of systems for permanent in-plant installation.

The types of wastes being solidified are spent ion exchange resins, concentrated solutions of boric acid and sodium sulfate and calcium fluoride sludges. Various lubricating and turbine oils have also been successfully solidified. Most of these wastes have, for the past several years, been solidified with Portland Cement using various additives to condition the wastes based on their chemical characteristics. A urea-formaldehyde (UF) based material has also been extensively used over the past 5 to 7 years.

The use of UF has come under increasing attack over the last two years because it is a condensing polymer and produces liquid as it polymerizes. When the resin hardens, it shrinks, forcing liquid out of the matrix. This liquid is very low in pH as a result of the acidic catalyst used to initiate the polymerization process.

A third product, which is only beginning to be used, is a material produced by Dow Chemical Company referred to as the "Dow media." The Dow process is a three part process which uses a binder, a promoter and a catalyst. For certain wastes, an extender is also required. The proportions of materials used, and the chemical formuli of the ingredients, are proprietary to Dow Chemical Company.

Bitumen, or asphalt, has been used for the solidification of radioactive wastes in Europe for several years. While a few systems using bitumen have been sold in this country for installation in nuclear power plants, none are in operation at this time.

Due to numerous recent changes in the burial site license in Barnwell, South Carolina, there has been a significant increase in the number of mobile systems in use over the last two years. Power plant operators have turned to mobile solidification services in order to satisfy evolving criteria. This increased use makes it very difficult to determine the exact number of power plants using mobile systems at any one time. However, it is estimated that 60 to 70 percent of the operating units were contracting for some form of mobile solidification service as of July of this year.

Typical System

Since almost all solidification of low-level radioactive wastes is performed using cement, a typical solidification system currently in use will be described. The components of the system include a disposable container with internal mixing blades, a mixing head, a mixing motor, a cement storage hopper, a cement feed system, a dust collector, a pump skid and a control panel.

When the radiation level of the waste materials is high enough to require shielding for the operator, the solidification process is performed with the disposable liner either in a process shield or in a shielded shipping cask (which can be used for subsequent transport of the waste

to the burial site). After the liner has been placed in its desired location, the mixing head with mixing motor is bolted to the liner. A thick rubber gasket between the mixing head and the liner neck provides a seal between the inside of the liner and the outside atmosphere. All other connections to the liner are made through the mixing head. A prefilled cement hopper is positioned on a scaffold and connected to the cement inlet valve on the mixing head via a flexible screw feeder. The cement feed motor is located on the mixing head. An induced draft dust collector is connected to the vent connection on the mixing head to catch any cement dust. A central control panel contains the necessary stop/start switches, indicators and control logic to operate the system.

Mobile systems are leased to a utility for periods ranging from the duration of a single solidification operation to several years of service. Operator services are supplied with the equipment. When the duration of the contract is long enough and the frequency of use is high enough, operating personnel are permanently located at the site. Upon termination of the contract, the equipment is removed from the site.

The procedure is quite different for permanently installed systems which are owned, operated and maintained by the utility. They are located within a building designed especially to afford the operator the maximum possible radiation shielding. These shield walls, however, tend to make the equipment less accessible. In-plant systems are substantially more automated than the mobile systems. A simplified process flow diagram of the in-plant solidification system being installed at the three-unit Palo Verde plant west of Phoenix, Arizona, for Arizona Public Service is shown in Figure 1.

Aside from the degree of automation involved, the primary difference between a mobile system and an in-plant system is how and where the mixing of wastes and solidification medium takes place. In an in-plant system, the mixing takes place outside the disposal container, be it a 55-gallon drum or a large liner. In the system shown in Figure 1, wastes to be solidified are transferred to the waste batch tank, where samples are taken and appropriate chemical adjustments are made prior to solidification. The batch tank is equipped with level indicators and an electric mixer. The waste transfer pump transfers the

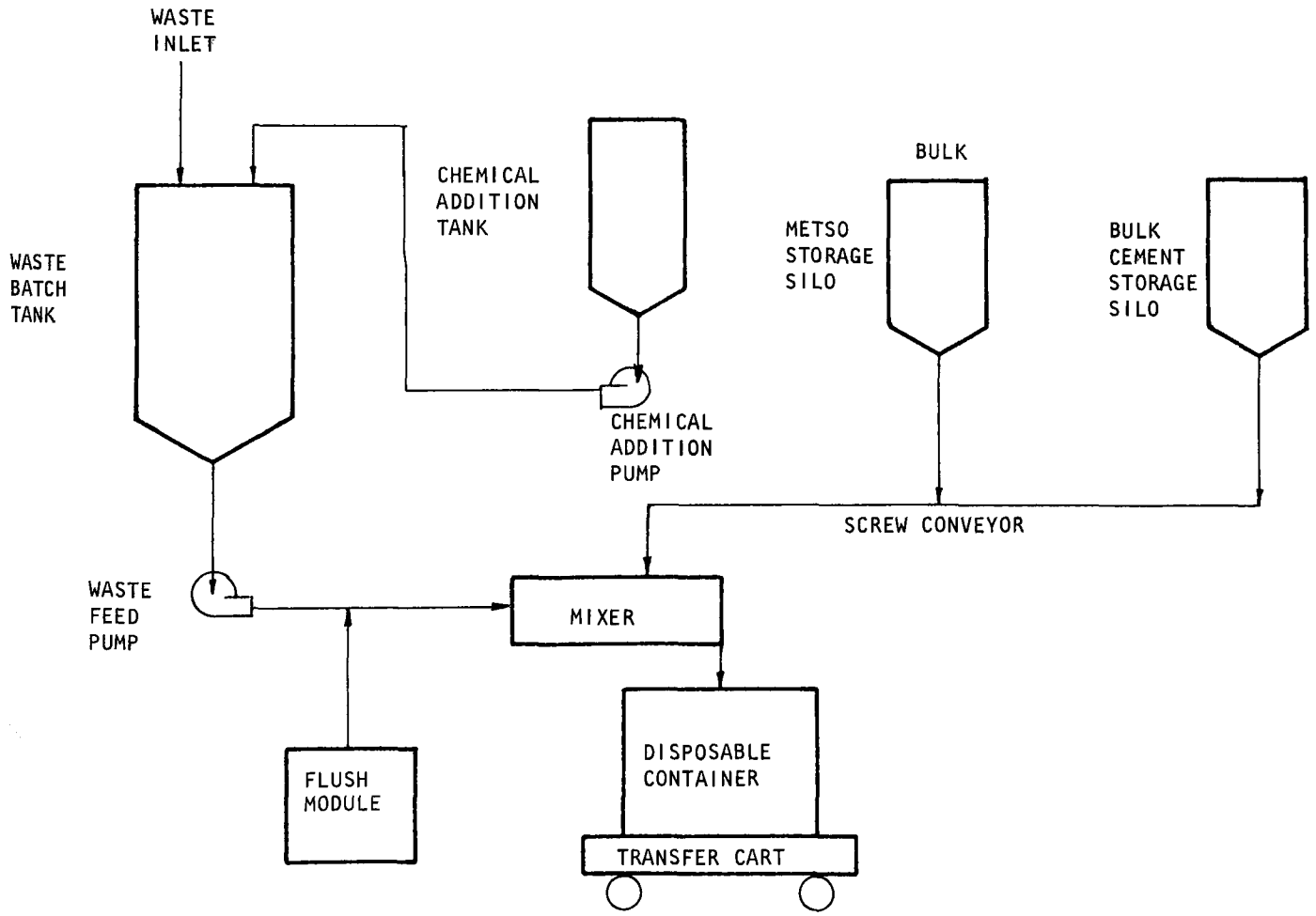

Figure 1.
Simplified Palo Verde PFD

wastes at a predetermined flow rate from the batch tank to the waste mixer.

The cement and Metso* are stored in silos, designed to hold large quantities of these materials to take advantage of bulk deliveries. Cement and Metso are discharged from the silos at feed rates controlled by horizontal screw conveyor. Direct current drive motors are used which allow the feed rates to be adjusted depending on the desired mixing ratios of waste, cement and Metso for each particular waste form. The cement/Metso mixture enters the unit from the top at the back end of the mixing screws. As the cement is moved forward, the pumped wastes enter the mixing barrel and are mixed with the cement. The discharge valve is opened and the cement paste drops into the disposable container.

At the end of each cycle, the waste feed system and the mixer are completely flushed. Extra dry cement added to the liner, or to the last drum, adsorbs the flush water. The primary flush module contains an air accumulator bottle which provides the motive force for flushing the mixer in the event of a loss of electrical power. The mixer also includes a hand crank on the motor so that it can be cleaned out manually if necessary. After the container is filled it is moved to a capping station where a lid is automatically affixed. The container is checked for external contamination, decontaminated if necessary, and moved into a shielded storage area to await transportation to the burial site.

TRANSPORTATION

Obviously, the primary design consideration of radioactive waste shipping casks are their radiation shielding capability. This concern is of little consequence in transporting hazardous chemical wastes. However, the structural integrity required in a design that must support thick steel and lead walls, and that conforms to the NRC regulations, results in a package whose ability to withstand foreseeable transportation accidents is not easily matched.

Several types of shipping containers exist including standard truck vans, shielded vans, box casks for handling small numbers of drums, and large cylindrical casks for shipping liners or drums. Figure 2 shows a box cask which holds 12 drums. A roller assembly pulls out from the end of the box for ease in loading and unloading drums. A cylindrical cask which will hold either a 170-ft^3 steel liner (6 ft high by 6 ft in diameter) or 14 55-gallon drums is shown in Figure 3. The 55-gallon drums used in the nuclear industry are designed and tested in accordance with DOT Specification 17H and are certified to hold 840 pounds of waste.

The tie down connection of both the box casks and cylindrical casks are designed to withstand the following acceleration loadings:

- Front to back 10 g
- Side to side 5 g
- Vertical 2 g

Thus, the tie down connections on a typical shipping cask weighing 50,000 pounds are designed to withstand simultaneous loads of 500,000 pounds forward, 250,000 pounds sideways and 100,000 pounds upwards. Although the trailers used to transport the cask cannot withstand these forces, the strength of the containers insures that the contents will remain undamaged and the cask integrity will not be breached.

Figure 2.
Reusable Cask Which Holds 12 Drums

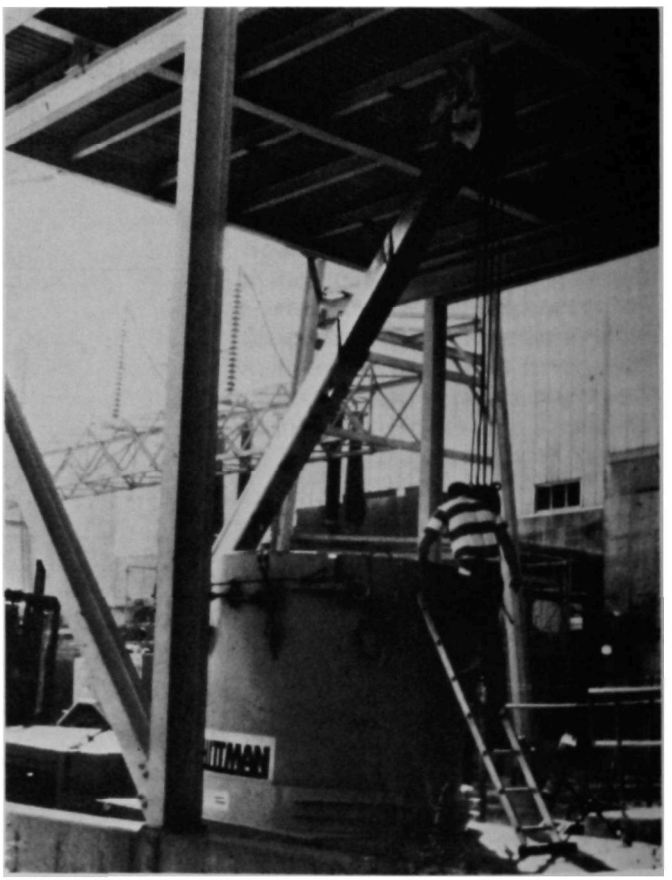

Figure 3.
Reusable Cask for a 170 ft^3 Steel Liner or 14-55 Gallon Drums

*Registered trade name for sodium metasilicate anhydrous, manufactured by Diamond Shamrock, Soda Products Division. The full product name is Metso Beads 2048.

Drop tests must also be performed on the casks. The cask must be dropped onto an unyielding surface with no resultant damage to its contents or to the cask integrity when dropped in every orientation. Two drop tests exist: a one-foot drop test and a thirty-foot drop test. Most casks are designed to withstand the one-foot test, although in all probability these casks would not yield in a drop test of as much as ten feet. Only specialized casks, designed to handle "large quantities" of radioactive material, will withstand the thirty-foot drop test.

CHEMICAL VERSUS RADIOACTIVE WASTES

Before the use of the cement solidification technique for toxic and hazardous wastes is examined, the advantages and disadvantages of handling chemical wastes as compared to radioactive wastes should be noted. This is done in Table I.

APPLICATION OF EQUIPMENT TO SPECIFIC USES

In considering using the equipment described above for radioactive wastes for the immobilization of hazardous wastes, one must first define the conditions under which hazardous wastes are found. It is expected that the contents of many of the drums will be unknown, lagoons containing undefined substances will be encountered and the quantities of contaminated soils and sludges will be considerable.

Drums containing solids are not candidates for solidification. The emphasis in this paper is on the solidification of liquids and pumpable sludges. Containers that are intact must be opened and the contents inspected. Breached drums must also be inspected to determine the status of their contents. Once the containers with liquids are identified, their contents must be transferred to a batch tank or a disposable liner depending on the type of system to be used. This transfer from the dumping grounds to the solidification area will probably be the most critical and most dangerous step in the process.

Table I.
Advantages and Disadvantages of Handling of Chemical Wastes Compared to Radioactive Wastes

Advantages	Disadvantages
1. The material is not radioactive, therefore proximity of the worker to the waste, or thicknesses of walls and material density, are not a problem.	1. Small exposures to some wastes through inhalation or physical contact could be fatal even in very small doses.
2. Contact of the waste with protective clothing can be permitted.	2. Contents of most containers will be unknown and identification nearly impossible.
3. Glass and/or plastic viewing devices can be built into the system wherever deemed appropriate.	3. Some of the wastes may be explosive.
	4. Procedures for the transfer of the liquids to the batch tank or a disposal liner must be carefully planned.
	5. Synergistic effects may result when different wastes are mixed.
	6. Chemical analysis of the contents of each container will have to be made.
	7. Process control plans will have to be developed for each site.

ADAPTATION OF MOBILE SOLIDIFICATION SYSTEMS

First Example

In order to assess how the equipment could be used, two scenarios were developed and studied. The first situation is the best case for a mobile system. It is a small site containing drummed wastes and requires that no liquids leave the site. It is assumed that the number of drums present is less than a thousand, with most still intact.

Before the actual solidification process can start, it is recommended that a prefabricated enclosure be erected over a prepared surface. The prepared surface prevents any spilled liquid from further contaminating the surrounding soil. The prefabricated enclosure will protect the equipment and personnel from the elements and establishes a controlled environment around the process to minimize airborne hazards.

Drums are brought into the enclosure where they are opened, inspected and samples taken for analysis. The chemical analysis can be best accomplished in a centralized laboratory equipped to handle toxic and hazardous materials. It should be assumed that a particular drum could be in the enclosure for as long as two weeks while the chemical analyses are being performed. When the contents of several drums have been selected as a combined batch for solidification, additional samples must be taken. Samples of equal size from each drum are combined and the proper pretreatment, as determined by the chemical analysis, is made. Typical pretreatments include pH adjustment, addition of emulsifiers or addition of solvents.

The goal of the pretreatment process is to produce a mixture which will dissolve or remain suspended in water. This is essential since the setting of the cement is dependent on the presence of water. Upon completion of the pretreatment process a small quantity, approximately 100 to 400 ml of the mixed wastes, are solidified as a test sample. Several samples may actually be made using different ratios of waste and cement.

In the final analysis, two samples are selected to represent a range of waste to cement ratios that will result in an acceptable product. These ratios are then used to determine the optimum quantity of wastes to be solidified in a single operation and to estimate the quantity of cement necessary to successful solidification. This procedure, or process control program, is repeated for each batch of wastes that differs significantly from previous batches.

When the successful solidification tests are completed, the actual waste processing can be initiated. Since the chemical analysis previously performed has identified the wastes, the appropriate precautions can be taken regarding proper clothing and the necessity for breathing apparatus. The operating personnel, properly dressed, would then transfer the contents of the drums to the mixing liner and the designated pretreatment would be accomplished.

Liquids would be transferred by pump. Sludges and pasteous solids might have to be hand transferred. For large quantities of nonpumpable materials, the drums might better be emptied into a mixing tank with the top opened or half-opened. The material could then be pre-

treated and mixed until a slurry is developed that can be pumped into the disposable liner for solidification.

Once the waste is in the liner, the operation is identical to the operation for radioactive wastes. Cement and any designated dry additives are put into the liner through a screw feeder at approximately 100 lb/min. During this phase of the operation, a dust collector continuously pulls air from the liner and exhausts it through a baghouse filter. Additional off gas controls may have to be included depending on the type of materials handled, and gas generation expected due to the pretreatment operation or to the reaction of the wastes to the solidification media.

There are obviously certain materials that do not lend themselves to this on-site solidification. Materials too hazardous to risk direct handling could be handled remotely. However, the type of equipment necessary for remote handling is not conducive to the limited scope of this scenario. These materials would have to be packaged and sent to a centralized facility.

With the solidification process complete, the mixing motor is removed and all other connections are broken. The container is capped with either a standard 55-gallon drum lid or with a snap tight, nonremovable lid. At this time the liner is moved to a suitable storage location to await transportation.

Second Example

The second scenario also describes the use of a mobile system and is, again, a small site, but one in which broken and leaking drums litter the site causing contaminated soil and sludges. Damaged and/or leaking drums could be handled in a centralized processing facility if they are considered too dangerous for on-site processing. These drums could be repackaged in an overpack such as an 83-gallon drum for transportation. The basic setup described in the first scenario for handling intact drums could still be used, although precautions would be necessary due to the high probability of exterior contamination. Decontamination facilities could be provided with subsequent solidification of the decontamination solutions.

Small quantities of sludge and contaminated soil are best handled onsite in loading drums or liners (depending on the viscosity of the material), which are then moved to the solidification facility. In-drum mixing systems can be used for soils to keep the motor sizes reasonable.

ADAPTATION OF IN-PLANT SOLIDIFICATION SYSTEMS

The significant question regarding toxic and hazardous wastes is how to handle large uncontrolled sites where thousands of drums and millions of gallons of chemical wastes have been indiscriminately dumped. Cleanup of these sites will take years. No simple solutions are available. The costs are going to be high and the progress slow. In most instances complex processing facilities built at the existing dump sites will be the technical, if not the political, solution. The ultimate disposal of the newly processed wastes will depend on the specifics of each site.

Once the decision is made to process existing wastes by immobilization in an inert binder such as cement, a determination of the exact nature of the wastes to be processed and the support facilities required must be made. The forms which these wastes may take include:

- Liquids from lagoons, settling ponds and drums
- Sludges from lagoons, settling ponds and leaking drums or other containers
- Contaminated soils caused by leaking containers or direct dumping of liquids and sludges
- Pasteous solids from breached and/or intact containers
- Solids in drums or in other containers or from open contaminated sites

Facility Design

Using these five waste forms as a basis for facility design and considering the possible hazardous nature of the materials, a conceptual facility flow pattern can be made. This flow pattern, shown in Figure 4, includes several features commonly used in the nuclear power industry for waste handling and personnel access control. Depending on the specifics of the site and the wastes, many of these operations can be performed remotely. These remote operations are performed using TV monitors mounted throughout the facility and overhead bridge cranes to move containers about.

As shown in Figure 4, materials from the site are brought into the facility at the receiving point, probably by truck. The containers are unloaded and moved into an inspection room where the container is opened and the contents inspected. If the contents are stable, a decision can be made to send the container to the storage area for shipment or to the repackaging area for placement in an overpack. In either case, a sample may be taken for analysis to aid in determining the proper method of ultimate disposal.

Containers, whose contents upon inspection are identified for solidification, are first sampled. While the samples are being analyzed, the containers are sent to a contaminated storage area after appropriate labeling. Containers with similar contents are identified and sample solidifications are performed to develop specific process parameters and determine necessary additives. These containers are then retrieved from storage and moved into the area with the batch tank. The contents of each container are transferred to the batch tank by pump or by picking up the container using special handling equipment and pouring. The batch tank is sealed and the contents mixed with appropriate solvents, emulsifiers and chemicals for pH adjustment. At the end of the mixing cycle a sample can be drawn for verification purposes.

Remote Operations

This section discusses a solidification operation that is controlled remotely and automatically from a central control panel or control room. Dry cement feed is fed along with the waste feed but enters the mixing device prior to the wastes. Feed rates are controlled and can be adjusted if necessary. The cement paste free falls into a disposal

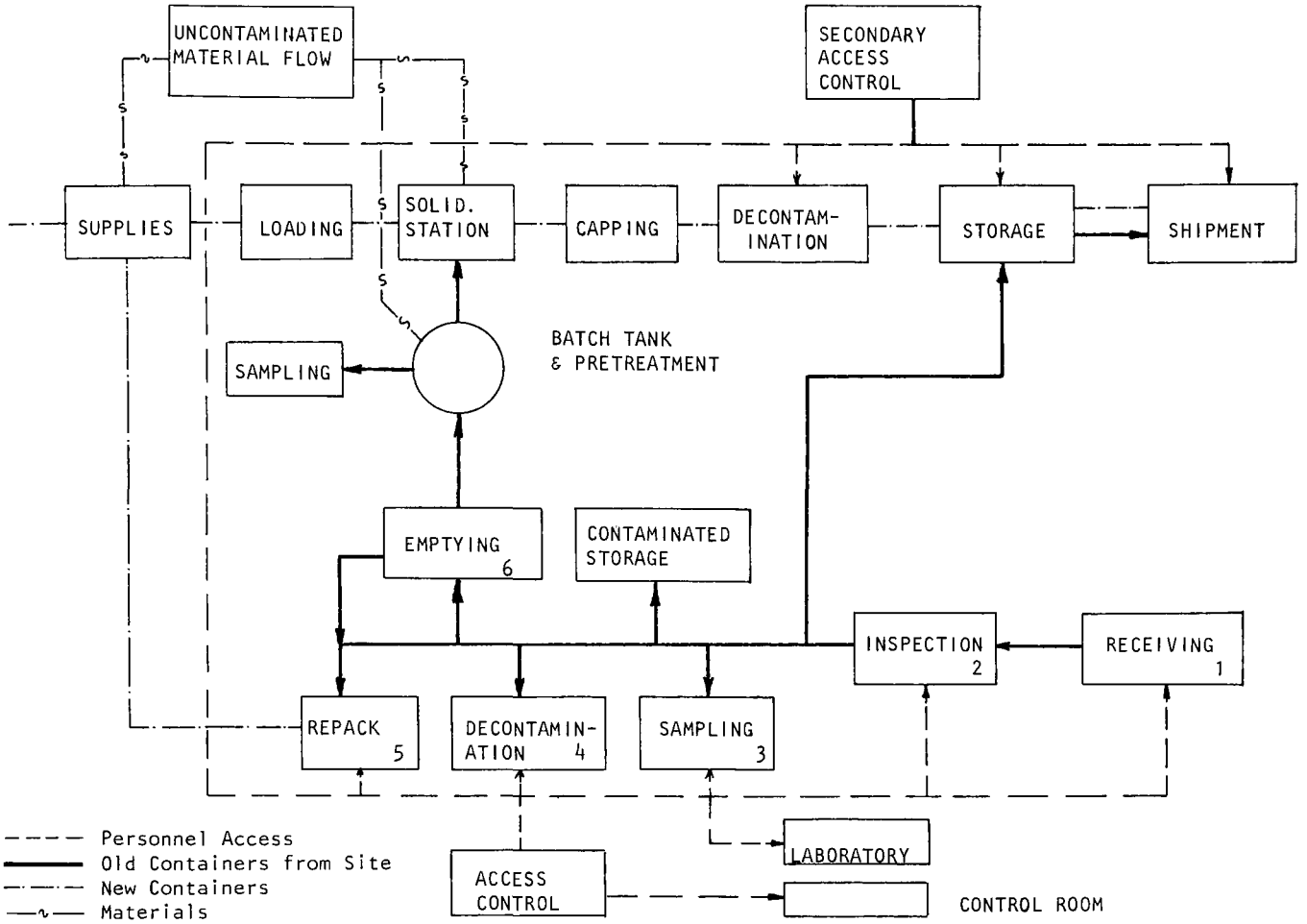

Figure 4.
Hazardous Waste Solidification Facility Flow Diagram

container until a preset level is reached. The interface between the mixer and the container is sealed with appropriate vent connections. Ultrasonic level probes are used to prevent contamination of the instruments.

When the container is full, waste feed is terminated by either diverting it back to the batch tank or by completely flushing the lines. The diversion mode is selected when additional containers are to be processed within a reasonable time frame. If the batch tank is empty, or insufficient material is available to process another container, the feed line is flushed. Additional dry cement is fed through the mixer and into the container to hydrate the flush water. Once the container is full it moves out of the fill position into the capping station where it is capped and sealed.

The solidification process itself has several fail-safe design features built into it. First, the motor for the mixer is located outside the solidification area and contains a hand crank. This back-up system permits emptying of the mixer should the process be stopped in mid-stream due to motor failure or loss of electrical power. Maintenance on the motor can also be performed without entering a contaminated area.

Second, the system flush is controlled through a flush module mounted outside the solidification area, again for maintenance purposes. The flush water is kept under pneumatic pressure at all times so it is available even during a loss of electrical power. This module is used for normal operations to ensure that the proper quantity of flush water is used and to ensure that the unit is operable if needed in an emergency.

Capped containers are inspected and tested for external contamination and decontaminated if necessary. With the container certified as free of contamination it should be labeled as to its contents and status and stored until final transportation for disposal.

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RENOVATION OF A WOOD TREATING FACILITY

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INTRODUCTION

In August 1981, work began on the renovation of an out-of-service wood processing facility located on a 130 acre site in St. Mary's County, Maryland. The project is a cooperative effort between regulatory and service agencies and the private sector to clean up a significant hazardous waste problem in a fairly commonplace industrial operation.

BACKGROUND

In the summer of 1975, inspectors of the Maryland WRA determined that the waste practices at a wood treating facility in St. Mary's County, Maryland, might be impacting groundwater. Subsequent investigation indicated that wastewater from a creosote and pentachlorophenol (penta) wood preserving operation was being discharged to unlined "evaporation lagoons." While the practice was obviously unacceptable, the regulatory programs at that time were not designed to handle groundwater discharges.

After much discussion, it was decided that the best revision to this facility would be to construct a recycle/treatment facility utilizing spray irrigation for excess wastewaters. Using this system, most of the penta and creosote would be recycled. Wastewater containing tannins and lignins in addition to waste preservatives would be lagooned and disposed of by spray irrigation. The estimated discharge would be about 1,000 gal/day.

In addition to the ongoing problem, the company would be required to renovate the existing lagoons and clean up the area. In August of 1977, a State Discharge Permit was issued requiring the development of a plan for site renovation and requiring the construction of a wastewater treatment facility. During the summer of 1977, the State obtained some composted sewage sludge to incorporate into the contaminated soils to determine if biodegradation by land farming was possible.

When the test proved successful, the original plan was modified to include on-site renovation of soils contaminated by the waste ponds. The idea was to construct three spray irrigation fields. One would be in use, one as a back-up and the final one to reclaim the contaminated soils. Each year a portion of the contaminated soils would be mixed with compost, tilled and seeded. The following year, that site would be rotated into spray irrigation use. Any remaining liquid waste in the ponds would be treated in the first year with the normal plant waste.

SITE INVESTIGATION

In 1975, samplings of waters in a spring fed "fresh water pond" near the wood treating facility showed phenolic concentrations of 1.80 mg/l. Analyses of oily material floating on the pond was determined to contain 77.5 mg/l of phenolics. There was no evidence of a surface connection between the plant's waste ponds and the fresh water pond. It was observed at the site that the oily material was "bubbling" up from the spring end of the pond.

These observations made it necessary to consider the imposition of site renovation conditions on the property owner. To support the conditions, a field investigation was begun.

On May 6, 1975, three monitoring wells were installed in augered soil borings. The boring logs showed that a coarse to fine silty sand formation existing from the surface to a depth of 15 to 20 ft. Below this is a sandy, blue/black clay which extended to a depth of at least 50 ft. Field investigators noticed strong phenolic odors in soil samples 9 to 13 ft below the surface. The monitoring wells were constructed with 1.25 in. PVC schedule #40 pipe with 5 ft slotted screens. The screens were located approximately 15 to 20 ft below the surface. The water table was between 1.5 to 3.5 ft from the surface.

Water samples obtained from these three wells on June 11, 1975, showed concentrations of phenols of 1.0, 9.0 and 14.4 mg/l. The pH of the groundwater ranged from 5.5 to 5.7 The groundwater flow determined from water elevations in the monitoring wells was from the wastewater holding ponds to the fresh water pond. The conclusions of this interdepartmental study was that waste phenolics in the ponds had percolated into the groundwater and then migrated to the fresh water pond.

The stream which drains the fresh water pond was studied by a private consultant. In that study, a water sample taken approximately 900 ft below the pond contained 0.12 mg/l phenol. The consultant reported that few aquatic insects were found in this section of the stream. However, phenol concentrations decrease and the biomass increases substantially within 0.25 mile from the

first sample point. The data indicate a significant improvement of water quality as the distance from the fresh water pond increases.

To support the pending legal actions, a more detailed hydrogeologic investigation was conducted. On December 7, 1978, WRA investigators sampled ground and surface waters. A sample of the groundwater from one of the wells installed in 1975 showed creosote concentrations of 1.6 mg/l and pentachlorophenol concentrations of 1.34 μg/l. Analyses of liquid samples in the holding ponds showed PCP concentrations ranging from 0.62 to 66.06 μg/l and creosote concentrations ranging from 0.654 to 70.72 mg/l. Analyses of the stream samples showed PCP ranging from 0.01 to 27.0 μg/l and creosote concentrations ranging from 0.001 to 1.769 mg/l. Pentachlorophenol and creosote concentrations in the fresh water ponds were 0.01 μg/l and 0.308 mg/l respectively.[1]

Samples taken at various monitoring wells on the site indicated that the phenolic concentrations increased with depth until the water table was intercepted. At the water table, analyses showed a band of high phenolic concentration that indicated that the wood preservatives were "floating" on the groundwater.

Sampling of shallow dug residential wells in the area failed to substantiate the County Health Department's sampling that showed high phenolics. Samples also showed phenolics in monitoring wells up the hydrologic gradient from the facility. It was proposed that an air vector was responsible for carrying vapors from the venting of the pressure vessels to these sites. This theory will never be tested as the site is shut down.

TECHNICAL BASIS FOR THE RENOVATION PLAN

Renovation of the wood preserving plant incorporates basic biological wastewater treatment processes currently used in the wood preserving industry.[2] For this project, freshly composted sludge from the Washington, D.C. Wastewater Treatment Plant was mixed with the creosote and penta contaminated soils to accelerate biological degradation. The composted sludge provides a biologically active soil addition containing up to 25% dead and living microorganisms. Bacteria, actinomycetes and fungi comprise most of the active microbial population.[3]

Since the contaminants are by nature, bactericides, the microorganisms introduced to the contaminated soils will undergo some acclimation. Following acclimation, however, creosote reductions exceeding 90% have been observed in activated sludge and soil irrigation wastewater treatment processes. Additionally, penta reductions exceeding 99%, during a 50-day period, have been reported in a bench-scale study utilizing activated sludge treatment.[4] Increased soil organic matter has also been shown to expedite penta degradation within the soil medium.[5]

The composted sludge to be used for site renovation will be composted for 21 days and in lieu of the usual curing process will be applied to the site. Incorporation of the composted sludge into the waste contaminated soils will not only restore the microbial population but will also create optimum soil conditions for biological activity. These soil conditions include pH, structure, moisture and temperature. The compost contains approximately 15% limestone and has a pH near neutral. At the planned application rate 125-130 tons/acre, the composted sludge should adjust the previously acid soils to a pH more conducive to microbial activity.

The subsoils on the site range from sandy to clayey. Incorporation of the composted sludge into sandy or droughtly soils increases the moisture holding capacity of the soil. In a clayey or compacted soil, the incorporated compost enhances soil structure allowing better water and gas exchange within the soil and thus promoting a more aerobic environment.

Soil temperature will be affected not only by microbial activity, but also by its ability to hold solar radiation. The existing soil color will be darkened by the composted sludge additions. The darker soil color should maintain warmer soil temperatures later in the fall and early in the spring and consequently enhance biological activity during colder months of the year. In addition to microbial degradation of the creosote and penta contaminants, sunlight should contribute to the destruction of other phenolics and wood chemicals particularly in existing lagoon and "fresh water" pond areas.

Contaminants which have leached past the zone of microbial activity in the soil, are expected to eventually disappear via dilution. Following seeding, the composted amended soils should be more than adequate to promote revegetation of the site.[6]

METHOD OF SITE RESTORATION

Site restoration for this facility is to be executed according to plans prepared by Lyon Associates, Inc. of Baltimore, Md. Following general site inspection, all supply and test wells are to be abandoned and sealed. The lagoons are to be drained and spray irrigated in a designated disposal area. Following this procedure all containers will be cleaned and stored on site for removal. At the same time the lagoons will be breached to prevent further ponding of water.

Following dewatering, all contaminated structures in the pond area such as cement foundations, steel pipes, etc., will be removed and hauled to an approved hazardous waste facility. Proper erosion and sediment controls will be utilized during the land clearing.

The "fresh water" pond will be dewatered by breaching the embankment. Sediment control will be maintained downstream from the pond by using soil erosion control fencing. Since the pond is spring fed, spray irrigation may be utilized at the discretion of the contractor.

The earthwork will involve uniform regrading of the lagoon area maintaining slopes less than 1 to 2. The fresh water pond embankment will also be removed.

Following regrading, composted sludge will be applied to the entire site at the rate of 125-130 tons/acre (approximately 2 in.) and tilled into the top 4 to 6 in. of soil. The site will then be hydroseeded and the grass mowed as required during the growing season.

CONCLUSIONS

When this project was begun five years ago, the State had in mind several objectives. The first was to demonstrate the feasibility of reclaiming a hazardous waste site. At the time this renovation began, RCRA and other laws governing safe disposal of hazardous wastes were just being discussed; the techniques applied here were innovative.

The second objective of the cleanup was the development of low cost, unsophisticated solutions to waste problems to encourage cooperation and participation by industry in cleaning up their own problems. Too often, over-zealous enforcement combined with unclear and overly restrictive technical support have caused activities to occur in the court room with technically ill-prepared judges making decisions instead of renovation of a site by experts.

Finally, from a management standpoint, the State desired to treat or destroy hazardous wastes at, or as close to, the point of generation as possible. This technique eliminates possible transportation accidents and the prospect of creating two hazardous waste problems instead of one.

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THE FORT MILLER SITE: REMEDIAL PROGRAM FOR SECUREMENT OF AN INACTIVE DISPOSAL SITE CONTAINING PCB'S

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INTRODUCTION

In September 1980, the General Electric Company and the New York State Department of Environmental Conservation (NYSDEC) signed the first major agreement in the nation in which a corporation agreed to pay for remedial action to clean up abandoned hazardous waste dump sites where, in the past, it had disposed of its industrial waste. The agreement involves remedial actions at seven land disposal sites in Saratoga, Rensselaer, and Washington Counties. General Electric has agreed to carry out all engineering studies and the necessary remedial action at four locations and has agreed to pay a percentage of the cost of the engineering studies and necessary remedial action at the three other sites.

One of the sites included in the agreement is known as the Fort Miller Site. It is located in the Town of Fort Edward, Washington County, approximately 7.5 miles south of Hudson Falls, New York. (Figure 1.)

GE/NYDEC AGREEMENT

Terms of Agreement—Fort Miller Site

General Electric, under the terms of the agreement, conducted field investigations at the site to determine the current condition of the site, including the hydrogeology, the areal and vertical extent of waste present, the physical state of the waste and the means by which wastes have been released, may be released, have migrated or may migrate from the site.

At the completion of the field investigations, an engineering report was prepared to include:

- All data from the field investigations
- Identification of alternative remedial programs
- Selection of a recommended remedial program to meet established goals. (The goal of the remedial program was to abate any significant current and future releases of hazardous wastes from the site.)
- Implementation schedule and preliminary plan including the identification of all property to which access would be required to implement the remedial program
- Program for continuing site maintenance
- Establishment of monitoring plan to evaluate the success of the remedial program

Following approval of the engineering report from NYSDEC, General Electric submitted a final plan for implementation of the recommended remedial program. Following approval of the final plan, General Electric will complete the construction elements of the remedial program at the site.

Upon completion of the construction elements of the remedial program and following certification by NYSDEC that the construction elements are in accordance with the approved engineering report and final plan, General Electric will maintain and monitor the site for a 30 year period.

Current Status

The Fort Miller Site Engineering Report and final plan have been approved by NYSDEC. The construction elements of the recommended remedial program will be begun in March, 1982 and will be completed during 1982.

FORT MILLER SITE

General

The Fort Miller Site was an open municipal/industrial dump site of 2.5 acres which was reported to have oper-

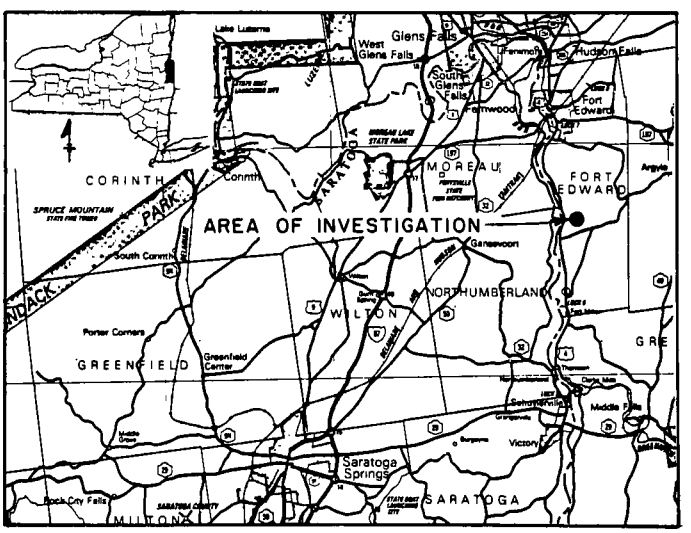

Figure 1.
General Site Location Plan

ated as a burning dump between 1953 and 1965. During the period in which dumping was taking place at the site, waste products containing polychlorinated biphenyls (PCBs) were deposited at the site. These waste products included reject electrical components which contained PCBs.

Background Information

Prior to developing a field investigation work plan at the site, all background regional and site specific historical information was reviewed including aerial photographs of the site prior to and during the years in which the site was operated. The aerial photographs aided in identifying the manner and mode in which the site was operated. County-wide soil and groundwater surveys, local groundwater well logs and USGS topographic mapping were also reviewed.

Field Investigations

A field investigation was undertaken to determine the three-dimensional limits of the site, and to defined the ways and extent by which PCBs were migrating from the site. The field techniques utilized during the field investigation included:

(1) Topographic survey
(2) Magnetometer survey
(3) Subsurface exploration (test borings and test pit trenching)
(4) Groundwater monitoring
(5) Surface water monitoring

Topographic Survey

A topographic survey was conducted at the site and immediate surrounding area to determine the location and elevation of significant features at the site. Elevations ranged from about 215 feet (USGS datum) at the south end of the site to 160 feet at the toe of the site. Surface water runoff from the site and adjacent areas flows into intermittent drainage ways which ultimately empty into the Moses Kill, a tributary of the Hudson River.

Magnetometer Survey

A magnetometer survey was conducted at the site to define the southern, western and northwestern limits of dumping at the site. The steeply sloped northern and eastern limits were determined by visual observation. It was necessary to accurately define the limits to insure that alternative remedial programs considered would encompass the entire area containing dumped refuse.

Subsurface Exploration

Subsurface explorations included the drilling of test borings and the digging of test pit trenches. Fourteen (#1, 3, 7, 8, 9, 11, 12, 13, 13A, 14, 19, 20, 21, 22) test borings were drilled at the site as shown in Figure 2. Seven (#1, 3, 9, 13, 19, 20, 22) of the test borings were drilled to refusal and in two of them (#1, 20), rock core samples were obtained. In the seven test borings drilled to refusal, soil samples were taken at five-foot intervals. In the remaining seven, no samples were taken and soil description were made from the driller's observation of auger cuttings as they came from the hole.

The subsurface materials encountered at the site were consistent with those reported in the county soil survey. They were divided into three basic soil types: A medium stiff to very stiff brown to gray brown clay. Generally this material, within the limits of the dumping area, extended to bedrock. Outside the limits of the dumping area the brown to gray clay material was underlain by a medium to stiff gray varved clay. The brown to gray, medium to stiff gray varved clay was generally encountered at a depth of 10 to 15 feet below grade. This material was softer and moister than the brown to gray brown clay. The bedrock encountered, underlying the above clay soil, was a gray, very dense, silty weathered shale. Depth to bedrock under the site and along the periphery ranged from 23 to 35 feet.

Test pit trenching operations were conducted to verify horizontal limits of the site as determined by the magnetometer survey, to determined the vertical limits of the dumping at the site and to determine the limits of capacitor dumping at the site, which if the dumping was isolated to a smaller area(s), would allow the remedial program to address a smaller area(s). The location of the test pit trenches are shown in Figure 2.

With the exception of trench No. 1, all trenches had evidence of various quantities of capacitors or capacitor paper. Based on these data, it was decided that the remedial program would encompass the entire site. The horizontal limits of the site defined by the magnetometer survey were verified by the test pit trenching. The vertical limits of dumping at the site were defined by data obtained from the trenching operations in conjunction with test borings installed through the site to the clay. The estimated volume of refuse was 20,000 yd^3.

During the trenching operations, water was observed at the clay/refuse interface in trenches 4, 5, and 6. In each of these locations a stainless steel groundwater observation well was installed for sampling prior to backfilling. A cross section through the site is shown in Figure 3.

Groundwater Monitoring

Groundwater monitoring wells were installed in each of the fourteen test boring holes. In addition, five (#2, 4, 5, 6, 10) five-foot long stainless steel wellpoints were installed at the base of the dumping area. Three others (#16, 17, 18) were installed in test pit trenches #4, 5, 6, respectively, prior to backfilling. The location of all groundwater monitoring wells is shown in Figure 2.

Several sets of groundwater elevations were taken at the site. Wells #16, 17, 18, and 21 were shallow monitors (5 to 10 feet below grade) which extended through the dumped refuse to the clay. The measured groundwater elevations in these wells, along with the visual observations made during the test pit trenching operations, indicated the

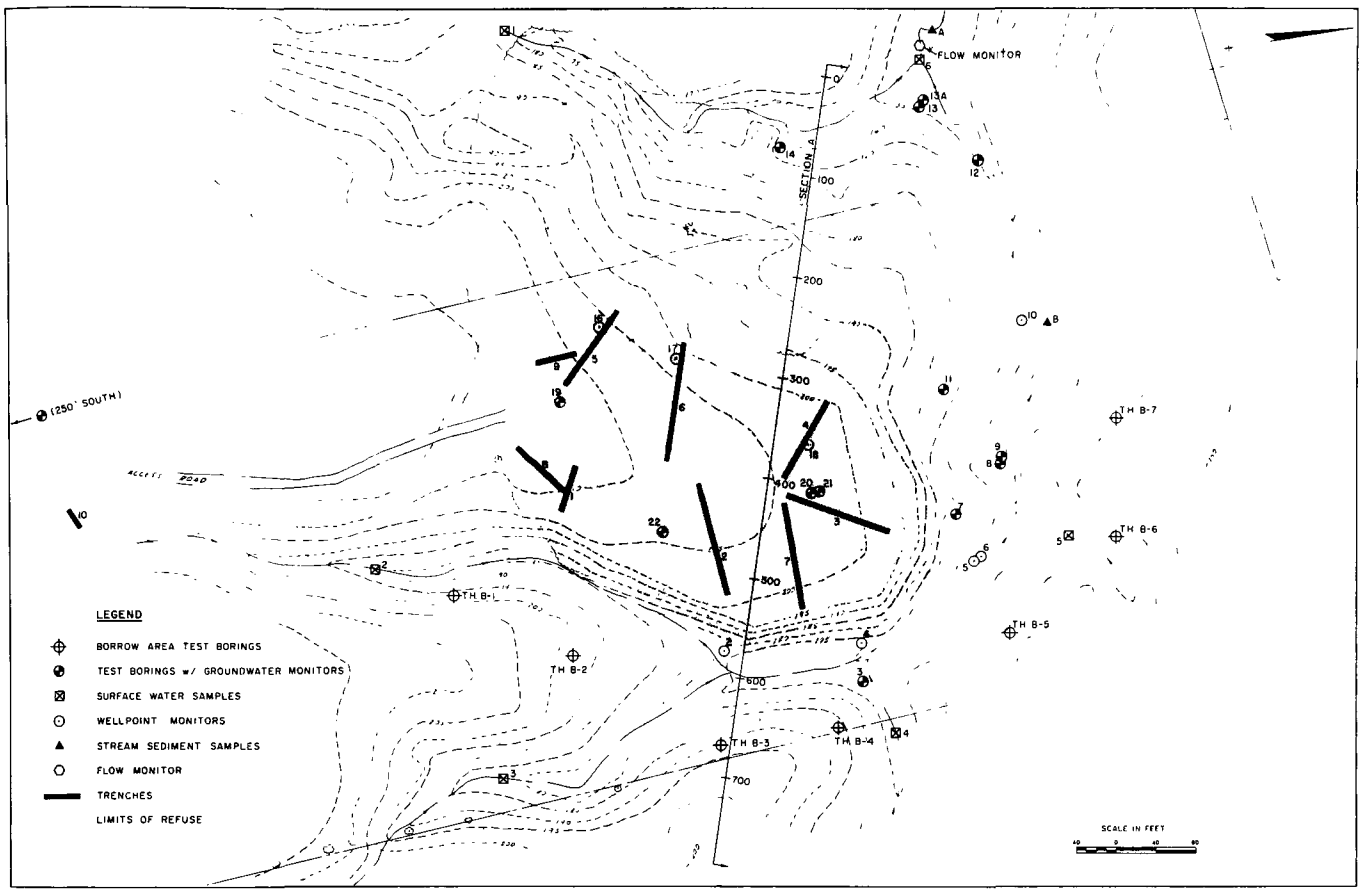

Figure 2.
Fort Miller Site—Existing Site Plan

presence of a local zone of saturation (or perched water table) at the refuse/clay interface. Discharge of this perched water table does occur along the exposed faces of the dumping area.

Well Nos. 19, 20, 22 are deep monitors (23-25 feet below grade) which extend into the underlying clay. Based on groundwater elevations taken from these wells, the permanent water table generally occurs at a depth of from 3-15 feet below the clay. A profile of the permanent groundwater table is shown in Figure 4. Based on the profile, it was determined that groundwater moves radially from the site towards the intermittent streams.

Groundwater samples were collected from 21 of the 22 wells (#21 was dry). A strict sampling protocol was implemented to eliminate inadvertent introduction into the well (or sample) of substances which lead to inaccurate results during subsequent laboratory analysis. A quality control procedure was also implemented to insure accuracy of the field and laboratory procedures and analyses. The collected samples were analyzed for pH, conductivity, PCB, Total Organic Carbon (TOC) and selected heavy metals (lead, chromium, nickel, copper, selenium and zinc). For verification purposes, several of the wells were resampled and reanalyzed. All groundwater samples were filtered prior to analysis.

Of primary interest to this field investigative effort was the concentration of PCB migrating from the site. A general summary of the data is as follows:

- No PCB was detected in the background well (#1).
- The concentration of PCB in the wells installed around the periphery of the fill area ranged from less than 0.01 to 3.7 µg/l averaging 0.7 µg/l.
- The concentration of PCB in the wells (#16, 17, 18) installed in the perched groundwater table ranged from 1.23 to 46 µg/l averaging 19.74 µg/l.

Surface Water Monitoring

Surface water runoff from the Fort Miller Site is collected in a system of drainage swales which converge, at the northwest corner of the site, into an unnamed intermittent stream, tributary to the Moses Kill. A V-notch weir was installed across this stream at the location shown on Figure 2.

Flow measurements were taken at the weir location for a two month period. Also, rainfall intensities were monitored over the same period of time.

Stream samples were collected at peak and base flow conditions at the weir and at background locations and analyzed for PCB. The concentration of PCB at the weir location (#6) (Figure 2) during the peak and base flow conditions were 0.30 and 0.80 µg/l respectively. The concentration of PCB at the background locations (#1, 2, 3, 4, 5) (See Figure 2) during the peak and base flow con-

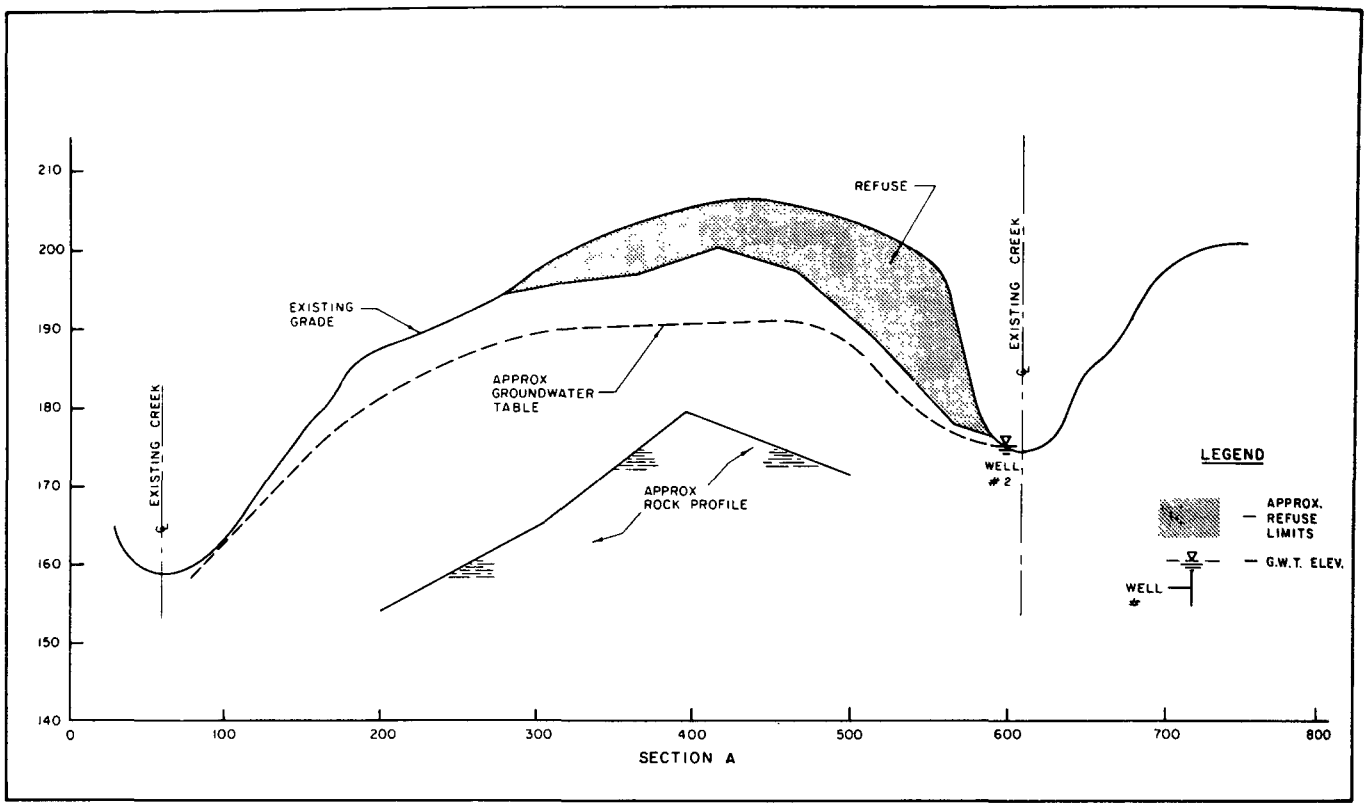

Figure 3.
Existing Site Plan—Cross-Section A

ditions ranged from 0.04-0.58 µg/l and 0.08-0.96 µg/l, respectively. Surface water samples were not filtered prior to analysis.

Air Monitoring

Prior to the initiation of the Fort Miller Site, it was acknowledged, because of previous air monitoring conducted by NYSDEC, that volatilization and airborne dispersion of PCB from the site was a problem which would have to be addressed by the proposed remedial program. For that reason air sampling and analysis was not conducted at the site.

Safety Protocol

The implementation of the various field investigative techniques in an area known to contain PCB wastes required the use of a field safety protocol. The safety protocol implemented was:

- During the drilling of test borings, the installation of groundwater monitoring wells, the digging of surface trenches and the sampling from groundwater wells, a dual carbon respirator, disposable rubber gloves and boots and a disposable acid-resistant suit were worn.
- During other field investigations, the safety equipment listed above was optional, unless a distinct chemical odor was noted, in which case the dual carbon respirator was worn.

With the exception of the dual carbon respirator, new safety equipment was worn each day (when used) and was buried at the site at the end of each day's work. Field personnel were instructed to replace filters on a weekly basis. A hard hat was worn at all times and a Scott Air Pack and emergency eyewash station were available on-site for use if needed.

PCB TRANSPORT MODES

As stated previously, the goal of the remedial program is to abate any significant current and future releases of wastes from the site. The sampling and analyses which were accomplished indicate that the contaminant of primary concern is PCB. Identified transport mechanisms by which PCB may be released from the site included groundwater migration, erosion transport and volatilization.

Groundwater Migration

From the field investigations, it has been determined that there are two groundwater zones at the site, a shallow perched groundwater zone at the clay/refuse interface and a permanent groundwater zone at a depth of 3-20 feet below grade within the dumping area.

The groundwater discharge flow rates from the shallow perched groundwater zone and the clay permanent groundwater zone were calculated to be 500 gal/day and 5,000 gal/day, respectively.

Results of sampling and analysis from monitoring wells installed within the dumping area indicate PCB concentration in the leachate ranging from 1.23 to 46 μg/l. At the maximum flow rate of 500 gal/day in the perched water table, the peak quantity of PCB discharged from the site in the leachate flow would be in the range of 0.002 to 0.070 lb/year. Similarly, measured PCB concentrations in the permanent groundwater zone at the periphery of the site range from 0.01 to 0.37 μg/l, indicating a peak quantity of PCB discharged from the site through the groundwater system (maximum flow rate of 5,000 gal/day) would be on the range of 0.0002 to 0.0056 lb/year.

Erosion Transport

As discussed previously, samples of surface water runoff were collected from the drainage channels during a rainfall event and analyzed for PCB. Although these data are insufficient to accurately quantify PCB losses, they indicate that the actual transport of wastes through erosion was on the magnitude of 1.0 lb/year.

Volatilization

As discussed previously, volatilization of PCB from the site was a known phenomena which would have to be addressed by the recommended remedial program.

ALTERNATIVES

Based upon a review of the PCB transport modes and their significance at the Fort Miller Site, potential securement alternatives were identified and evaluated. The three alternatives which were considered in the engineering report were:

- In-place containment of wastes
- Removal of wastes to new on-site secure landfill
- Removal of wastes to off site secure landfill

Under each of these alternatives there were a number of options pertaining to construction materials, surface drainage, groundwater control, leachate collection and control of volatilization. The criteria used in evaluating the alternatives included technical feasibility, ease of implementation, compliance with regulatory requirements and costs.

Each of the three alternatives considered, if properly implemented, would satisfy the goal of the Fort Miller Remedial Program. Also, each alternative is compatible with existing State and Federal regulations and would be likely to receive regulatory agency acceptance.

Within certain limitations, each alternative is technically feasible. However, there are certain advantages and disadvantages to each of the alternatives. The primary advantage of in-place containment was that existing solid waste deposits would not be disturbed. Under the other two alternatives, the excavation and transfer of the refuse greatly increases the exposure, and therefore the potential for release, of PCB to the environment.

The critical period of exposure would be during the excavation phase, when the main PCB deposits now buried below the surface would be uncovered. An intense rainstorm during this period could result in a large loss of PCB to the environment through erosion. The potential for volatilization losses during this period would also be greatly increased during removal to a new on- or off-site facility. The period of potential exposure includes the transportation from the site to the secure facility. Based on the above and cost estimates, in-place containment of wastes was recommended for the Fort Miller Remedial Program.

RECOMMENDED REMEDIAL PROGRAM

The recommended remedial program is in-place containment of wastes, to include a clay cap with vegetative cover, a relocated surface drainage system, a leachate collection system and a gas venting system. The purpose of these facilities is to isolate the waste materials from the surrounding environment. The plan also includes provisions for maintenance of the facilities, and monitoring to measure the effectiveness of the remedial program. For the purpose of describing the remedial program and monitoring plan, the site will be defined as the vertical and horizontal area containing dumped refuse.

Site Preparation

All trees and brush within the area to be capped will be removed, and stumps will be ground to grade. The wood chips will be spread evenly over the site prior to capping. Tree stumps within the area to be capped will be chemically treated to kill roots and prevent resprouting. To minimize future vertical displacement of the final cap, the surface of the existing site will be proof rolled.

The site area will be regraded to reduce the slopes at the northern and eastern sides. The regrading will consist of placing fill at the base of the site to extend to toe of the slope northward and eastward.

The material to be used as fill will be on-site clay which will be excavated from borrow pits located east and north of the existing drainage swales. The material will be installed in lifts not to exceed 12 ft at a standard proctor density of 80-85%.

Final Cover

Following site preparation, the site will be covered with a clay cap, using the same on-site soils from which the embankments are to be formed. The cap will consist of a minimum 3.5 ft thick clay layer. The bottom 2 feet layer will be installed in 6" lifts with each lift achieving standard proctor density of 90%. The top 1.5 ft (minimum) clay layer will be installed in 0.5 ft lifts with each lift achieving a standard proctor density of 80-85%. The cap will be covered with a minimum of 0.5 ft of topsoil and seeded to promote a grass cover.

Each winter, the upper zone of the cap will be subjected to freezing. In frost-susceptible soils, such as clays, the formation of ice lenses, and the subsequent thawing of these lenses in the spring, can leave cracks in the clay ma-

terial which could raise the average permeability of the soil mass. The degree of ice lens formation is related to the depth of protective cover, the availability of the fresh water and the size of the pore spaces in the soil.

At the Fort Miller Site, ice lens formation should not be a serious problem because the on-site silty clays are generally less frost susceptible than other silty types. In the Fort Miller area, the average depth of frost penetration is about 2.5 ft. Construction of a minimum 3.5 ft thick clay cap, covered with 0.5 ft topsoil will leave a compacted clay layer extending 1.5 ft below the average frost line, minimizing the possibility of cracking the impervious layer due to annual freeze/thaw cycles.

In dry summer months, an exposed clay layer would be subject to shrinkage cracking. The placement of the topsoil layer along with the vegetative cover will provide an insulating effect which would prevent evaporation and subsequent shrinkage. If minor cracks do develop, the reintroduction of moisture into the clay will result in swelling which will close the cracks.

The clay cap will be installed on a 5% grade on top, and a 1:6 slope over the horizontal limits of the site. In areas outside the limits of the cap, the clay materials will be installed on a 1:4 slope in fill areas and a 1:3 in cut areas.

Surface Drainage

At the present time, all surface runoff from the site is collected in a series of drainage channels along the toe of the site. The fill placed during regrading operations will cover the existing channels along the north and east faces of the site, and new channels will be constructed at the base of the proposed slopes.

Groundwater Control System

The surface drainage channel will be installed to a depth of a minimum of ten feet below the toe of the refuse to control the level of the permanent groundwater table.

Leachate Control System

After placement of the final cover, the infiltration of surface water into the refuse layer and the subsequent leaching of this water through the face of the landfill will be eliminated. Leachate could continue to discharge from the site, however, until the local zone of saturation at the interface of the refuse and underlying clay is drained. To eliminate this potential uncontrolled discharge, a leachate collection system will be installed around the site.

The collection system will consist of perforated drainage pipe installed along the base of the landfill. The pipe will be laid in a shallow trench backfilled with granular material up to the elevation of 1-2 ft below the bottom of the refuse. The side of the trench downgradient of the landfill will contain a barrier of compacted clay fill to prevent leachate from migrating beyond the drain.

The collection system will discharge to a pumping station which will pump the leachate to an underground holding tank, the content of which will be periodically pumped to a portable tanker for transport to a permitted treatment facility. Since the impermeable cap over the site will eliminate percolation of surface water into the refuse, the source of additional leachate will be removed and the existing leachate should be collected and disposed of within an estimated six months to one year following cap installation.

Gas Control System

In a typical municipal landfill, methane gas is produced by the biological degradation of organic materials under anaerobic conditions. Following the installation of the cap over the site, the generation of gases from the refuse could result in pressure-induced stresses which could damage the cap.

The length of time the site has been closed, along with the burning of refuse which has been reported, would indicate that most organic materials have already decomposed, and that the potential for future generation of significant quantities of methane is therefore quite limited. However, to ensure that the cap is not damaged by gas pressures, the recommended remedial program will include a passive collection and treatment system.

The gas collection system will consist of a network of perforated pipes laid in shallow trenches excavated into the surface of the refuse. The trenches will be backfilled with gravel and enclosed at the surface by the final cover material. The gas collection pipes will lead to a common above-ground vent. The vent will be fitted to an adsorbent-type treatment unit and will remain open to the atmosphere.

Site Security

Site security will include fencing sufficient to restrict unauthorized access and warning signs to discourage trespassers. The Final Plan showing the recommended alternatives is shown in Figure 4. A cross-section taken through the site is shown in Figure 5.

MAINTENANCE PROGRAM

A major portion of the long-term maintenance effort will involve the vegetative cover on the completed cap. No trees, shrubs, brush or deep rooting weeds should be allowed to germinate or establish on the site. If visual observations made during the performance of other maintenance activities indicate that low growing, deep rooting weeds have germinated from the cap, a herbicidal weed control program would be initiated. Periodic inspection of the site will also reveal any problems of erosion, disease, or thinning of grasses which would then be corrected. The grasses on the site will also be moved periodically as required.

The estimated 50,000 gal of leachate will be collected and treated as required. The gas collection facilities will be operating continuously. The adsorbent-type treatment unit will be replaced as required. All mechanical equip-

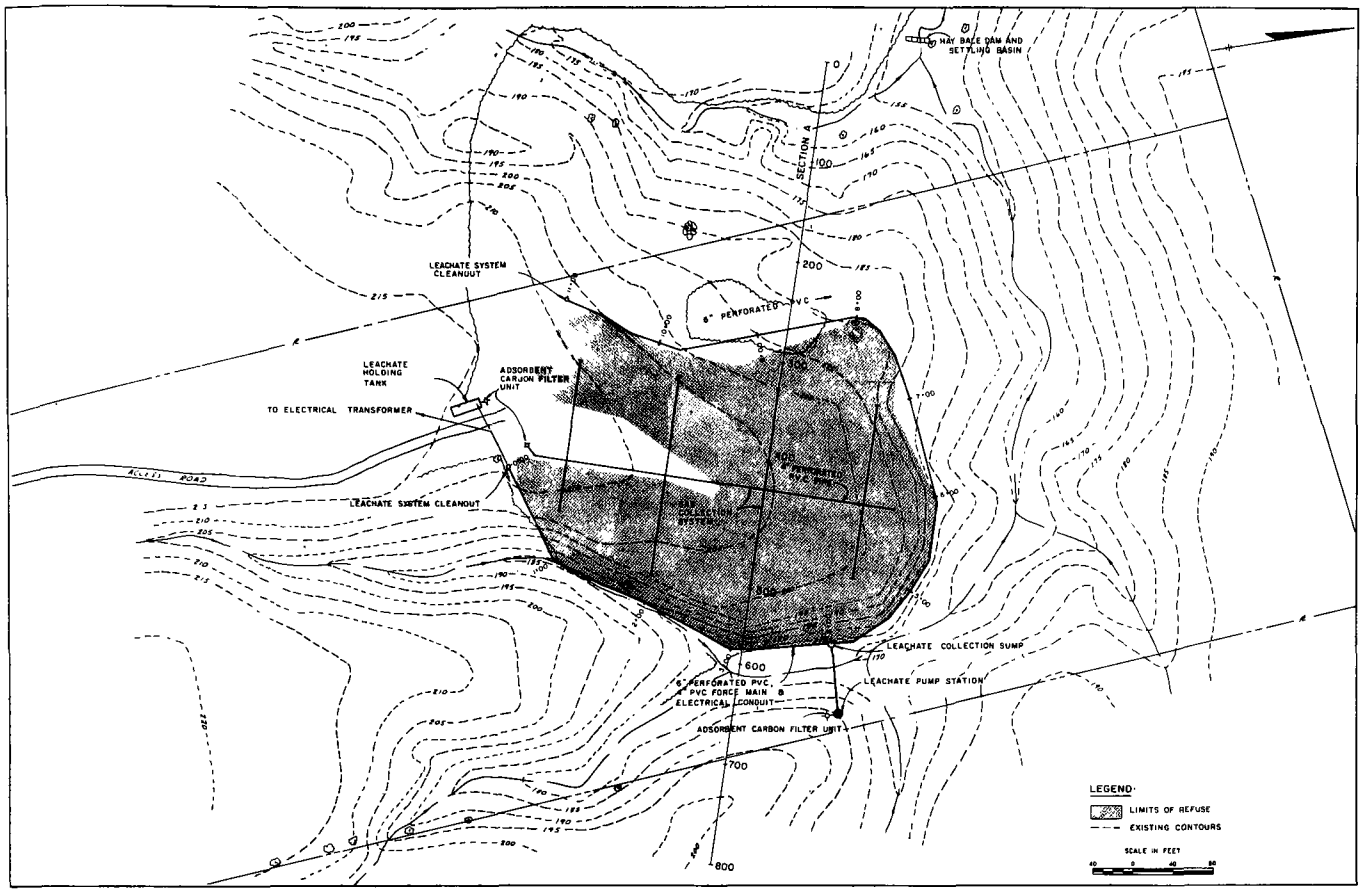

Figure 4.
Fort Miller Site—Final Plan

ment (i.e., pumps) will be maintained as suggested by the manufacturer.

MONITORING PROGRAM

The purposes of undertaking monitoring activities are to measure the effectiveness of the remedial program.

A 30 year monitoring program was developed to determine failure of the remedial program. Failure of the remedial program is deemed to have occurred if any of the following conditions are observed:

(1) Any portion of the cap is eroded, allowing wastes to be carried away by surface runoff
(2) Surface water percolates through the cap and into the refuse, creating a source of leachate
(3) Waste material is volatilized through the cap in excessive quantities
(4) The groundwater table rises above the bottom of the refuse, resulting in water saturation of the refuse and the possibility of the formation of leachate

The monitoring activity which will determine if the above failure modes have occurred, respectively, is as follows:

(1) Cap Erosion—Periodic inspection of the cap
(2) Surface Water Infiltration—Flow is observed in the leachate collection system (after the shallow perched groundwater has been drained).
(3) Volatilization—PCB concentration rise significantly above baseline concentration. The baseline concentration will be established following cap installation.
(4) Groundwater Table Interrupting Site—Groundwater levels rise to intercept the site. The groundwater table will be monitored continuously in the vicinity of the toe of the site.

By undertaking the monitoring activities outlined above, it will be possible to measure the effectiveness of the remedial program and to detect any failure of the system to abate the release of material from the site.

Failure of the remedial program will not be determined by analyzing groundwater or surface water samples for PCB. The very low PCB concentration levels in the groundwater, presently below the refuse layer, may differ at different sampling locations or differ at the same sampling location at different times for many years.

A variation in PCB concentration at any downgradient groundwater monitoring or surface water location could simply be the result of a higher or lower zone of PCB concentration moving slowly past the sampling point. Because these PCB concentrations may vary considerably and since such variation would not necessarily be the result of a failure of the remedial program, it was not attempted to define failure of the remedial program by attempting to interpret such results.

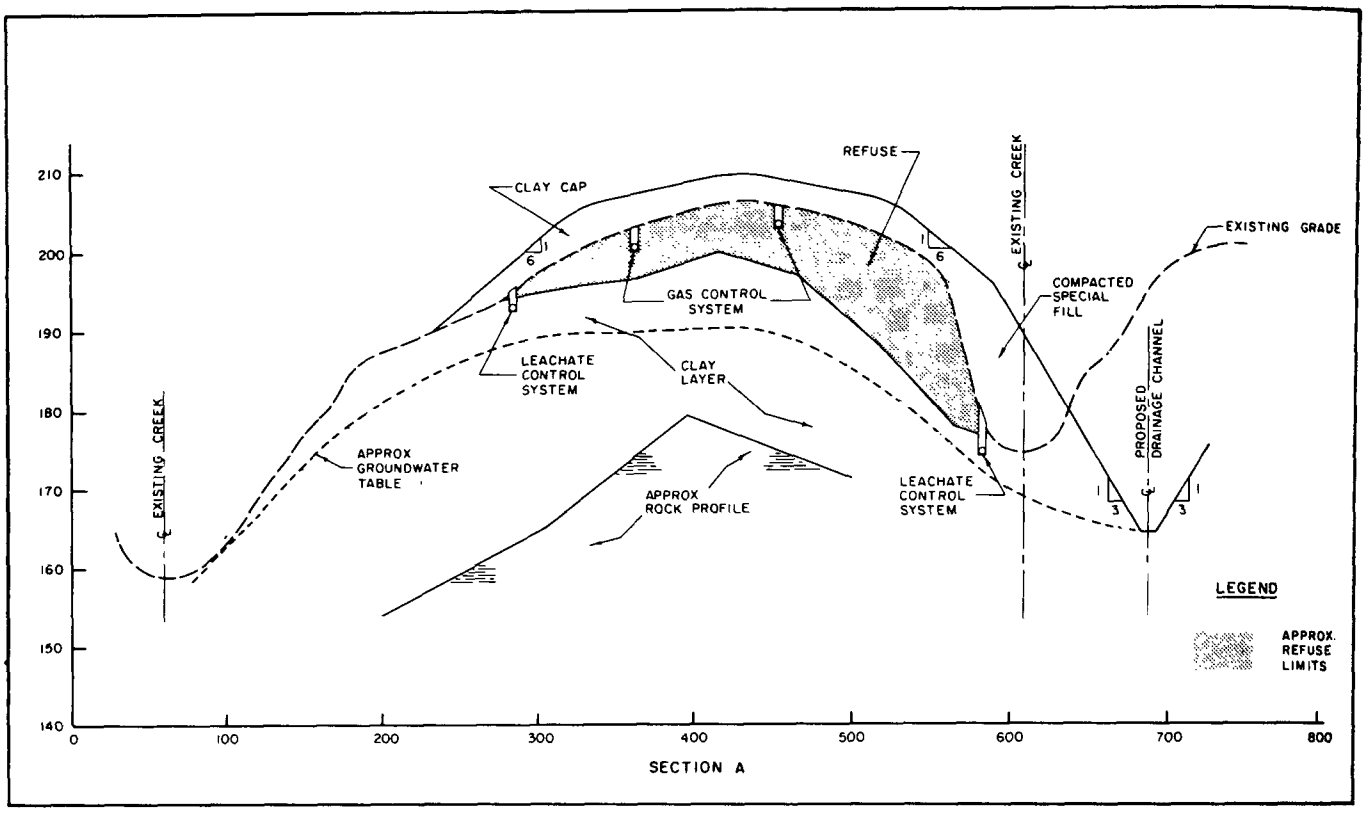

Figure 5.
Final Plan—Cross-Section A

CONCLUSIONS

The work accomplished under this program and the results can be briefly summarized as follows:

(1) Field investigations were undertaken to determine the condition of the Fort Miller site and the physical extent of the wastes. It was determined that there are about 20,000 yd^3 of refuse which have been dumped in an area of approximately 2.5 acres.

(2) Sampling and analyses were undertaken to define groundwater flow patterns and rates, and to estimate the magnitude of migration of wastes (PCB) from the immediate dumping area via groundwater flow. It has been shown that the loss of PCB by this mechanism is insignificant.

(3) The primary means by which PCB could be transported from the dumping area are volatilization and erosion.

(4) Three alternative remedial programs for the Fort Miller site were evaluated: in-place containment, removal to a new on-site landburial facility and removal to an off-site landburial facility. The criteria used to evaluate these alternatives include compatibility with program goals, technical feasibility, ease of implementation, compliance with regulatory requirements and costs. In-place containment has been designated as the recommended remedial program for the Fort Miller Site.

(5) A recommended Fort Miller remedial program has been presented. The program is based on in-place containment of the wastes, including a clay cap with vegetative cover, relocated surface drainage system, leachate collection system, and gas venting system. The plan also includes provisions for maintenance of the facilities and monitoring to measure the program's effectiveness.

(6) The preliminary implementation schedule calls for construction activities to be completed during 1982.

REFERENCES

1. Blasland, W.V., Knowles, G.D., Lynch, E.R., and Goldman, R.K., "Remediation at an Inactive Municipal Disposal Site Containing PCB's", *Proc. 13th Mid-Atlantic Industrial Waste*, June 29, 30, 1981; 476.

ORGANIC LEACHATE EFFECTS ON THE PERMEABILITY OF CLAY LINERS

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INTRODUCTION

Saturated conductivity or permeability is the primary laboratory measurement made on compacted clay soils to assess their suitability for use in constructing compacted clay liners for hazardous waste landfills or surface impoundments. The value obtained for the permeability is used to judge whether a compacted clay soil liner will prevent the movement of leachates into water bodies below or adjacent to the disposal facility.

There is, however, little information available on the impact of organic fluids, likely to be placed in such confinements, on the permeability of the liner. Also, there has been on simple permeability test method developed that could be suitable for use with the range of possible waste fluids. Furthermore, a study evaluating the permeability of a range of typical clay soils with a spectrum of potential waste fluids would generate a valuable data base, useful for hazardous waste disposal permit applicants, writers and reviewers. Consequently this study was undertaken with the following objectives:

- To construct from available information a delineation of the physical classes of fluid-bearing hazardous waste, the leachates they generate, and the predominant fluids in these leachates.
- To develop a simple, inexpensive and rapid method for the comparative permeability testing of compacted clay soils, that would be suitable for use with a wide range of possible waste fluids.
- To evaluate the permeability of a range of typical clay soils to a spectrum of potential waste fluids.

PHYSICAL CLASSES OF HAZARDOUS WASTE

Land disposed hazardous wastes generally fall into the following four physical classes: aqueous-inorganic, aqueous-organic, organic, and sludges[1] (Table I).

Aqueous-inorganic is the class of wastes in which water is the solvent (dominent fluid) and the solutes are mostly inorganic. Examples of these solutes are inorganic salts, metals dissolved in inorganic acids and basic materials such as caustic soda. Examples of wastes in this category are brines, electroplating wastes, metal etching wastes and caustic rinse solutions.

Aqueous-organic is the class of wastes in which water is the solvent and the solutes are predominantly organic. These solutes are organic chemicals that are polar or charged, as is inferred by their water solubilities. Examples of this class of waste are wood preserving wastes, water-based dye wastes, pesticide container rinse water and ethylene glycol production wastes.

Organic is that class of wastes in which an organic fluid is the solvent or dominant fluid and the solutes are other organic chemicals dissolved in the organic solvent. Examples of this class of wastes are oil-based paint wastes, pesticide manufacturing wastes, spent motor oil, spent cleaning solvents and solvent refining and reprocessing wastes.

Sludges represent the fourth class of wastes. They are generated when a waste stream is dewatered, filtered or treated for solvent recovery. Sludges are characterized by high solids content such as that found in settled matter or filter cakes and consists largely of clay minerals, silt, precipitates, fine solids and high molecular weight hydrocarbons. Examples of this waste are API separator sludge, storage tank bottoms, treatment plant sludge or any filterable solid from any production or pollution control process.

Both economic and pollution control pressures continue to mandate solvent recovery and reductions in discharges of aqueous waste streams. These factors have made, and will continue to make sludges the fastest growing class of wastes. After placement of sludges in a waste disposal facility, leachates migrate out of the sludge due to gravitational forces, overburden pressures and hydraulic gradients. These leachates are similar in physical form to the first three classes of waste shown in Table I.

LEACHATE GENERATED BY HAZARDOUS WASTE

To determine the effect of a specific waste on the permeability of a specific clay liner, two unique leachates

Table I.
Physical Classes of Hazardous Wastes

Waste Class	Solvent Phase	Solute Phase
Aqueous-inorganic	Water	Inorganic
Aqueous-organic	Water	Organic
Organic	Organic Fluid	Organic
Sludges	Organic Fluid or Water	Organic and Inorganic

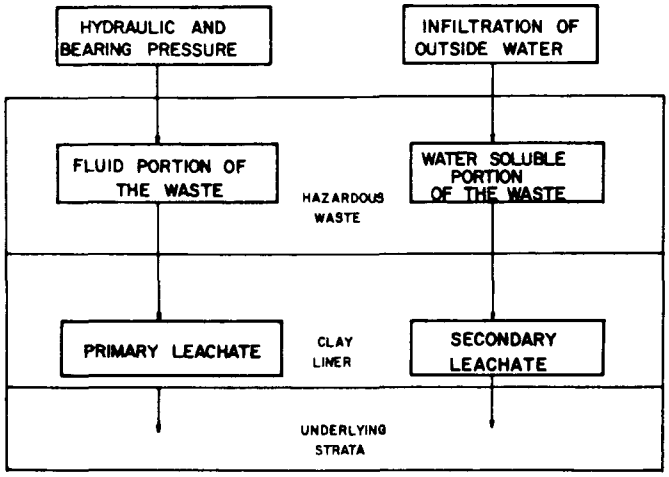

Figure 1.
Sources of Leachate that May Come in Contact with Clay Liners

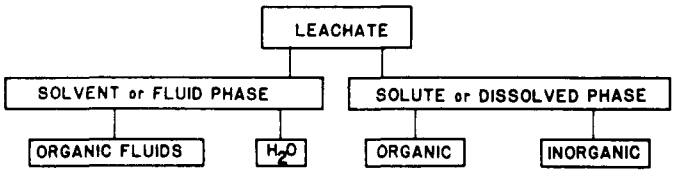

Figure 2.
Composition of the Leachate of a Waste

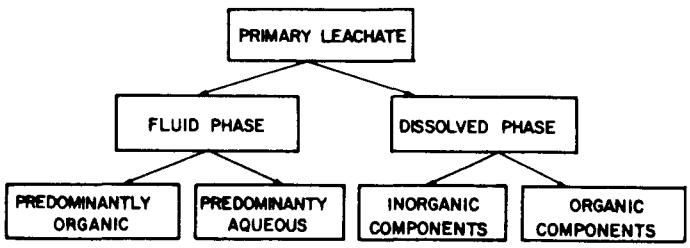

Figure 3.
Primary Leachate Generated at Disposal Sites

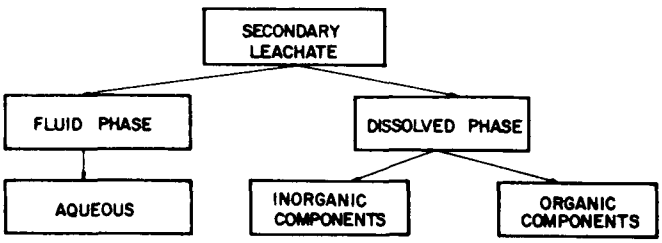

Figure 4.
Secondary Leachate Generated at Disposal Sites

must be investigated. These leachates are the flowable constituents of the waste and the flowables generated from percolating water leaching through the waste (Figure 1).

Flowable constituents of a waste, hereafter referred to as the primary leachate, includes both fluids in the waste, the solvent and all components dissolved in these fluids, the solutes. Depending on the physical class of a waste, its primary leachate may be aqueous-organic, aqueous-inorganic or organic. Leachate generated from water percolating through a disposal facility is composed of water, the solvent and all the components dissolved or carried with it in the water, the solutes. This flowable mixture, hereafter referred to as the secondary leachate, may be aqueous-organic or aqueous-inorganic, depending on the composition of a waste.

The predominant fluid or solvent phase of a leachate may be water or any organic fluid (Figure 2). Corresponding solutes in a leachate are any chemicals that dissolve in the solvent phase. As in the physical classes of wastes, both primary and secondary leachates are divided into a solvent phase (the predominant fluid component) and a solute phase (components dissolved in the solvent). (Figures 3 and 4). While the solutes in the leachate may affect the permeability of a clay liner, the solvent phase will usually exert a dominating influence on permeability.

Essentially all available literature describing leachates generated by hazardous waste disposal considers only water as the predominant fluid.[2,3] Water is viewed as the carrier fluid and the organic chemicals are considered to be present in only trace quantities. While this is probably the case at the interface of a secondary leachate and a water table, the fluid phase at the interface of a primary leachate and a clay liner will depend on the physical class of the waste being disposed. An organic waste or sludge with an organic fluid phase will most probably expose the clay liner to the concentrated organic fluids contained in the waste.

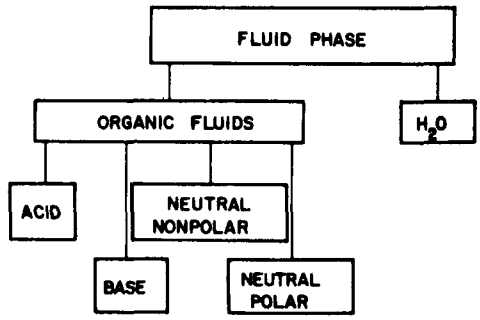

Figure 5.
Solvent Phase of the Leachate of a Waste

FLUIDS IN HAZARDOUS WASTE LEACHATE

As stated previously, organic fluids that have been placed in waste impoundments cover the spectrum of chemical species. For the purpose of experimentally evaluating the effects organic fluids may have on the permeability of clay soils, the fluids have been classified into four groups. These groups are based on the physical and chemical properties that will govern their interactions with clay minerals. These properties include acidity, basicity and polarity (Figure 5). All clay liners are initially wetted with water. Consequently, the interaction of organic fluids with clay minerals must be viewed in the context of fully hydrated clay minerals.

Table II.
Properties of the Four Organic Fluids and Water

Fluids	Temp. Range of Fluid State (°C) Melting Point	Boiling Point	Density at 20°C g/cm^3	Viscosity at 20°C Centipoise	Water Solubility at 20°C g/l	Dipole Moment (debyes)	Dielectric Constant at 20°C
Acetic Acid	17	118	1.05	1.28	∞	1.04	6.2
Aniline	-6	184	1.02	4.40	34.0	1.55	6.9
Xylene	-47	139	0.87	0.81	0.2	0.40	2.4
Methanol	-98	65	0.79	0.54	∞	1.66	31.2
Water	0	100	0.98	1.0	∞	1.83	80.4

Regardless of the type of organic fluid, if it has a low viscosity, it will be leachable. Fluids with low viscosity are "by their very nature" leachable and able to extract organic components from otherwise dry waste.[4] However, several other fluid properties effect the resultant soil permeability values. Some of these properties are discussed with respect to the four groups of organic fluids and water in the following sections.

Organic Fluids Studied

Organic fluid representatives of the four classes of organic fluids (Figure 5) were selected for use in the comparative permeability studies. The four classes studied were acidic (acetic acid), basic (aniline), neutral polar (methanol) and neutral nonpolar (xylene) organic fluids. The four organic fluids and water along with their relevant physical and chemical properties are shown in Table II.

Water containing $CaSo_4$ at a concentration of 0.01N was used to establish the baseline permeability of each soil core and as the control fluid. The calcium salt was selected for use due to its stabilizing effect on permeability. A concentration of 0.01N was selected because it approximates the salt concentration typically found in soils.

Clay Soils Studied

Four clay soils typical of those used for the lining of hazardous waste landfills and surface impoundments were selected for these studies. These clay soils are referred to by the following names: noncalcareous smectite, calcareous smectite, mixed cation kaolinite and mixed cation illite. The soils are described in Table III.

MATERIALS AND METHODS

To assess the suitability of compacted clay soils for the lining of waste disposal facilities, the primary laboratory measurement made is saturated conductivity or permeability. These tests often take months to complete for two reasons. Compacted clay soils often have permeability values lower than 10^{-8} cm/sec, and it is often necessary to pass a pore volume of water through a soil before a stable baseline permeability value can be obtained. After the permeability baseline is established, the passage of at least a pore volume of the organic test fluid may be necessary to fully determine the effects an organic fluid may have on the permeability of the compacted clay soil. Consequently a pressurized air source has been used to increase the hydraulic gradient and reduce the time needed for testing.[5,6]

In this study, the authors utilized a pressurized, air-induced, elevated, hydraulic gradient in a rapid comparative permeability method for use on compacted clay soils. A hydraulic gradient of 361.6 (equivalent to a hydraulic head of 42.2 m of water) was used for the two smectite clay soils. A hydraulic gradient of 61.1 (equivalent to a hydraulic head of 7 m of water) was used for the illitic and kaolinitic clay soils.

Table III.
Properties of the Four Clay Soils

Clay Soil Description	Noncalcareous Smectite	Calcareous Smectite	Mxd Cation Kaolinite	Mxd Cation Illite
% Sand (50nm)	35-37	7-8	39-41	14-15
% Silt (50-2.0nm)	26-28	42-44	17-18	38-39
% Clay (2.0nm)	36-38	48-50	42	47
Predominant clay minerals*	S M K	S K	K M	I S
Shrink-Swell Potential	Very high	Very high	Mod.	Mod.
Corrosivity (Steel)	High	High	High	N.D.
Cation Exch. Capacity (meg/100g)	24.2	36.8	8.6	18.3
Total Alkalinity (meg/100g)	3.3	129.3	0.8	4.2

*In order of descending quantity in the soil.
N.D. Not determined
S—Smectite, M—Mica, K-Kaolinite, I—Illite

The equation used for calculating the permeability of the compacted clay soils was as follows:

$$K = \frac{V}{ATH} \qquad (1)$$

where:

K = permeability constant (cm/sec)
V = volume of liquid (cm^3)
A = cross-sectional area of liquid flow (cm^2)
T = time (sec.)
H = hydraulic gradient

Compacted soil cores used to evaluate the permeability of the soils to organic fluids were prepared at or above the optimum water content. After the clay soils to be tested were compacted into the soil chambers, they were mounted in permeameter base plates and fitted with a fluid chamber and permeameter top plates. Each top plate was fitted with a pressure inlet to connect it to the pressurized air source via the pressure distribution manifold (Figure 6).

A moisture trap, pressure regulator and pressure gauge was placed between the pressurized air source and manifold. The moisture trap was positioned between the air source and regulator to prevent the buildup of debris on the membrane in the regulator. The pressure gauge went between the regulator and manifold so that the hydraulic pressure being applied to the permeameters could be monitored.

Cutoff valves for the pressure leading to each permeameter were placed between the manifold and permeameter top plates. These valves allowed the placement or removal of individual permeameters without depressurizing the entire test system.

To avoid channel formation, the compacted clay soils were seated at low pressure. By letting 10 cm of the standard leachate stand on the soils for 48 hours, an effective seat was obtained for the top few millimeters of the soil. The thin layer prevented bulk flow, thereby permitting the rest of the soil to adequately seal the permeameter sidewalls at elevated pressures.

All gaskets used in the permeameters were teflon to prevent their deterioration and possible blow out from contact with the various organic fluids. To avoid leakage around the hard teflon gaskets, all metal surfaces against which the gaskets seated were wiped clean of grit. In general, all permeameter components were found to withstand continuous operational use at pressures equivalent to 50m of water.

Directly under the soil chambers and in the permeameter base plates were porous stones to permit seepage of the leachate to the outlet in the base plate. To limit the extent of leachate mixing after passage through the compacted soil, the outlet was fitted with an adapter to 0.3 cm inside diameter teflon tubing. The use of translucent teflon at the outlet on the base plate provided a convenient window with which to monitor the expulsion of trapped air. Standard leachate (0.01N $CaSo_4$) was passed through all soil chambers until there were no air bubbles visible in the outlet tubing. Where soil piping occurred in soil samples, eluded soil clay particles were visible both clinging to the inside walls of the outlet tubing and as a suspension in the collected flow samples.

Teflon tubing carried the leachate to an automatic fraction collector which collected leachate samples simultaneously from ten permeameters at specific time increments. Since there was a potential for volatile losses occurring during leachate delivery from the tubing to the sample bottles in the fraction collector, the top of each sample bottle was fitted with a long stem funnel and the fraction collector was placed in an air tight cooled chamber. Additionally, the entire test apparatus was fitted into a vented hood (Figure 6). This extra precaution was taken as insurance against worker injury in the event of accidental spills or system leaks.

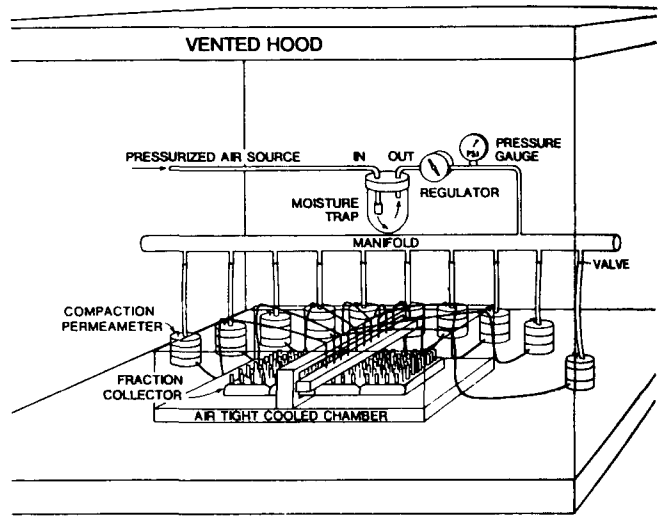

Figure 6.
Schematic of the Permeability Test Apparatus

After the cores were seated in the permeameters at low pressure, the selected air pressure was applied to the fluid chamber until stable permeability values were obtained with the standard leachate. At this point, the pressure was released and the permeameters were disassembled to permit examination of the core for signs of swelling or deterioration of any kind. If the clay had expanded out of its mold, the excess was removed with a straight edge while trying not to smear the surface of the soil. All material that had expanded out of the cores was oven dried and weighed to estimate the percent swelling that had taken place.

With the three soil types that had swollen, additional standard leachate was passed to ensure that the permeability was not affected by the excess soil removal. This extra step was not necessary with the kaolinitic soil since it experienced no swell after passage of the standard leachate.

Next, the remaining standard leachate was removed from the fluid chambers and replaced with the organic fluids. After passage of the simulated primary leachates (organic fluids), the permeameters were depressurized, disassembled and the cores dissected to determine if structural changes had taken place in the compacted clay soils.

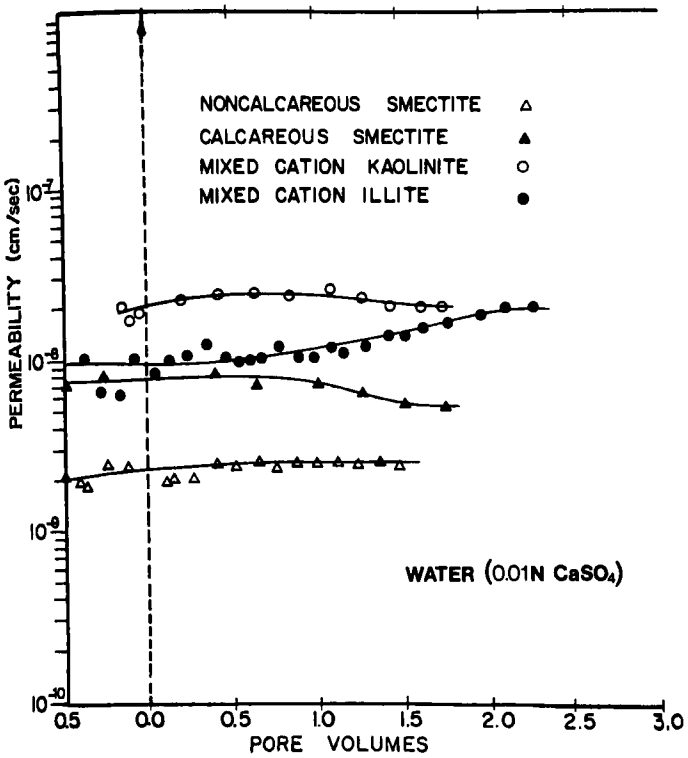

Figure 7.
Permeability of the Four Clay Soils to Water (0.01N $CaSo_4$)

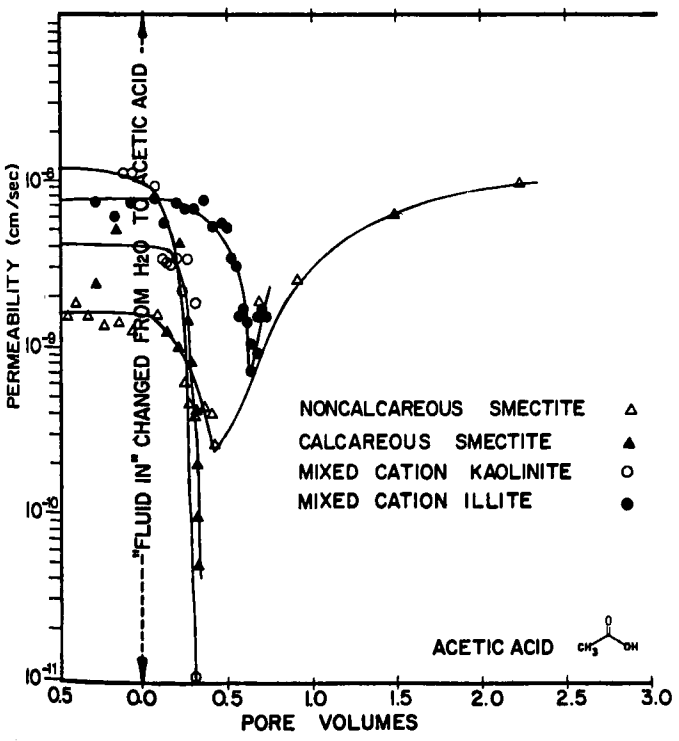

Figure 8.
Permeability of the Four Clay Soils Treated with Acetic Acid

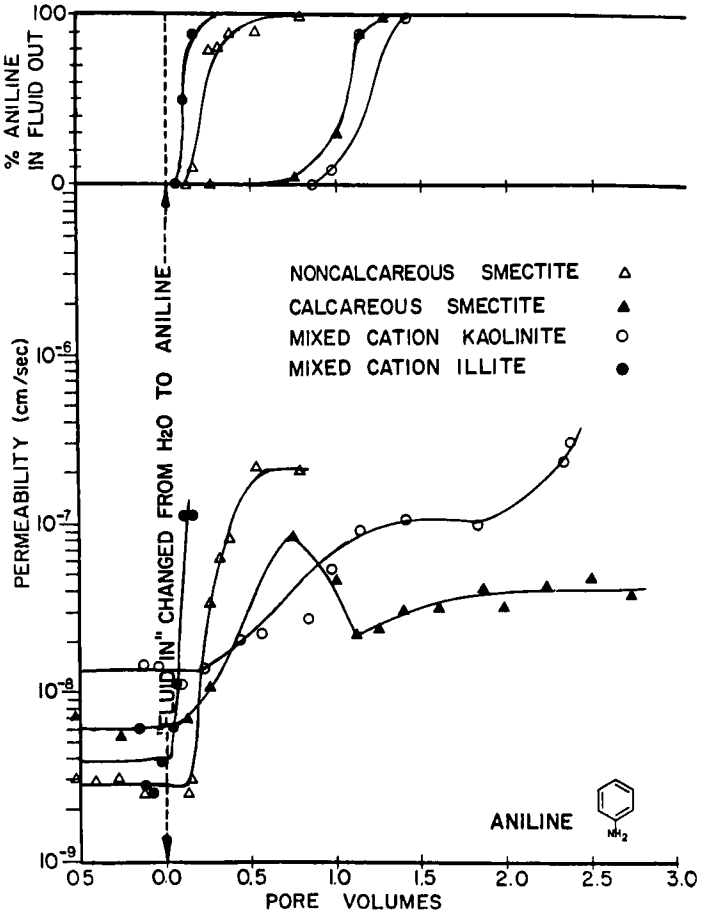

Figure 9.
Permeability and Breakthrough Curves of the Four Clay Soils with Aniline

Permeability values for the clay soils have been plotted against the cumulative pore volumes of the test fluids that passed through the compacted cores. The volume of "fluid out" is divided by the volume of the pore space in a given core to obtain the fraction of a pore volume passed at each permeability value. Recorded data values are shown graphically in Figures 7 through 11.

In several of the figures representing primary leachate treated cores, the increase in organic fluid as a percentage of the incremental leachate volume ("fluid out") has been depicted across the top of the permeability graphs. For these breakthrough curves, the values for "fluid out" were determined by one of two methods depending on the fluid to be analyzed. Fluids that were insoluble (xylene) and minimally soluble (aniline) were determined simply by recording the volume of the organic and aqueous layers in the sample collection bottles. The only miscible fluid for which determinations were made was methanol. The percentage of methanol in water was determined using a thermoconductivity gas chromatograph.

RESULTS AND DISCUSSION

Permeabilities of the four compacted clay soils to the standard leachate (0.01N $CaSo_4$) are depicted in Figure 7.

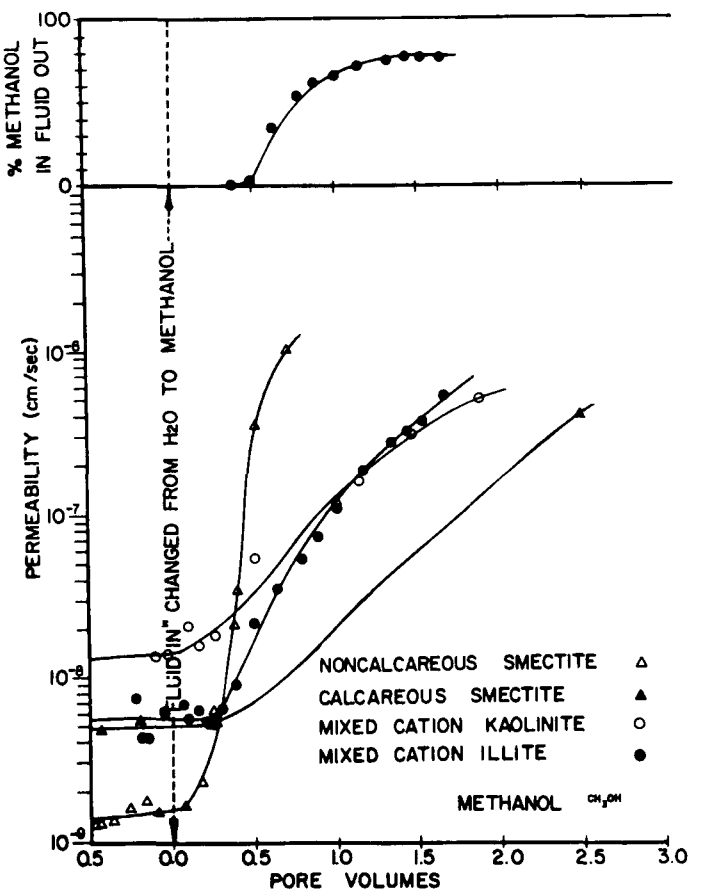

Figure 10.
Permeability of the Four Clay Soils Treated with Methanol and the Breakthrough Curve for the Mixed Cation Illite Soil

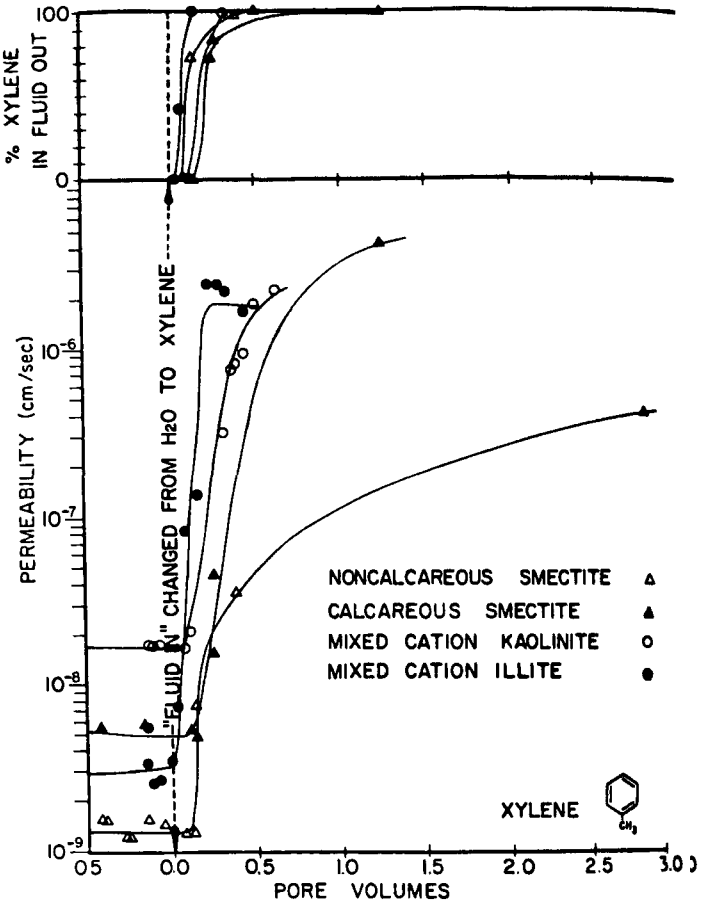

Figure 11.
Permeability and Breakthrough Curves of the Four Clay Soils Treated with Xylene

The vertical dashed line represents the point at which the permeameters were depressurized for the final time prior to placement of the organic fluids in the non-control permeameters. There appears to have been little effect of depressurization on the permeability of the control cores.

Permeability of the noncalcareous smectite and mixed cation kaolinite soils were essentially constant during the passage of approximately two pore volumes of the standard leachate. In contrast, the permeability of the calcareous smectite decreased slowly while the permeability of the mixed cation illite increased slowly.

Traditionally, the permeability testing of prospective clay liners for hazardous waste landfills and surface impoundments, has used only standard aqueous leachates (such as 0.01N $CaSo_4$ or $CaCl_2$) as the permeant fluid. All four of the clay soils used in this study, if only evaluated by this traditional test, would qualify as adequate for lining hazardous waste disposal facilities on the basis of their having permeabilities lower than 1×10^{-7} cm/sec.

All four clay soils permeated with acetic acid showed initial decreases in permeability (Figure 8). However, there was also a significant amount of soil piping occurring in these cores as was shown by the presence of soil particles both clinging to the inside walls of the outlet tubing and deposited on the bottom of the leachate collection bottles. In addition, the leachate from these cores was usually tinted (red, creamy or black) indicating that soil components were dissolved by the acid. The initial decrease in permeability is likely due to the partial dissolution and subsequent migration of soil particles. These migrating particle fragments could then lodge in the fluid conducting pores, thus decreasing the crossectional area available for fluid flow.

Two of the soils treated with acetic acid (calcareous smectite and mixed cation kaolinite) showed continuous permeability decreases throughout the test period. Both the noncalcareous smectite and the mixed cation illite eventually began to rebound from the initial permeability decreases, but not until passage of 39% and 62% of a pore volume respectively. The permeability increases on both of these soils were probably due to the progressive soil piping that eventually cleared the initially clogged pores.

Permeabilities and breakthrough curves for the four clay soils treated with aniline are given in Figure 9. While all four clay soils showed significant permeability increases, the calcareous smectite soil showed the least.

Both the noncalcareous smectite and mixed cation illite exhibited early breakthrough of aniline with concurrent

permeability increases. There was some indication that the rate of permeability increase for these two clay soils was leveling out just above the 1 x 10^{-7} cm/sec benchmark. While the permeability of the mixed cation kaolinite soil eventually exceeded 1 x 10^{-7} cm/sec, the breakthrough of aniline and concurrent permeability increases took significantly longer to occur. Only the calcareous smectite clay maintained a permeability value below 1 x 10^{-7} cm/sec.

Permeabilities and a breakthrough curve (mixed cation illite) of four clay soils treated with methanol are given in Figure 10. All four clay soils eventually attained permeabilities substantially in excess of 1 x 10^{-7} cm/sec. The permeability of the noncalcareous smectite increased the fastest and reached the highest permeability value of the four methanol treated cores. Examination of the methanol treated soil cores revealed structural rearrangements of the soil particles resulting in the formation of large pores and cracks visible in the surface of the soils.

Methanol breakthrough was monitored on the mixed cation illite soil. Figure 10 depicts the step by step concurrent increase in the permeability and percent methanol in the "fluid out" for the illitic soil. Since no particle migration was detected in the methanol treated cores, soil piping was ruled out as a mechanism for the observed permeability increases. There was likewise no leveling of the rate of permeability increases as might have been expected if the increases were solely due to the lower viscosity and density of methanol compared to water.

Permeabilities and breakthrough curves of the four clay soils treated with xylene are given in Figure 11. All four xylene treated soils showed rapid permeability increases followed by leveling at a permeability roughly two orders of magnitude above their permeability rates of water. These permeability increases are far greater than could be explained in terms of the lower viscosity and density of xylene compared to water, indicating that other factors such as structural changes in the soil are responsible for the large increases observed.

CONCLUSIONS AND RECOMMENDATIONS

The time needed for the comparative permeability testing of clay soils can be significantly decreased by the use of elevated hydraulic gradients. A hydraulic gradient of between 50 and 100 seems optimal for such tests in that the tests can be completed in 2-3 months, while permeability increases occur slowly enough to obtain several points along a changing permeability curve.

Three classes of organic fluids (basic, neutral polar and neutral nonpolar) may cause substantial increases in the permeability of clay liners. Organic acids may also degrade the effectiveness of clay liners although not as quickly as the other three organic fluid classes examined.

Consequently, permeability of a clay liner may be effected by the primary leachate (free fluids) of a waste. Whenever organic liquid bearing wastes are to be contained in a landfill or surface impoundment by a clay liner, the permeability of the liner should be evaluated with a standard leachate (such as 0.01N $CaSo_4$), and also with the primary leachate of a waste.

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MULTIATTRIBUTE DECISION MAKING FOR REMEDIAL ACTION AT HAZARDOUS WASTE SITES

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INTRODUCTION

Many modern technology related problems, especially those involving man created risks, are extremely complex and uncertain. Large volumes of data and multiple conflicting objectives lead to the requirement for incorporating subjective judgments into the decision process. If the existence of adversary positions (i.e., a politicized conflict) is involved, then something other than just intuition must be relied on to find generally acceptable solutions. The problem area of hazardous waste management is just such a situation. It would be beneficial to find a systematic technique which would allow decision makers to adequately address the complex issues involved and develop viable solutions.

Multiattribute decision analysis is an apparently effective tool for this type of problem. It is highly flexible, incorporates methods to handle uncertainty, multiple objectives, etc. and is a well developed technique. However, it is not without faults. The most glaring as pointed out by Rowe[3] is its inability to properly treat the public's subjective perception of risk. In addition, conventional decision analysis can become extremely cumbersome if the problem being analyzed is complex and no readily available means of tree "pruning" exists.

An obvious answer to this is to somehow integrate multiattribute decision analysis with a quantitative risk assessment technique which addresses public perception. The basic steps entailed in such a unified approach are delineated below:

1. Construct a decision tree for the potential course of remedial actions.
2. Complete a detailed risk analysis.
   a. Determine the objective risk of each decision branch. (Note: According to some authorities[3] this would be termed modeled risk.)
   b. Determine the appropriate risk referents.
   c. Use an objective risk vs. risk referent comparison to determine if a decision branch requires modification or should be eliminated from consideration (i.e., pruned).
3. Conduct a sensitivity analysis of the risk comparison to determine which branches are only "marginally" acceptable.
4. Complete the multiattribute decision analysis with the pruned tree.
5. Conduct a sensitivity analysis of the "solution."

This paper will explore this integrated technique in more detail.

DECISION TREE CONSTRUCTION

The organization of decision and consequence sequences is the first task in the decision making process. Generally the following steps should be utilized to construct a tree:

1. Generate an objective hierarchy which terminates in the desired attributes and attribute measurements (Figure 1 diagrams a possible hierarchy for hazardous waste problems).
2. Determine the viable courses of action available.
3. Determine the possible chance events (i.e., hazards, outcome, etc.) resulting from a decision.
4. Arrange the decision options and resulting chance events in chronological order (Table I provides a generalized structure for problems which largely involve risk).
5. Evaluate the specific probabilities for each chance event.
6. Evaluate the magnitude of each attribute.

A number of key areas in this process require a more detailed explanation. First it is necessary to take a closer look at the meaning of "viable courses of action." The

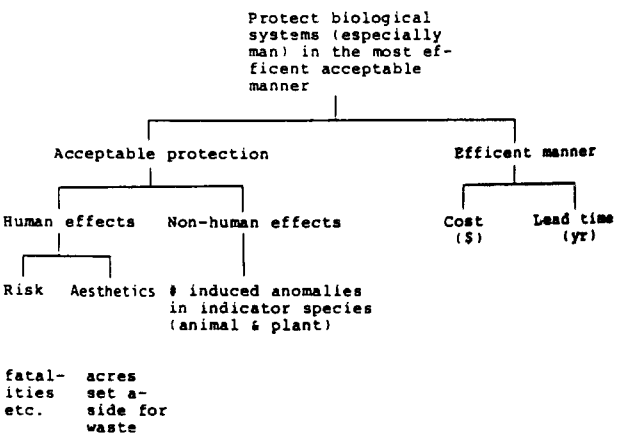

Figure 1.
Hazardous Waste Objective Hierarchy

Table I.
Possible Risk Classification Scheme

Risk Description	Class of Consequence Fatalities	Morbidity	Property Damage
Immediate			
Catastrophic			
Involuntary	X	X	X
Regulated Voluntary	X	X	X
Ordinary			
Involuntary	X	X	X
Regulated Voluntary	X	X	X
Delayed			
Catastrophic			
Involuntary	X	X	X
Regulated Voluntary	X	X	X
Ordianry			
Involuntary	X	X	X
Regulated Voluntary	X	X	X

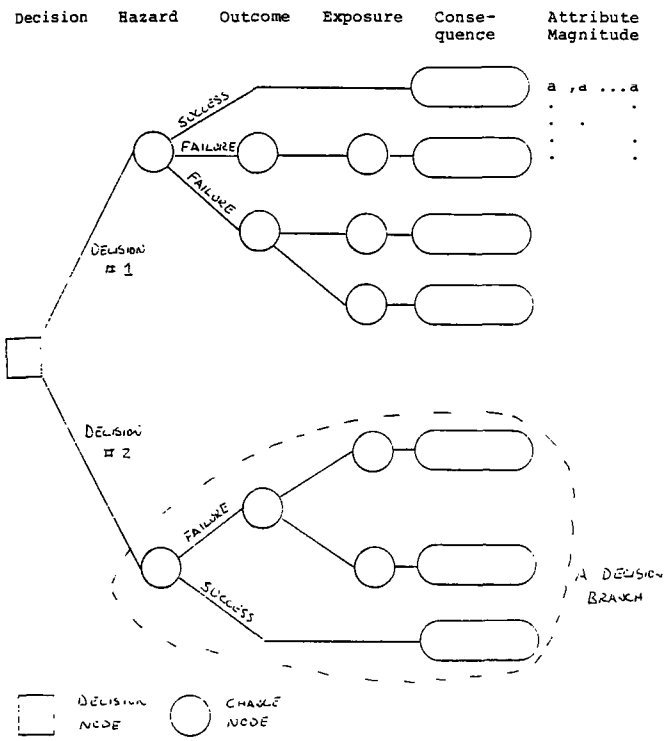

Figure 2.
Generalized Decision Tree Structure

term implies that some pre-decision tree criteria is used to eliminate "non-viable" alternatives from entering into the decision making process. In the hazardous waste area the principal criteria to serve this purpose is implementation time. The discovery of an uncontrolled dump site for highly toxic substances would require initial positive action be implemented in a minimum of time. The number of viable options would probably be small. In the case of planning a new controlled disposal/storage site this constraint would be greatly reduced, therefore, allowing for the consideration of a much wider scope of options.

A keener look is also required in the area of hazard event space. A quick glance at Figure 2 would cause some to think that what we are talking about is one "success" event and a few (one or more) "failure" event(s). This is of course far from the truth in anything but the most simplistic cases. In most "real-life" problems the failure pathways shown correspond to the top event of an appropriate fault tree. A fault tree is another type of analytical tree which allows us to depict the logical interrelationships between basic events that lead to a undesired event (i.e. the failure event). Using fault trees, Boolean algebra and various statistical techniques[6] it is possible to determine failure event probabilities. In many cases the probabilities determined are only order of magnitude estimates. The success events in Figure 2 represent the summation of all possible success events for a specific decision. In practical terms the probability of success is equal to one less the sum of all the computed failure event probabilities for a specific hazard chance node.

This leads us right into the next area of decision tree construction which requires elaboration, the significant potential inaccuracies in both probability and attribute assessments. As indicated in the prior paragraph even when "objective" methods are used, the information obtained may be only accurate within an order of magnitude. When intuitive judgments are involved, which is often the case in these assessments, then even more inaccuracies can be expected. In fact, the level of accuracy could be so low that a single "correct" answer cannot be determined. This does not negate the value of using quantitative techniques but should caution us to refrain from making unjustifiable claims of accuracy. Because of this, it is almost as important to obtain variance information about assessments as it is to know their mean. This variance information becomes especially important in the subsequent step of sensitivity analysis.

Table II.
Denney Farm Risk Data Summary

Alternative	Joint Probability (Term)	Involuntary Fatal.	Involuntary Morb.	Reg. Vol. Fatal.	Reg. Vol. Morb.
1. Leave buried	.01 (long)	145	1301		
	.9 (long)	12	107		
2. Install & maintain a groundwater monitoring system	3.3×10^{-4} (long)	38	341		
	.45 (long)	12	107		
3. Excavate & store material on site	.2 (short)				3
	3.2×10^{-5} (short)	5	45		
	.04 (long)	7	60		
	.1 (short)			4	36
	2.5×10^{-2} (short)	12	108		
4. Excavate & transport liquids and residues via truck to Syntex	same as 3 plus:				
	3.5×10^{-7} (short)				2
	3.5×10^{-7} (short)	1	9		

Table III.
Risk Referent Assumptions

Indirect gain-loss balance:

Class	Alt	Balance	Value
Involuntary (public)	1	Marginally unfavorable	.001
	2	Indecisive	.01
	3/4	Marginally favorable	.1
Regulated Voluntary (workers)	3/4	Favorable	1.0

Controllability:

Alt	Control Approach	Degree of Control	State of Implement.	Basis of Effect.
1	.1	.1		
2	.3	.3	.5	.5
3/4	1.0	1.0	1.0	1.0

RISK ANALYSIS

Risk cannot be meaningfully analyzed in an aggregate.[3] It must be separated into classes which are commensurate with the factors leading to subjective perception. A possible classification scheme for hazardous waste problems is provided in Table III. This scheme is modified slightly from that advocated by Rowe in order to specifically fit the area of hazardous waste. The principal changes are the deletion of the following risk classes: identifiable risk, voluntary risk, natural risk and man-triggered risk. Since generally acceptable solutions are our interest, not the acceptability to specific groups, the identifiable classification is not needed. Only the involuntary and regulated voluntary classes are required since the worker's environment is regulated. Finally, since we can usually classify all hazardous waste problems as man-originated, there is no need for the other origination classes.

After agreeing on an appropriate classification scheme, the objective (estimated) magnitude of risk of each class on each decision tree must be determined. In general this would be formulated in the following manner for each decision branch when a decision tree format is used:

$$R_o(A_i) = (P_j)(a_{ij})/ET$$

Where j a specific path in a decision branch

Pj - joint probability along path j

Ai a specific risk class

a_{ij} - the consequence magnitude of risk Ai on path j (i.e. number of fatalities, etc.)

E total population exposed to risk Ai

T - time in years

R_o Objective risk magnitude

(Note: This provides a measure of risk commensurate with the manner of data presentation used by Rowe[3].)

The next step is to determine appropriate risk referents. The purpose of a risk referent is to serve as the measure of risk acceptability (incorporating subjective perspectives). Rowe has proposed a methodology of calculating risk referents which is composed of two steps:

1. Using historical data as a base, absolute risk references are determined for each risk class.
2. These absolute references are modified to fit the specific situation being analyzed producing risk referents.

A clearer understanding of the purpose of this process can be gained by examining Figure 3. In this exhibit the risk referent calculation steps are related to the transformation factors responsible for the subjective perception of risk. It should be noted that Rowe's assessment of the accuracy of this method indicated potential variances in excess of one order of magnitude. Prospect theory[5] provides a formal explanation of the psychological rationale behind the determination of risk referents and gives some hope for future refinement of this process.

The final phase of the risk analysis can now be accomplished. This is nothing more complicated than a comparison of a decision branch's estimated risk (for each class of risk) with the appropriate risk referent. If the risk does not exceed the referent by more than one order of magnitude then the risk is considered publicly acceptable. This order of magnitude comparison is used due to the inherent inaccuracies in the risk information. If this criteria cannot be met then the choice remains to either modify the decision branch (which will probably effect some or all of the non-risk attributes being considered such as cost) or to eliminate that branch. It should be noted that one of the modification steps possible when the difference between objective and subjective risk is large is to attempt to educate the public to the "actual" risk. In many cases this may be a difficult, costly and time consuming path but in some cases it may be the only option other than complete abandonment of a project.

Factors involving type of consequence:
- •Voluntary or involuntary (1)
- •Discounting of time (1)
- •Controllability (2)

Factors involving nature of consequence:
- •Position in hierarchy of consequence (1)
- •Ordinary of catastrophic (1)

Other factors:
- •Magnitude of probability of occurrence
- •Propensity for risk taking (2)

(1) Explicitly included in determination of absolute risk reference.
(2) Explicitly included in determination of risk referent.

Figure 3.
Transformation Factors Utilization in Risk Referents

MULTIATTRIBUTE DECISION ANALYSIS

This process can be broken into three principal parts: 1) the determination of utility functions for each attribute, 2) the development of a multiattribute utility function and 3) the calculation of expected utilities. The first two are by far the most complicated. The determination of an attribute's utility function is a well developed analyst-decision maker interrogation procedure. It normally includes questioning both the qualitative and quantitative

Table IV.
Risk Referent Calculation Factors

Risk Classification	Risk Ref	Risk Prop Fac.	Proportion. Derating Factor	Control. Factor
Involuntary, catastrophic, fatal	1×10^{-7}	.1	Alt 1 .001 2 .01	Alt 1 .01 Alt 2 .015
Involuntary, ordinary, fatal	5×10^{-6}	.1	Alt 1 .001 2 .01 3/4 .1	Alt 1 .01 2 .015 3/4 1.0
Involuntary, catastrophic, health effect	5×10^{-7}	.1	Alt 1 .001 2 .01	Alt 1 .01 2 .015
Involuntary, ordinary, health effect	3×10^{-5}	.1	Alt 1 .001 2 .01 3/4 .1	Alt 1 .01 2 .015 3/4 1.0
Regulated voluntary, ordinary, fatal	1×10^{-4}	1.0	1.0	1.0
Regulated voluntary, ordinary, health effect	6×10^{-2}	1.0	1.0	1.0

Note: All risks are treated as immediate

characteristics of the decision makers preferences. The result is a function which transforms attribute magnitudes into a cardinal measurement, utility, structured so that the best course of action is always the alternative with the highest expected utility.

The development of a multiattribute utility function basically involves the assessment of attribute independence and then the development of an appropriate mathematical formulation. This formulation allows the analyst to combine each attribute's utility function into a single utility function. A simplified summary of the independence assumptions and resulting formulations in multiattribute utility theory is provided in Figure 4. It should be noted that the concept of preferential independence involves attributes under the condition of certainty while utility independence is specifically concerned with uncertainty. This process is developed according to the decision maker's perception of the attributes' relationships, not according to some established standard rules. Some general observations about the independence perceptions likely to be held by most decision makers in hazardous waste problems seems in order though. First, the risk attributes normally will be both preferential and utility independent of the other attributes. Second, each risk attribute would normally be both preferential and utility independent of each other.

The third part of the procedure, the calculation of expected utilities, is basically just a mechanical process of "averaging out" and "folding back." Averaging out involves nothing more than the computation of P_jU_j (p_j-joint probability along decision path j; U_j-utility magnitude for the jth path) for a decision node. Folding back entails the elimination of the less desirable paths at a decision node. Unlike most of the other aspects of this integrated analytical procedure, this portion of the process is purely "objective."

SENSITIVITY ANALYSIS

Sensitivity analysis is used at two points in this integrated procedure: 1) after the risk analysis and 2) after completing the decision analysis. A good question at this point is what is this sensitivity analysis about and why is it necessary? As expressed previously, a significant level of inaccuracy is inherent in the type of problems we are dealing with. Sensitivity analysis is a post solution investigation that indicates how much trust should be placed in solutions when we know that all or most of our parameter values (probabilities, attribute assessments, etc.) are not certain. Therefore, sensitivity analysis has a very important part to play in the overall analysis. Using this technique after risk analysis allows us to ascertain if any of the "acceptable" decision branches is really only marginally so. There would be a great deal of doubt if one of these marginally acceptable branches was the solution or a part of the solution chosen during decision analysis. In that case we would probably be inclined to look at the problem with even greater intensity. In addition this technique will help us identify options which have no realistic chance of being accepted. The same type of function is provided by the sensitivity analysis conducted after decision analysis.

Sensitivity analysis does not have any rigid rules about what specific methods to use. Within the context of the problems we are addressing, two possibilities present themselves. The first is simply to change the value of selected parameters and see if the "solution" changes. A more useful approach involves the substitution of variables for selected parameters (normally one at a time), then solving the decision problem in terms of the variable. By changing the variable we can graphically depict the effect it has on the desirability of each possible decision. This allows us to quickly determine which parameters are significant and therefore require close attention.

Independence Definitions:

Preferential Independence (PI)—attribute X is PI of attribute Y if preference for consequence (x,y^1) with y^1 held fixed do not depend on the amount of y^1.

Utility Independence (UI)—attribute X is UI of attribute Y if preference for lotteries on (x,y^1) with y^1 fixed do not depend on the amount of y^1.

Additive Independence (AI)—attribute X and Y are AI preferences for lotteries (x,y) depend only on the marginal probability distributions on x and y.

Utility Formulations:

If Xi Ui $\bar{X}$i, i = 1,2..., n then

$u(x) = \Sigma k_i u_i(x) + k_{ij} u_i(x) u_j) + \ldots k_{1\ldots n} nu, (x_1) \ldots u_n(x_n)$

If $\{X_1 Xi\}$ PI $\bar{X}_{1,i,}$ i = 2,3,...,n and X_1 UI X_1 then either

1) $1 + ku(x) = \Pi 1 + kk_i u_i(x_i)$ or

2) $u(x) = \Sigma k_i u_i(x_i)$

If Xi Ai $\bar{X}$i, i = 1,2,...,n then

$u(x) = \Sigma k_i u_i(x_i)$

Source: (1)

Figure 4.
Summary of Multiattribute Utility Theory

APPLICATION

In order to illustrate the use of the integrated methodology, the case study of Denny Farm 1[1] will be used. In this case an uncontrolled chemical dump site containing TCDD along with other substances was discovered in Missouri. The problem posed is how best to eliminate the health risk at and around this site. Four viable alternatives were suggested: (1) leave the site as is, (2) install and maintain a groundwater monitoring system, (3) excavate the dump and restore the waste in a controlled manner on the current site, and (4) excavate the site and transport liquids and residues via truck to Syntex, an approved hazardous waste storage site. Since joint probabilities for each chance path have been delineated in the study, the simplified decision tree shown in Figure 5 is used. Due to the limited information provided in the report only four attributes can be used: two classes of human risk, fatalities and morbidity, cost and lead time. The division of human impacts between fatalities and morbidity is made possible by adopting the arbitrary assumption that ten percent of all possible harmful human exposures determined in the study will result in fatalities. In reality this assumption would have to be verified and revised as necessary.

The next step is to proceed with a risk analysis. The risk data provided by the study is summarized in Table II. Use of this data requires that it be expressed in terms commensurate with the risk referents that will be calculated. This requires that a time duration in years for long term risk be established and that estimates of the total population exposed be determined. For the purposes of this paper the long-term risk duration is assumed to be evenly distributed over a span of 30 years. Estimates of the total population exposed were calculated using data provided in the study. In some but not all cases this could be reasonably assumed to be equal to the maximum exposed numbers derived in the study. The objective risk was then calculated using the equation provided in the "Risk Analysis" section of this paper. These risk estimates are summarized in Table V. With objective risk determined, the next step was to calculate risk referents. This was accomplished using the procedure outlined by Rowe.[3] In order to do this some reasonable assumptions about the public's and worker's perception of the indirect gain-loss balance and the controllability of each alternative had to be made (see Table III). A summarization of the factors used in the risk referent calculation is shown in Table IV. A comparison of objective risk and risk referents is provided in Table V. A quick glance at this comparison indicates that none of the proposed alternatives is "acceptable" to the public and that alternatives 3 and 4 are only marginally "acceptable" to the workers in terms of fatalities.

Regretfully, no information was provided in the study with which to conduct a sensitivity analysis of the above risk assessment. Illustrating this procedure will require that some reasonable variance information be postulated. It will be assumed that:

- The parameters used in the decision tree, joint probabilities and attribute magnitudes, can vary by ± 50% within the limits imposed by the exposed population size and the maximum possible probability of 1.0.
- The risk referents can vary by ± one order of magnitude.

Using these assumptions, the information calculated in Table VI indicates the possible range of variance in both objective risk estimates and risk referents. This provides a sound basis for assessing which alternatives have a realistic chance of being acceptable.

At this point it is fairly clear that alternatives 1 and 2 will under no foreseeable circumstance approach an acceptable level of risk so they can be eliminated. It appears potentially feasible and worthwhile to modify alternatives 3 and 4 by eliminating the risk to the public of significant release of residual TCDD after excavation by either eliminating most of this residual during the clean-up or by

Table V.
Risk Comparison

Alt	Risk Classification	Objective Risk	Risk Referent
1	Involuntary, catastrophic, fatal	3.3×10^{-5}	1.0×10^{-1}
	Involuntary, ordinary, fatal	3.0×10^{-3}	5.0×10^{-2}
	Involuntary, catastrophic, health	3.0×10^{-4}	5.0×10^{-2}
	Involuntary, ordinary, health	2.7×10^{-2}	3.0×10^{-1}
2	Involuntary, catastrophic, fatal	1.1×10^{-6}	1.5×10^{-2}
	Involuntary, ordinary, fatal	1.5×10^{-3}	7.5×10^{-4}
	Involuntary, catastrophic, health	9.9×10^{-6}	7.5×10^{-2}
	Involuntary, ordinary, health	1.3×10^{-2}	4.5×10^{-2}
3/4	Involuntary, ordinary, fatal	1.7×10^{-4}	5.0×10^{-3}
	Involuntary, ordinary, health	1.5×10^{-3}	3.0×10^{-7}
	Reg. voluntary, ordinary, fatal	3.2×10^{-3}	1.0×10^{-4}
	Reg voluntary, ordinary, health	3.3×10^{-2}	6.0×10^{-1}
3/4 Mod	Involuntary, ordinary, fatal	4.1×10^{-5}	5.0×10^{-4}
	Involuntary, ordinary, health	3.7×10^{-4}	3.0×10^{-7}
	Reg. voluntary, ordinary, fatal	3.2×10^{-3}	1.0×10^{-4}
	Reg. voluntary, ordinary, health	3.3×10^{-2}	6.0×10^{-1}

Table VI.
Sensitivity Analysis

Alt	Risk Classification	Objective Risk Range	Risk Referent Range
1	Involuntary, catastrophic, fatal	8.4×10^{-6}–7.5×10^{-5}	1.0×10^{-14}–1.0×10^{-1}
	Involuntary, ordinary, fatal	7.5×10^{-5}–5.0×10^{-3}	5.0×10^{-13}–$5.0\ 10^{-11}$
	Involuntary, catastrophic, health	7.5×10^{-5}–5.0×10^{-4}	5.0×10^{-14}–$5.0\ 10^{-12}$
	Involuntary, ordinary, health	7.6×10^{-4}–$3.3\ 10^{-2}$	3.0×10^{-12}–3.0×10^{-10}
3	Involuntary, ordinary, fatal	4.5×10^{-5}–4.0×10^{-4}	5.0×10^{-7}–5.0×10^{-7}
	Involuntary, ordinary, health	3.9×10^{-4}–2.8×10^{-3}	3.0×10^{-8}–3.0×10^{-6}
	Reg. voluntary, ordinary, fatal	7.9×10^{-4}–5.2×10^{-3}	1.0×10^{-5}–1.0×10^{-3}
	Reg. voluntary, ordinary, health	8.3×10^{-3}–7.5×10^{-2}	6.0×10^{-3}– .06
3 Mod	Involuntary, ordinary, fatal	1.0×10^{-5}–9.0×10^{-5}	Same as 3
	Involuntary, ordinary, health	9.0×10^{-5}–8.0×10^{-4}	
	Reg. voluntary, ordinary, fatal	Same as 3	
	Reg. voluntary, ordinary, health		

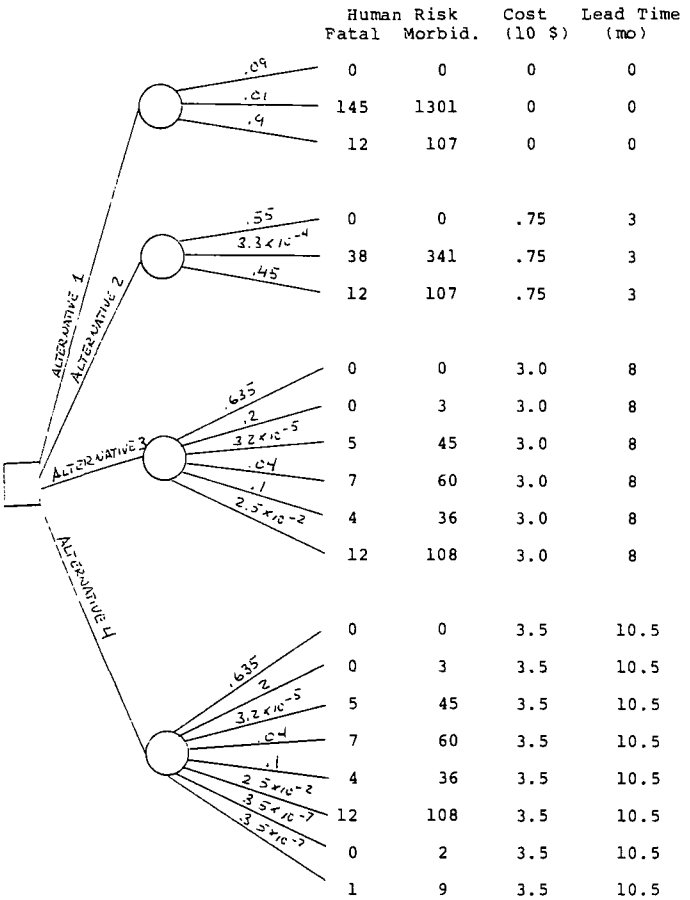

Figure 5.
Initial Decision Tree

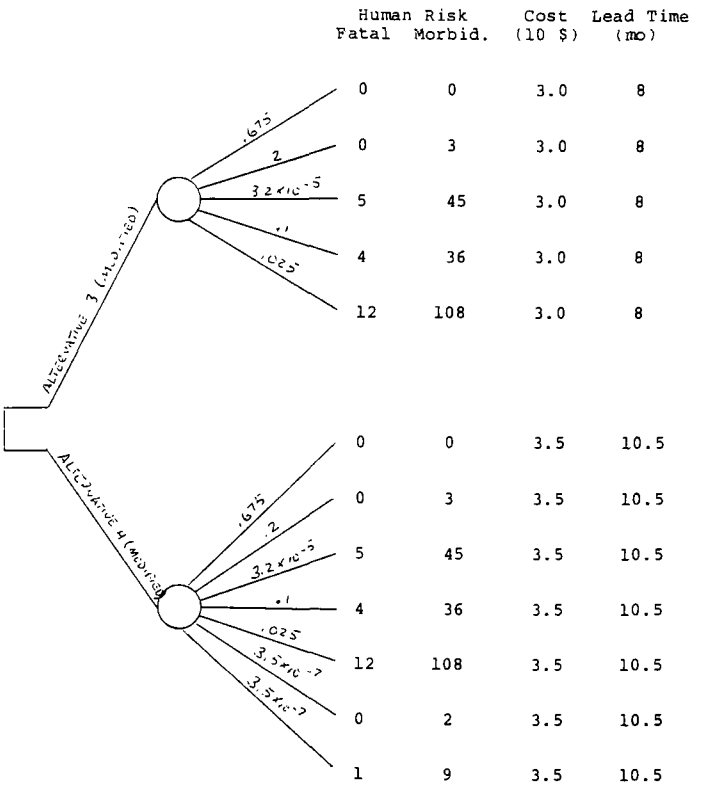

Figure 6.
Revised Decision Tree

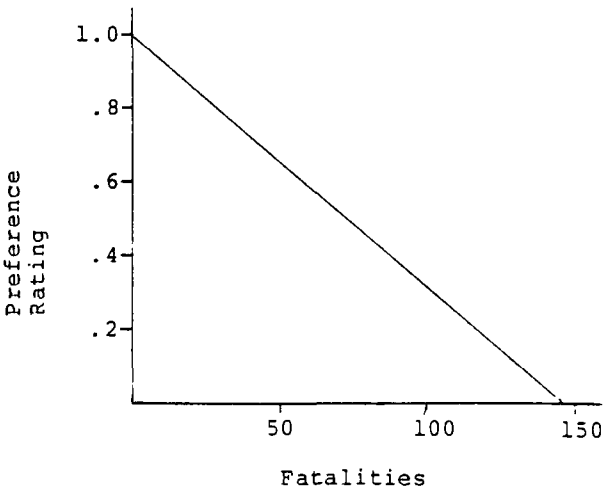

Figure 7.
Fatalities Utility Function

some form of encapsulation. This modification will cause both the cost and lead time of each alternative to be increased. No other risk modifications seem realistic with the information given. As indicated in Tables V and VI, even with the suggested modification alternatives 3 and 4 would still not be acceptable. This would suggest that it is time to "go back to the drawing board" and assemble some other alternatives. Possible other approaches would need to include means to either mitigate or eliminate the public exposure due to tornados and contaminated workers. Since no in-depth information is provided by the study for other approaches or modifications, the heroic assumption that alternatives 3 and 4 (modified) are the best that can be offered must be made to proceed with the analysis. In real life this is a possible outcome; in which case someone is stuck in the unenviable position of explaining this to the public.

With the risk assessment completed a revised decision tree including only alternatives 3 and 4 (modified) is all that is necessary (see Figure 6). Completion of the analysis requires utility functions for each individual attribute and a multiattribute utility function. The utility functions used for each of the attributes are diagramed in Figures 7-10. Figures 7 and 8, Fatalities and Morbidity, provide an example of risk neutral functions while Figure 9, Costs, is slightly risk prone and Figure 10, Lead Time, is risk adverse. These functions would be a direct result of the perceptions of the decision maker considering the problem. It should be noted that the original cost and lead time for the modified versions of alternatives 3 and 4 are being used. Due to the similarity of the two options and the likelihood that the change would be relatively small, this should cause no problems within the resolution of the

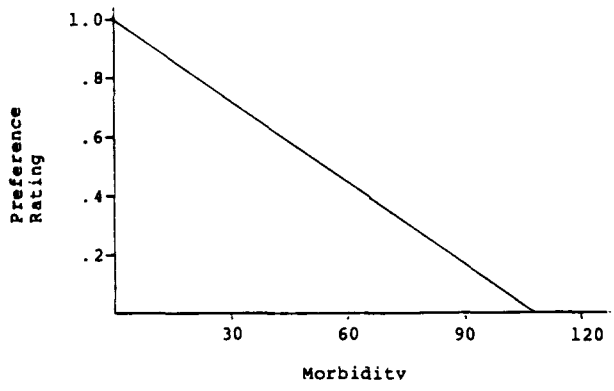

Figure 8.
Morbidity Utility Function

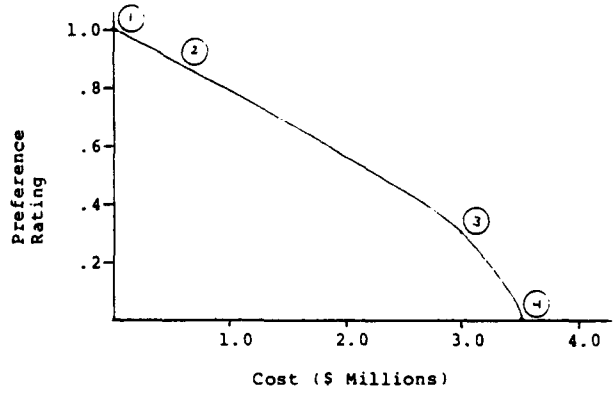

Figure 9.
Cost Utility Function

data. In order to combine the four separate utilities into a single utility value a multiattribute utility function is necessary. As in the case of the individual utility functions above, this function is directly related to the perceptions of the decision maker in question. For the purposes of this paper the use of an additive function seems reasonable due to the general observations mentioned previously and the small relative difference between the two alternatives being considered.

Finally expected utility for each path is calculated using the mechanics of decision analysis to arrive at a "solution." The decision tree with all calculated values is diagramed in Figure 11. Alternative 3 (modified) is obviously preferable to 4 (modified) in this particular case. Since both alternatives are so similar it is unlikely that a sensitivity analysis would show this to change within any reasonable limits.

CONCLUSIONS:

The proposed methodology provides a quantitative tool that is systematic but flexible; is capable of handling uncertainty, multiple conflicting objectives and the subjec-

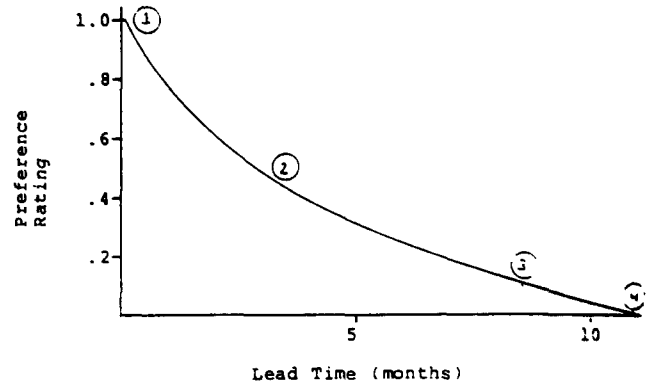

Figure 10.
Lead Time Utility Function

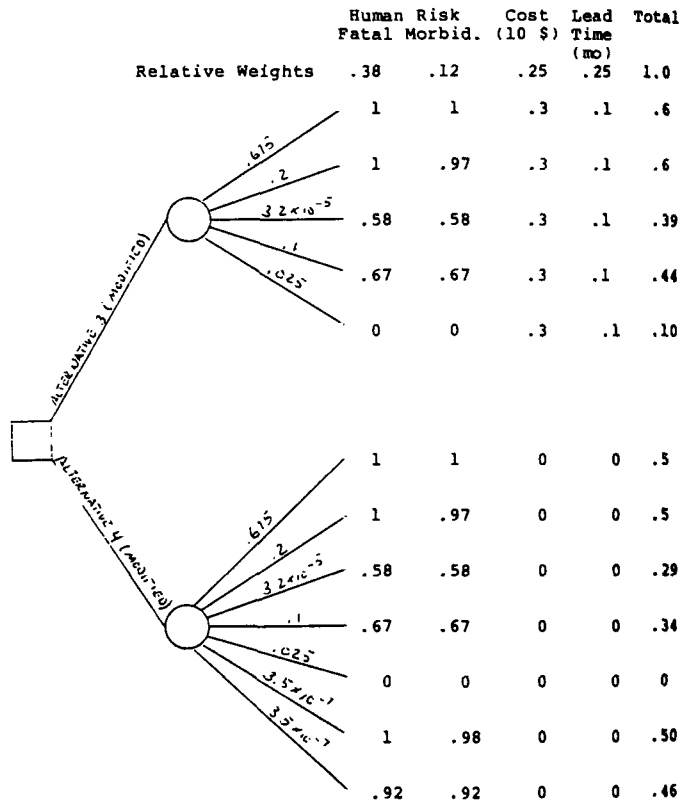

Figure 11.
Problem Solution

tive judgments of decision makers; and addresses the highly subjective nature of public risk perception. With the prudent use of a "viable option" criteria and risk analysis, the number of options that must be fully considered can be effectively limited. On the other hand, this approach will help pinpoint requirements for considering a wider scope of alternatives when necessary. The process is obviously powerful and, therefore, inappropriate for use with single attribute problems. Given the potential complexities inherent in hazardous waste prob-

lems the use of this technique appears justified. This method of problem solving does not try to eliminate the use of subjective value judgments, an impossible and counterproductive task, but does require these judgments to be openly scrutinized.

Finally, it should be obvious that this methodology is by no means perfect. It is an initial attempt to bring together a number of powerful quantitative tools and apply them to the area of hazardous waste. A great deal of refinement and improvement is still required in this area.

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RISK ASSESSMENT NEAR UNCONTROLLED HAZARDOUS WASTE SITES: ROLE OF MONITORING DATA

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PREVIOUS EXPERIENCE WITH RISK ASSESSMENT

Many assessments of the risks associated with human exposure to industrial chemicals have been carried out during the last decade. Most studies have been conducted by Government agencies, particularly OSHA and EPA or by industry in response to regulatory requirements. Public concern over exposures to carcinogens, in particular, has been a significant stimulant in encouraging such assessments.

Risk assessments have considered a number of technical approaches to several types of exposure scenarios. For example, clinical and epidemiological studies to investigate human health effects as the pivotal concern in risk assessments have been triggered by reports of worker exposures in certain manufacturing facilities. Modelling techniques, using limited data on chemical properties, have been employed to predict future risks that might result from the manufacture and use of newly developed chemicals. Finally, materials balance studies have been important in estimating environmental discharges from certain production processes and certain uses as a basis for risk assessments of industrial chemicals such as vinyl chloride and formaldehyde. While monitoring data have often been used in such assessments, only on a few occasions were the monitoring data collected in a systematic manner designed to support authoritative risk assessments.

The most widely used methodologies for assessing chemical risks have emphasized a chemical-by-chemical analysis. One approach has been to estimate the toxicity of the chemical as a function of dose, usually drawing on the results of laboratory experiments. A second approach relies on direct observations of the biological effects of the chemical exposure, effects either on human populations or more frequently on biological surrogate populations. In either approach the dose levels or the effects to critical receptor populations are estimated, with the risk then determined to be the probability that a person within the exposed population of concern will suffer an adverse effect from the likely exposure.

The uncertainties in these methodologies as illustrated in Figure 1 are well known. They include the problems on extrapolating effects from laboratory animals to man, in determining the critical receptor populations and their activity patterns, and in estimating dose levels. Nevertheless, these approaches have been used to support many regulatory decisions.

NEW FACTORS TO BE CONSIDERED AT UNCONTROLLED SITES

While past experience provides a point of departure for developing methodologies appropriate for assessing risks near hazardous waste sites, and specifically uncontrolled sites, different constraints and uncertainties must be addressed. Many types of chemical mixtures are involved, including mixtures of unknown composition. Thus, the chemical-by-chemical approach is not sufficient to estimate risks. Also, risks to future generations may overshadow the nearer-term risks that have often dominated past risk assessments. This longer time horizon requires greater attention to the chemical loadings of environmental compartments which serve as temporary pollutant reservoirs such as groundwater, sediments, and soil. Finally, containment uncertainties require the taking into account of unanticipated future chemical leakages from the site which over time could dominate concerns over risks.

Risk assessment methodologies must be flexible in order to accommodate a wide variety of site-specific characteristics. They should be adaptable to varying time limitations for carrying out assessments. This time span could range from a few months (which limits sampling to one time) to several years (which permits phased sampling and also seasonal sampling to take into account changes in weather and hydrological conditions) depending on both the urgency of the problem and the public perceptions of the urgency. With regard to budget constraints, different approaches may be required depending on the number of samples that can be processed.

The starting point for any risk assessment should be the purpose of the assessment. The purpose should shape the application of the methodology and the rigor of the assessment. In general, risk assessments are intended to clarify the degree of hazard and thereby help determine: (1) the priority for conducting detailed environmental evaluations and for undertaking preventive or remedial action or (2) the extent and character of the preventive or remedial action. The former objective usually requires a less extensive assessment. Often intertwined with these objectives are: (1) liability and related issues raised at legal proceedings and (2) concerns over the immediate hazard to area

residents. Indeed, risk assessment will often be used by several parties for somewhat different purposes, and there will frequently be a blue in distinguishing between assessments to set priorities and assessments to determine the magnitude of remedial action.

ADAPTING THE CHEMICAL-BY-CHEMICAL APPROACH

The assessment of the risks resulting from exposures to individual chemicals will undoubtedly continue to be an important consideration in assessing total risks near hazardous waste sites. Two key issues, however, are the selection of the chemicals of greatest concern and the aggregation of the risks posed by individual chemicals.

Several factors are important in selecting the chemicals for individual risk assessment. For example, certain chemicals may have been deposited at the site in very large quantities and therefore they are of principal concern simply because of their volume. Secondly, one or more of the chemicals known to be present at the site may be so toxic that the threat even at low volumes is obviously a major concern (e.g., dioxin). Certain "indicator" chemicals commonly found at waste sites may behave in the environment in a manner characteristic of many other chemicals as well and determining the environmental distribution of such "indicator" chemicals would be indicative of broader contamination problems. Analysis of leachate from the edge of the site or preliminary monitoring close to the site might identify chemicals that are escaping from the site. Finally, sampling for a group of chemicals which are usually analyzed as a package such as the 129 priority pollutants might result in considerable savings per chemical in analytical costs. All of these factors should have a bearing on the selection of the chemicals for intensive investigation.

After the chemicals of interest are determined, the classical approach of estimating source strengths, pathway loadings, location of critical receptor populations, and finally exposure levels can be pursued (Figure 2). In this regard, pathway loadings, including movement of the chemicals from one media to another, are of considerable importance in estimating both current exposures and exposures

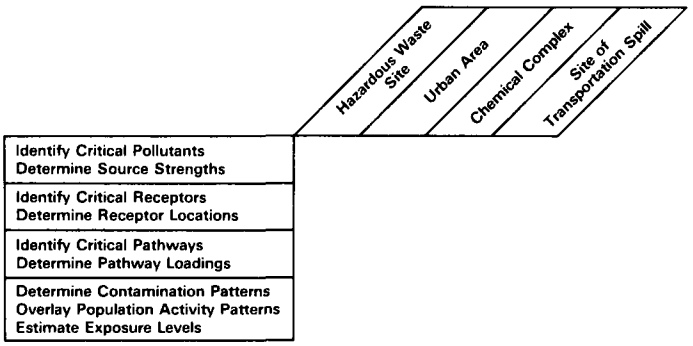


Figure 2.
Classical Approach to Estimating Exposure Levels

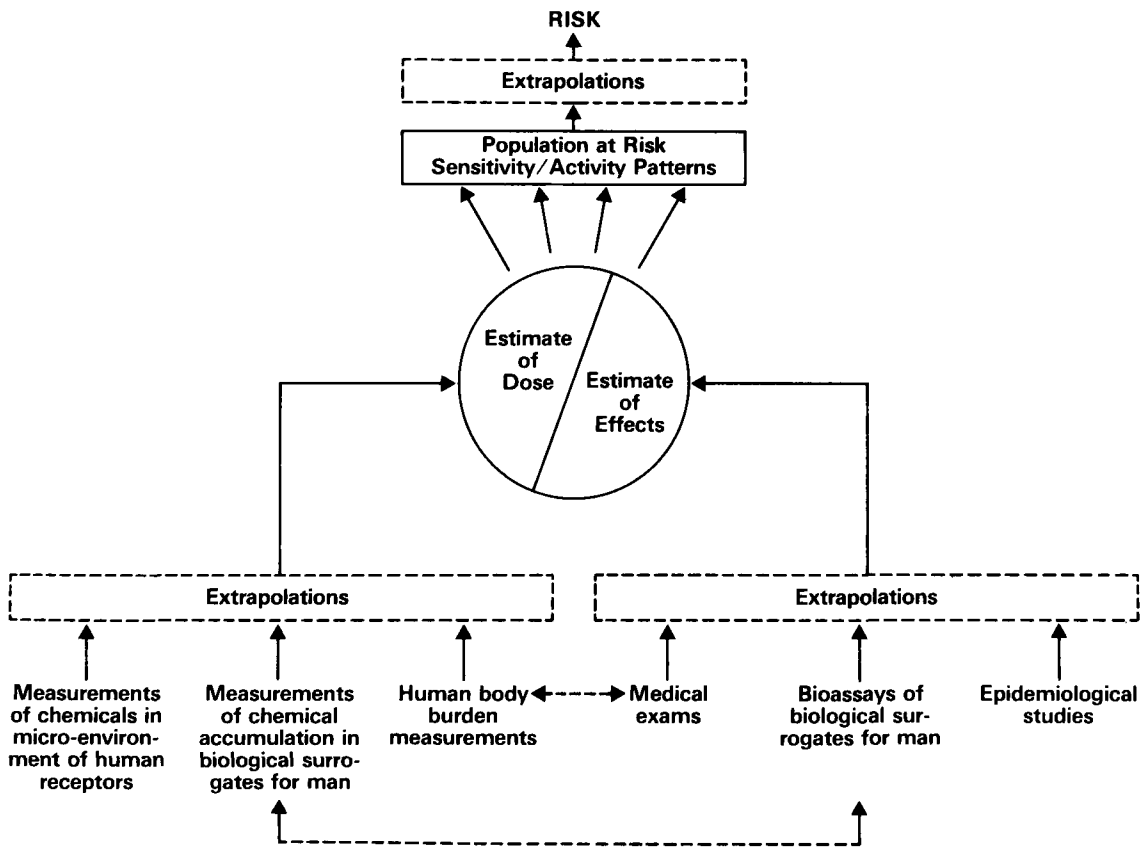


Figure 1.
Extrapolations Required in Determining Risk

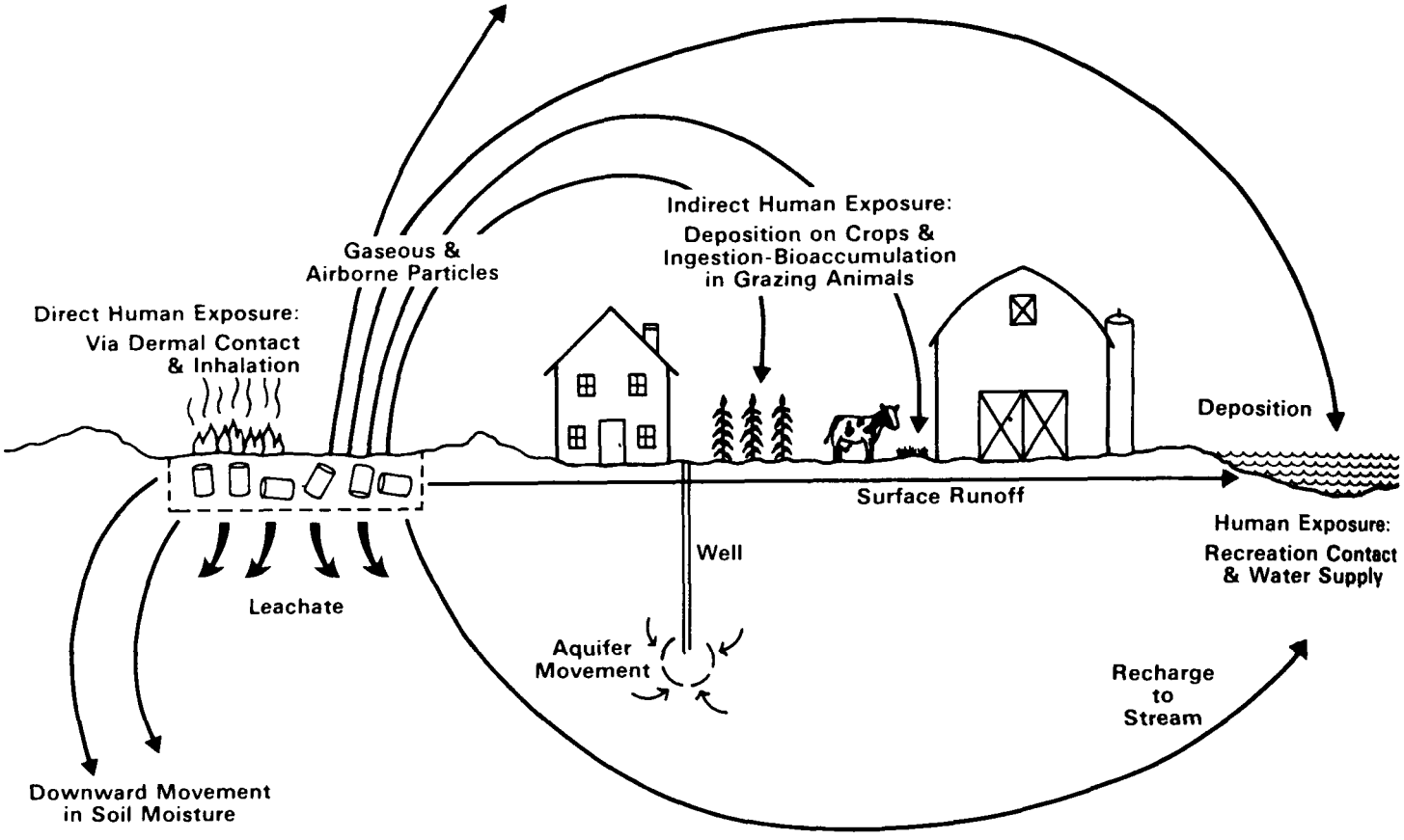


Figure 3.
Environmental Pathways from a Waste Site

of future generations. In addition to the natural pathways of air, water, soil and groundwater (Figure 3), man-made pathways such as sewers, drainage ditches and dump trucks can be important.

In most cases, monitoring is the only reliable approach to pathway analysis. However, frequently models (e.g., air pollution dispersion, hydrological and aquatic fate models) and analyses of the physical and other properties of the chemicals can assist in determining the best locations and time intervals for monitoring activities. Also, models can often provide a framework for snythesizing and analyzing monitoring data.

In recent years, the kinetic analysis model has become increasingly popular for providing a general framework for multi-media monitoring programs. This model emphasizes the determination and use of inter-media transfer coefficients as a basis for estimating how specific chemicals partition among different environmental compartments.

The interpretation of monitoring data as an indicator of exposure of subpopulations near waste sites to specific chemicals is more of an art than a science. Exposure levels, now and in the near term via air, food and drinking water and to a lesser degree through recreational uses of water and through soil contact, are usually of priority concern. Determining such exposure levels requires innovative approaches to matching the multi-media contamination patterns in the area with the habits and movement of resident populations. Even greater innovation is required with regard to future exposures, for the trends in both pathway loadings and population patterns must be estimated.

With the exposure patterns for individual chemicals in hand, estimates can be made of the dose that will reach the population. A variety of coefficients are needed, however, to convert chemical concentrations in the micro-environment of the receptor into effective dose. Inhalation, ingestion, and absorption coefficients in particular are needed for each chemical of interest. Finally, after determining the dose and the toxicity properties of the chemicals, estimates of the health effects can be made.

Methods do not now exist for aggregating the health effects of individual chemicals that reach human populations into valid causal health effects descriptions. The presence of one or more highly toxic chemicals might totally dominate, although such a case will probably be the exception. If several chemicals of comparable potency reach the receptor at comparable dose levels, an additive approach may be the only course although there is little scientific basis for judging whether simple addition will overestimate or underestimate the effects.

Approaches to determining the toxicity of complex mistures have been a subject of research for several years in

relation to discharges of industrial wastewater. Some of the existing mutagenic screening tests and aquatic bioassay procedures seem appropriate for classifying the relative hazard of specific waste samples, particularly in relation to safe handling in the field or in the laboratory. However, comparable approaches to estimating risks to a general population that is being subjected to a large number of chemicals are not available.

AN APPROACH TO COMPARATIVE CONTAMINATION LEVELS

Given the many uncertainties in attempting to assess risks near hazardous waste sites on a chemical-by-chemical basis, a complementary approach of comparing relative contamination levels can often be very helpful. The approach is intended to give a degree of perspective to the chemical contamination that is present in an area of environmental concern. The objective is to provide a basis for determining relative risk although little insight is provided as to absolute risk. Two approaches employing different types of "controls" are suggested below.

A control area with characteristics similar to the area of environmental concern is highly desirable. Of special interest would be a control area near the waste site—but insulated by geographic features from the direct influence of the site. This area would be impacted by all of the industrial emissions and effluents that permeate the region as well as other common sources of contamination such as agricultural chemicals. Thus, in comparing the contamination near the site with the contamination in the control area, it should be possible to attribute any higher levels found near the site to the influence of the site itself and not to the background characteristics of the region. The selection of control areas during investigations of Love Canal is shown in Figure 4.

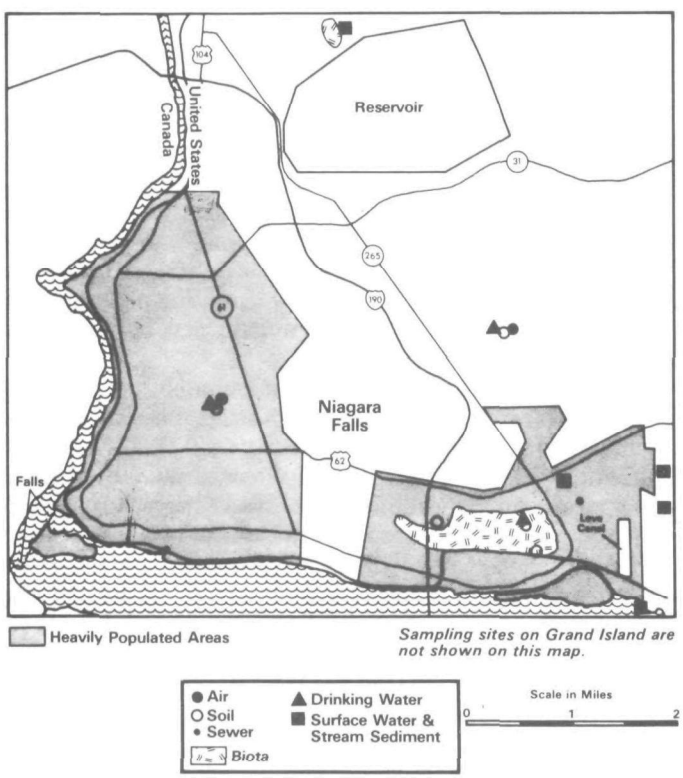


Figure 4.
Control Areas at Love Canal

A second type of control can be provided by national baseline data. Such data indicating the levels of ambient or background contamination usually encountered in different types of demographic settings can help clarify the significance of environmental measurements near a hazardous waste site. In Table I, an initial attempt is made to provide such comparative data. However, several problems were encountered in developing these data, including:

- Many environmental measurements reported in the literature are not based on sound quality assurance programs and therefore may be unreliable. Data of "research" quality, a relatively high quality level are presented in the table. Background data of this quality are in short supply.
- Many measurements are made in suspected hot spot areas of a highly localized character. Care must be taken to present only ambient data which are characteristic of a general area. Ambient data which are characteristic of several types of urban areas are given in the table.
- Data are available on only a few chemicals in most media. For some media, such as sewer sediments, soils and indoor air, little representative data are readily available.

Comparing data from different sampling programs involves considerable uncertainty. For example, seldom are the analytical precision and accuracy of the data reported and even less often is the representativeness of the sampling approach known. Even when comparing two areas using data from the same data set questions concerning comparability of data can arise.

Love Canal investigations involved comparisons of data from four areas:

(1) the canal itself,
(2) the adjacent Declaration Area,
(3) a nearby study area and
(4) the Control Areas.

For soil and sediment samples, the precision and accuracy of each data point were considered to be about a factor of three. Thus, if less than an order of magnitude separated two numbers, these two measurements might be considered to be essentially the same. When differences exceeded an order of magnitude, however, the measurements probably indicated significant differences in pollutant levels.

When comparing the sets of data collected in different areas, statistical techniques play a significant role. However, uncertainties in interpretation techniques remain. Should comparisons be made between maximum values, mean values or some other numbers? Is the frequency of occurrence of a chemical the significant aspect for comparison or is the frequency of occurrence overshadowed by major differences in levels? How are trace quantities to be handled? Finally, even this data set, which is much

Table I.
Comparative Nation-Wide Monitoring Data
in Commercial, Industrial and Chemical Cities

Volatile Organics Measured in Air and Water

	Air (μg/m³)			Surface Water (μg/l)			Drinking Water (μg/l)		
	Comm	Ind	Chem	Comm.	Ind.	Chem.	Comm.	Ind.	Chem.
		(1)			(2)			(2)	
Chloroform		ND-0 44	T-7.8		1-43	1/87	0.4-311	4-93	0.6-86
1,2-Dichloroethane		0.3	.02-1.1			1-9	T	T-0.4	T-6
1,1,1-Trichloroethane		ND-1 07	T-1.9						
Carbon Tetrachloride		ND-0 09	0.98-2.5						
Bromodichloromethane					4-7	1-8	0.9-29	0.8-28	T-16
Trichloroethene		ND-0 11	0 97-2.96						
Dibromochloromethane					4-8	4	T-16	T-17	T-5
Bromoform							2-3	T-1	
Tetrachloroethene		ND-0.066	0.02-1.8						
Chlorobenzene		ND-0 03	ND-0 45						

Research quality data. If only one value shown, only one detectable sample was reported.
ND = Not detected, T = Trace
(1)Range of mean values, (2) Range of single samples
*6-8 cities per category

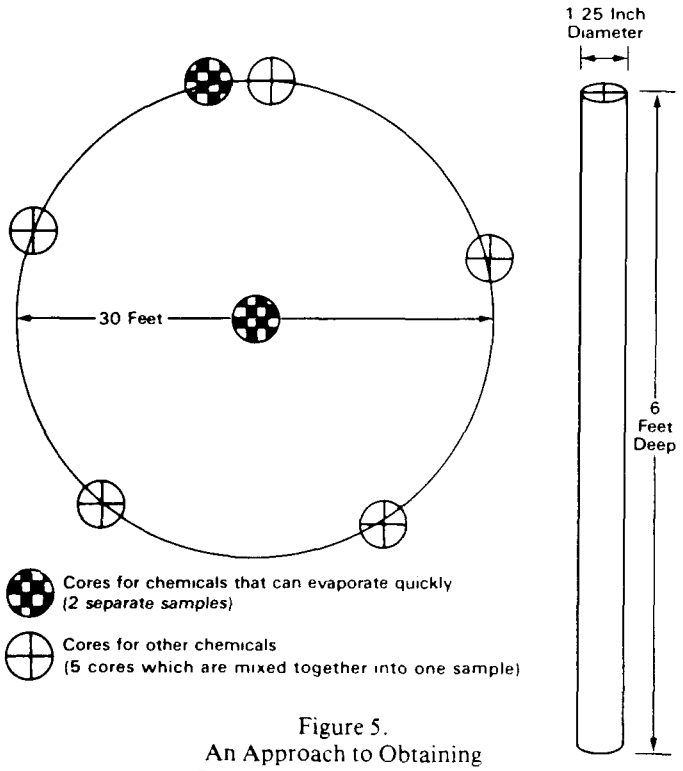


Figure 5.
An Approach to Obtaining
Representative Soil Samples

larger than the data sets usually available, could be criticized as being too small to allow authoritative conclusions.

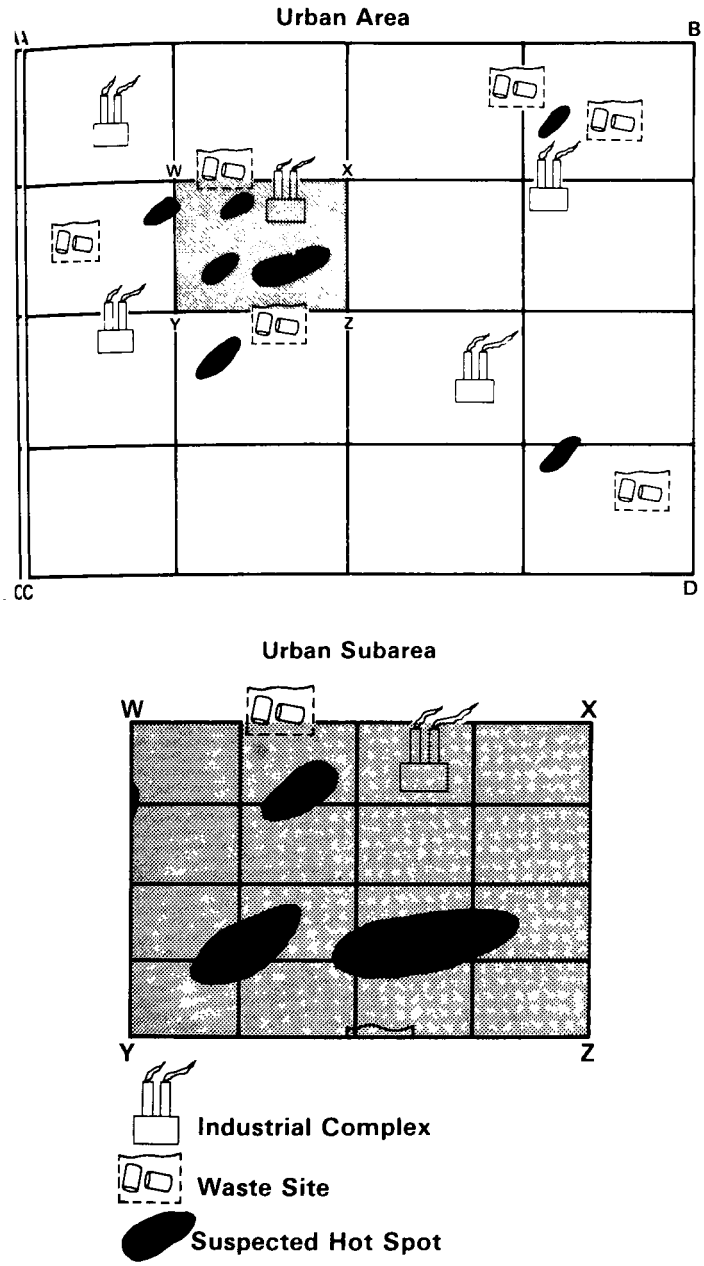
When comparing levels between sampling sites, care is needed to insure that the contamination of the samples taken at each site are representative of the overall contamination at the site. This problem is particularly acute when sampling soil and sediments. One approach to obtaining a representative sample at a soil sampling site is shown in Figure 5. This approach is useful if there is a likelihood that the contamination extends to significant soil depths. Obviously, if only surface contamination is of interest, a different approach would be appropriate.

Similarly, in comparing levels between sampling areas involving multiple sites, the sample sets should be representative of the areas as noted above. Ideally, the number of samples taken in each area of interest should be about the same. However, given limited budgets, fewer samples will undoubtedly be taken in control areas. A statistical approach to determining the minimum number of samples to be taken within an area is possible if the standard deviation of the individual samples can be estimated in advance. When the standard deviation cannot be estimated in advance, a preliminary sampling program to establish an estimate of this parameter can be particularly useful.

If the foregoing concerns are adequately taken into account in the design of the monitoring program, realistic comparisons of levels can be very useful as a basis for estimating relative risks. This approach can be of particular value in determining the most important environmental pathways. Indeed, the uncertainties associates with this approach may be of less magnitude than the extrapolation uncertainties usually encountered in the chemical-by-chemical approach described above.

COUPLING MONITORING DATA WITH POPULATION PATTERNS

The tendency in designing monitoring systems is to focus sampling in the immediate areas of suspected contamination and in areas near population concentrations. In a simple geographical situation involving a single site and a



1. Grid entire area (ABCD).
2. Determine sources, likely hot spots, and populations in each square.
3. Obtain monitoring data for each square. Emphasize squares with high populations and those with likely hot spots. Determine average concentration in each square.
4. Determine squares with highest level of:
   Average Concentration x Persons Hours per day in Square.
5. Subgrid squares identified in 4. (WXYZ).
6. Repeat 2,3,4 for subsquares.

Figure 6.
Linking Monitoring Data and Population Distribution

relatively small adjacent population, this approach seems adequate. However, frequently waste sites will be intermingled with other sources of chemical pollutants. More sophisticated approaches may be necessary to design the most cost-effective monitoring system that adequately characterizes the area while also providing insights as to which sources are the principal contributors to contamination levels of concern.

A systematic approach based on a geographical grid is depicted in Figure 6. The concept calls for determining the sources, the population characteristics and the concentration levels in each media of interest in each grid square. Squares of particular concern—due to suspected hot spots or high population densities—are further subdivided, and each subdivision is then investigated in more detail.

This approach, of relating all parameters of interest to a fixed grid, has special appeal when analyzing the effectiveness of proposed remedial action. Computer models can help test the sensitivity of exposure levels in each square to specific source reduction scenarios.

Certain population groups may be of greater concern than others. Some groups may be more susceptible biologically to adverse chemical effects, or their lifestyles may increase their exposures to chemicals. In Figure 7, some of the population characteristics that should be taken into account in detailed population studies are listed.

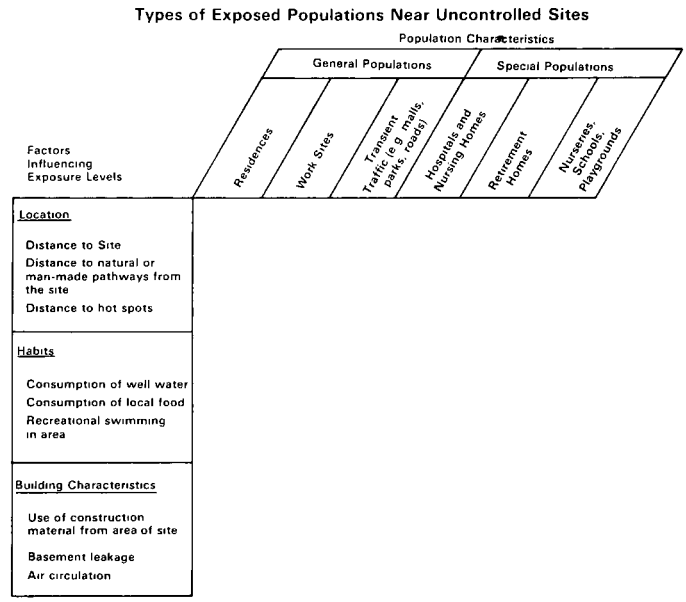


Figure 7.
Population Characteristics

INVESTIGATING A WASTE SITE

Risk assessment data requirements should be a principal factor in developing strategies for investigating a specific hazardous waste site. A combination of the chemical-by-chemical approach and a comparative assessment of general contamination of the area appears to be a practical method for addressing risks at the types of sites most commonly encountered. For large or complicated geographical areas, the sampling plan should be tied to a geographic grid to facilitate analyses of contributing sources and of exposure problems. Four activities used to implement such an approach are shown in Figure 8 and discussed below. They are:

- An analysis of current and archival aerial photography. Photo interpretation can be useful in identifying and

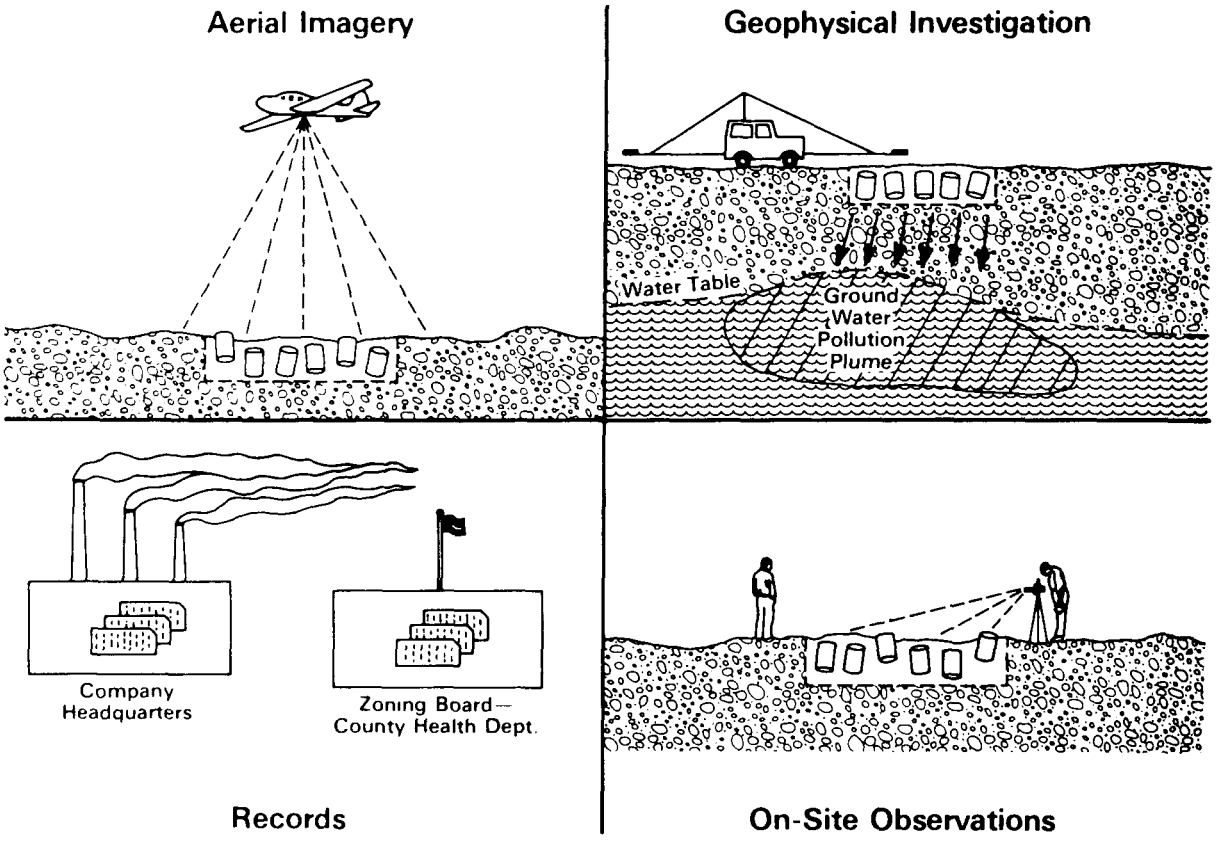


Figure 8.
Techniques for Targetting Monitoring Activities

Figure 9.
Use of Aerial Imagery to
Identify Possible Waste Sites

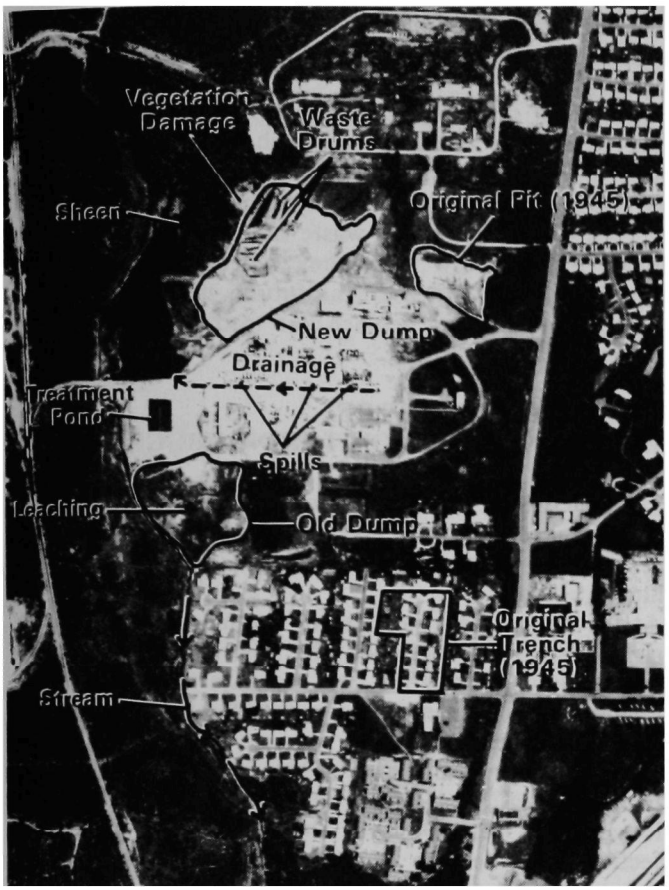


Figure 10.
Use of Aerial Imagery to Delineate Problems Near Waste Site

characterizing the site, pinpointing containment breaches and environmental pathways away from the site, and delineating nearby populations and valuable natural resources (see Figures 9 and 10).

- Geophysical surveys. Using a combination of ground based remote sensing devices (e.g., seismometers, magnetometers, radar, resistivity instruments), insights can be gained concerning the boundaries of the site, densities within the site, and anomalies in soil and water patterns around the site. In the future it may be possible to delineate subsurface plume patterns in certain types of terrain.
- A review of previously compiled Government and industry reports. Most major sites have been investigated by State or local Government agencies and, in addition, industry has some records for many sites. Of particular importance are records on the content of the site and suspected containment problems.
- On-site inspection. Even cursory on-site inspection of the site and of the surrounding area can provide insights as to possible problems that are not easily obtained from examination of records and photographs. Aerial photography can be helpful in guiding an on-site inspection.

Within this framework, a monitoring program can be effectively designed to provide data needed for risk assessment. The program should probably concentrate on the presence and movement of a limited number of specific chemicals and also screen for a larger set of chemicals in a variety of media. Certain environmental pathways of concern (e.g., locally grown food and drinking water contamination) may be obvious; others will probably warrant exploratory monitoring. In any event, a preliminary monitoring effort should help limit a more intensive monitoring effort so that within a limited budget a sufficient number of samples can be taken in the media and in the geographical areas of most concern to establish statistical credibility.

Political pressures to carry out a hurried program should be resisted and promises to deliver early results avoided. Four practical considerations argue against tight time constraints. First, a phased approach to sound and cost-effective monitoring is recommended. Secondly, monitoring during different seasons is usually important to take into account weather and runoff conditions. Third, technical problems inevitably arise in the taking and analyzing of samples with attendant delays of days and sometimes weeks or months. Finally, data formatting and interpretation almost always take much longer than anticipated.

There is no standard procedure for presenting monitoring data for risk assessment purposes. Both the site characteristics and the specific discoveries at the site will probably dictate somewhat unique formats that present the most information in an understandable manner. The results will seldom be clear cut, and adequate time should be allowed for debate prior to settling on an interpretation.

BIOLOGICAL MONITORING—THE TREND OF THE FUTURE?

The problems in extrapolating from exposure monitoring data to effective dose and then to human health effects have been noted above. Biological monitoring addresses some of these problems. In particular, this approach attempts to reduce the uncertainties concerning the biological availability of chemicals in the environment and the integration of exposures to chemicals through multiple environmental pathways. It provides a method of predicting human health effects while also directly measuring environmental effects.

As indicated in Figure 11, one type of biological monitoring is simply to measure the chemicals that accumulate in species indigenous to the local area. This type of program that was undertaken at Love Canal is shown in Figure 12. The species selected for the program are commonly found in many areas of the country. The chemicals of principal interest were those chemicals that were known to have been deposited in the Canal. The approach did not attempt to discriminate between the original chemicals that were taken up by the biota and the metabolites of these chemicals.

Biomonitoring was an additional dimension to increase the sensitivity of the overall monitoring program at Love Canal. It was hypothesized that chemicals not detected at significant levels in air, water or soil might accumulate to higher levels in biota because of the multiple routes of

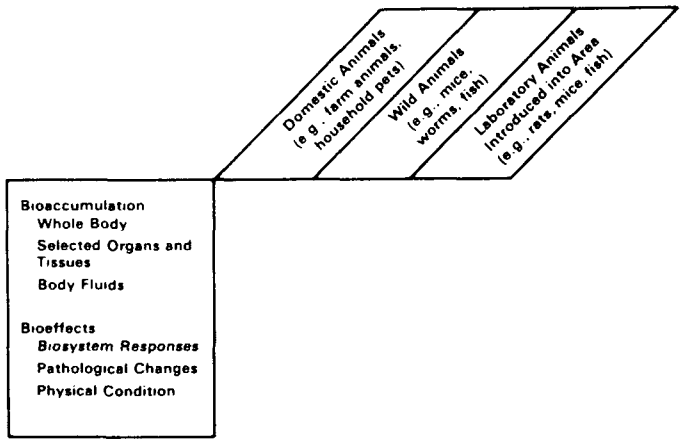


Figure 11.
Biomonitoring Using Selected Animal Species

Types of Samples	No. of Samples from Canal Area	No. of Samples from Declaration Area	No. of Samples from Control Area	Chemicals Analyzed
Field Mice:				
Carcass	6	35	32	Organics
Hair	2	12	13	Inorganics
Dogs		20	15	Inorganics in Hair
Crayfish		33	10	Organics in Whole Body
Earthworms	6	21	5	Organics in Whole Body
Silver Maple	8	14	14	Inorganics in Leaves

Figure 12.
Biological Monitoring Program at Love Canal

exposure. At the same time it was recognized that reliable uptake coefficients would be needed for both the chemicals that were found and for some that were not found before sound conclusions could be reached.

A second type of biological monitoring is the measurement of biological responses to chemical contaminants using either indigenous biological species or species introduced into the area of concern. There are many research reports indicating that certain species respond in various and consistent ways to different types of chemical exposures. However, operational use of this technique will require baseline data on response/exposure correlations developed in controlled laboratory experiments. In the absence of extensive filed on the correlations of such responses with different types of chemical exposures, such responses cannot be interpreted in a meaningful way.

Finally, the most direct approach of all may be medical investigations and human surveillance to identify possible health impacts on nearby populations. A variety of techniques have been tried in other types of environments exposed to air pollutants, food contaminants, and pesticide applications. These techniques have ranged from routine chemical analyses of blood, urine and breath to investigations of impacts on responses of the nervous and immunological systems.

Biological monitoring techniques are only now beginning to emerge from the research stage. Conceptually, these direct measures of chemical-biological interactions can provide persuasive evidence of the problems or lack of problems near hazardous waste sites. It seems likely that during the next few years they will be increasingly employed near sites. In the near future, however, they will complement and not replace our traditional reliance on conventional monitoring.

PRACTICAL ASPECTS OF IMPLEMENTING A MONITORING PROGRAM

In conclusion, the monitoring data will only be useful if the detailed aspects of collecting and analyzing the data are sound. Several practical suggestions in this regard include:

- At the outset the objectives of the monitoring program should be clearly defined. The users of the monitoring data should be satisfied that the data will be collected, analyzed, and presented in a manner which is responsive to their needs.
- Monitoring programs can be helpful both in identifying hot spots of near term concern and in assessing the longer term habitability of the area. Each of these objectives may require a different program orientation, however, as shown in Figure 13. Usually both objectives will be important in varying degrees, and the program emphasis should be adjusted accordingly.
- The entire array of monitoring opportunities should be reviewed at the outset. Many of the pathways that might be considered, particularly in situations where sites are

Assessing Exposures Near Uncontrolled Sites

	Assessing Hot Spots	Assessing Chemical Saturation
Objective	Identify near term exposure problems	Determine long term habitability of area
Chemicals of concern	High toxicity chemicals suspected to be in area	Many chemicals including degradation products
Levels of concern	"High" levels	All levels including trace levels
Likely sources	Past and current leakages at site	Past, current, and future leakages
Pathways of primary concern	Air, drinking water, food	Also, soil, sediment, biota, surface water, sewers, groundwater
Populations of concern	Susceptible individuals near hot spots	Entire population
Assessment emphasis	Determine highest integrated exposure levels for specific groups of individuals	Document highest and median concentration levels in individual media and compare such levels with control areas
Monitoring approach	Limited multimedia sampling broad areas and intensive single media monitoring of suspected hot spots near populations. Emphasize monitoring and interface of receptor	General multimedia sampling of broad areas with bias toward natural and man-made pathways from the site. Concurrent monitoring in nearby control areas. Monitor along entire environmental pathway

Figure 13.
Dual Approach to Risk Assessment

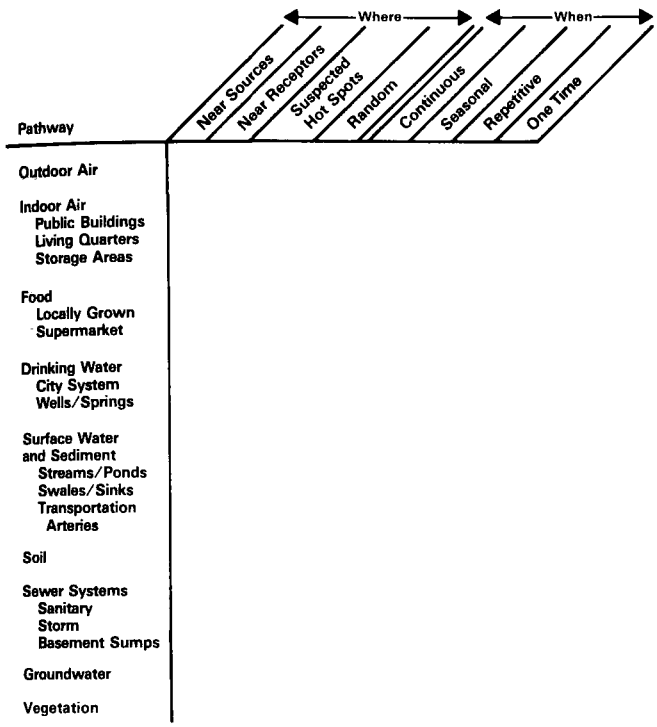


Figure 14.
Framework for Monitoring System Design

intermingled with other industrial activities in populated areas are shown in Figure 14.

- Statistical aspects are an important factor in the design of a monitoring program. A statistician on the planning team can help insure that adequate consideration is given to these aspects both in designing the program and in formatting and interpreting the data.
- A photo interpreter can also be an important member of the planning team, both in selecting monitoring sites and in designing the approach for relating concentration levels to population activities.
- Before any samples are taken, a complete sampling plan should be developed with built-in check points for adjusting the plan as sampling results are obtained. Deviations from the plan should be resisted other than to adjust the plan in response to unexpected data results.
- As a rule of thumb, on the order of 10% of the sampling might be for screening to help clarify hypotheses as to possible gradients and hot spots around the site, 80% directed to investigating the hypotheses and 10% reserved for supplementary sampling of neglected areas that arise late in the program
- The sampling scheme should include provisions to confirm or reject previously reported findings of a controversial nature.
- Access to preferred sampling sites is not always possible. The sampling plan should be sufficiently flexible to compensate for such problems.
- Geophysical investigations can be very cost-effective in targetting groundwater and soil sampling sites.
- A quality assurance program involving surrogate recoveries, inter and intra laboratory duplicates and field and laboratory blanks is essential. Each data point should be individually validated as acceptable data, and precision and accuracy data should be developed for each data set. The quality assurance program may account for 0% to 20% of the monitoring costs.
- Special efforts are needed to minimize holding times between sampling and analysis. However, extended holding times beyond two weeks may be unavoidable. In that event appropriate storage procedures are particularly important to prevent excessive decay of the samples.
- Contaminants associated with the sampling and analytical techniques are difficult to avoid, and data suspected of such contamination should be considered for discarding. Of particular concern, for example, are benzene and toluene when using Tenax traps, methylene chloride and phthalates that are present in laboratores, isophorone which can be a derivative of the laboratory solvent acetone and the high pH in groundwater associated with grouting of sampling wells that may result in artifacts being observed.
- Data formatting and presentation are of critical importance. Plotting each data point on maps is probably the safest way to insure a totally objective presentation of findings.
- Monitoring data may not provide a definitive portrayal of pollutant gradients or pollution patterns but may only be suggestive of general pollutant distribution. Interpretations of the data may be controversial, and efforts should be made to isolate criticisms of the quality of the data from criticisms of the interpretations.

COSTS OF REMEDIAL ACTIONS AT UNCONTROLLED SITES

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INTRODUCTION

During 1980, the U.S. Congress enacted the Comprehensive Environmental Response Compensation and Liability Act (CERCLA, also known as Superfund, P.L. 96-510) which was proposed to provide funds for the U.S. Environmental Protection Agency (EPA) to assist in the mitigation of pollution problems at uncontrolled waste disposal sites through remedial actions. The responsible offices within EPA (the Oil and Special Materials Division, and the Office of Environment) requested the Office of Research and Development to provide technical information to support this process. As a part of this effort, SCS Engineers was contracted to review, compile, update and integrate existing data on the costs of such remedial actions, in terms of discrete unit operations which could then be combined to construct conceptual remedial action scenarios.

This type of review-and-update approach was considered more appropriate than additional conceptual design efforts because much conceptual design work had already been done. The design work which exists, however, is scattered, incomplete and inconsistent in methodology; much of it is out of date and vague either about the methods used to arrive at a cost figure or about what components the cost figure included.

Through the review-and-update approach, a consistent methodology on the existing data in terms of scope, location, time frame and cost computations was imposed. In addition, the missing details were supplied and results presented in a uniform format, with a minimum of overlap between the individual unit operations. The resulting document presents these data in a framework of a broad and consistent methodology, with enhanced detail.

No new conceptual design work was done for this project. Where data were incomplete, some detailed information was provided, but the thrust of this work was to enhance previously existing conceptual design data and make them more available and useful to enforcement personnel responsible for overseeing the retrofit operations.

Because the document was intended for use in the retrofitting of uncontrolled sites, the unit operations examined are limited to those appropriate for the clean-up of closed or abandoned sites.

Methodology

In developing and characterizing unit operations for remedial action at waste disposal sites, hypothetical site profiles and their associated unit operation profiles were developed. Costs for each unit operation were then computed at three cost levels: high and low U.S. averages, and the price estimate for a single city, Newark, NJ (mid-1980 dollars).

SITE PROFILES

Site profiles, or hypothetical disposal sites, were developed for landfill disposal and for surface impoundments (disposal ponds). Each of these was portrayed at five scales of daily operation. The resulting site profiles were configured to conform to uniform sets of design criteria and environmental conditions. For both landfills and surface impoundments, the selected scales of operation were developed in terms of daily input. This emphasis on daily input is consistent with the usual view of landfill practices and the assumptions that surface impoundments are intended as temporary storage, with relatively short retention times.

Landfills

The size of the five hypothetical landfill disposal sites is shown in Table I. The range of scale sizes was developed from data presented in References (2) and (7). The following assumptions were made:

(1) The surface area for each landfill is square.
(2) All landfills are cut and cover operations, with cut slopes at a 2:1 ratio and fill slopes at a 3:1 ratio.
(3) Operation at each landfill was 260 days/year for ten years before the site was closed.
(4) The compaction rate was 0.596 tonnes/compacted m^3.

The layout of the hypothetical landfill site, without reference to the scale of operation is shown in Figures 1 and 2.

To allow comparison of remedial actions between sites operating at different scales, the following environmental conditions were also held constant:

(1) Ground surface and groundwater gradient are at a 1% slope.
(2) Groundwater is 4.0 m below the ground surface.
(3) Low permeability strata ($<10^{-6}$ cm/sec) is 15 m from the ground surface.
(4) Unconsolidated earth materials have a permeability of 10^{-5} cm/sec or greater.

Surface Impoundments

The scales of operation for surface impoundments are shown in Table II. The range of scale sizes was developed from data in References (3) and (8). In this case, the scale of operation is given in terms of the daily volumetric flow of influent.

Table I.
Size of Five Hypothetical Landfill Disposal Sites

Weight of Waste Material Contained (Tonnes)	Volume of Waste Material Contained (m^3)	Area of Waste Material Contained (ha)	Waste to Soil Ratio
24,000	40,000	0.99	1:1
120,000	200,000	3.33	1.5:1
240,000	400,000	5.41	2:1
700,000	1,200,000	12.80	3:1
1,200,000	2,000,000	18.51	4:1

1 tonne = 1.1 ton
skip that

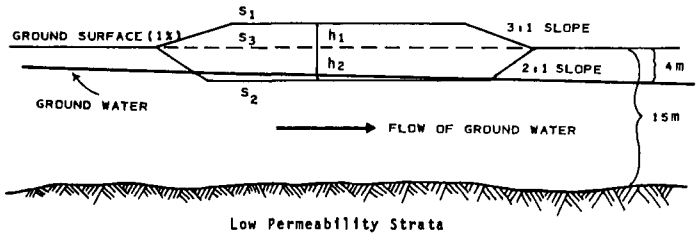
1 tonne = 1.1 tons
1 m^3 = 1.31 yd^3
1 ha = 2.47 acre

The plan of the hypothetical surface impoundment without reference to the scale of operation is shown in Figure 3. The following design criteria were common to all of the surface impoundment site profiles:

- The ponds are square and unlined.
- Berms were constructed from soils excavated during pond construction, and have 3:1 side slopes.
- The site operated 365 days/year for ten years before closure or abandonment.
- Sediment was removed from pond bottom every two years.
- Wastewater contained 100 mg/l settleable solids.
- Density of solids was 2 g/ml.
- Sludge is 70% moisture by weight when removed.
- Wastewater was recirculated after allowing three to ten days for solids settling.
- Because of short detention time and sludge on bottom, precipitation, evaporation and percolation losses are considered negligible when compared to the volumes involved.
- Average percolation $\leq$14 l/day/m^2 (0.2 gal/day/ft^2)

To help compare remedial actions for each of the scales of operation, the following environmental conditions surrounding each pond were developed:

(1) Ground surface and groundwater gradient are at a one percent slope.



Where:

T_L = Total volume of refuse (m^3)
D_L = Total volume of soil (m^3)
h_1 = Height of landfill above ground surface (m)
h_2 = Depth of landfill below ground surface (m)
S_1 = Top side of landfill (m)
S_2 = Bottom side of landfill (m)
S_3 = Side of landfill at ground surface (m)
A = Area of landfill at ground surface (m^2)

Figure 1.
Typical Side View of Landfill

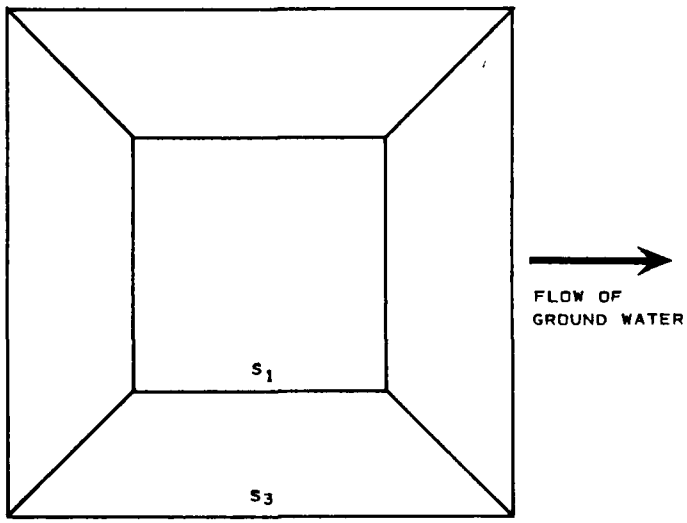


Figure 2.
Typical Top View of Landfill

(2) Groundwater is 4.0 m below the ground surface.
(3) Low permeability strata (aquiclude or aquitard; $K<10^{-6}$ cm/sec) located at 15 m from ground surface.
(4) Unconsolidated earth materials have a permeability of $\geq 10^{-5}$ cm/sec.

Table II.
Scale of Operation for Five Hypothetical Surface Impoundments

Influent Volume of Waste (m^3/day)	Total Surface Area (ha)	Detention Time (days)
10	0.038	3
50	0.081	3
500	0.468	10
5,000	2.033	10
50,000	11.076	10

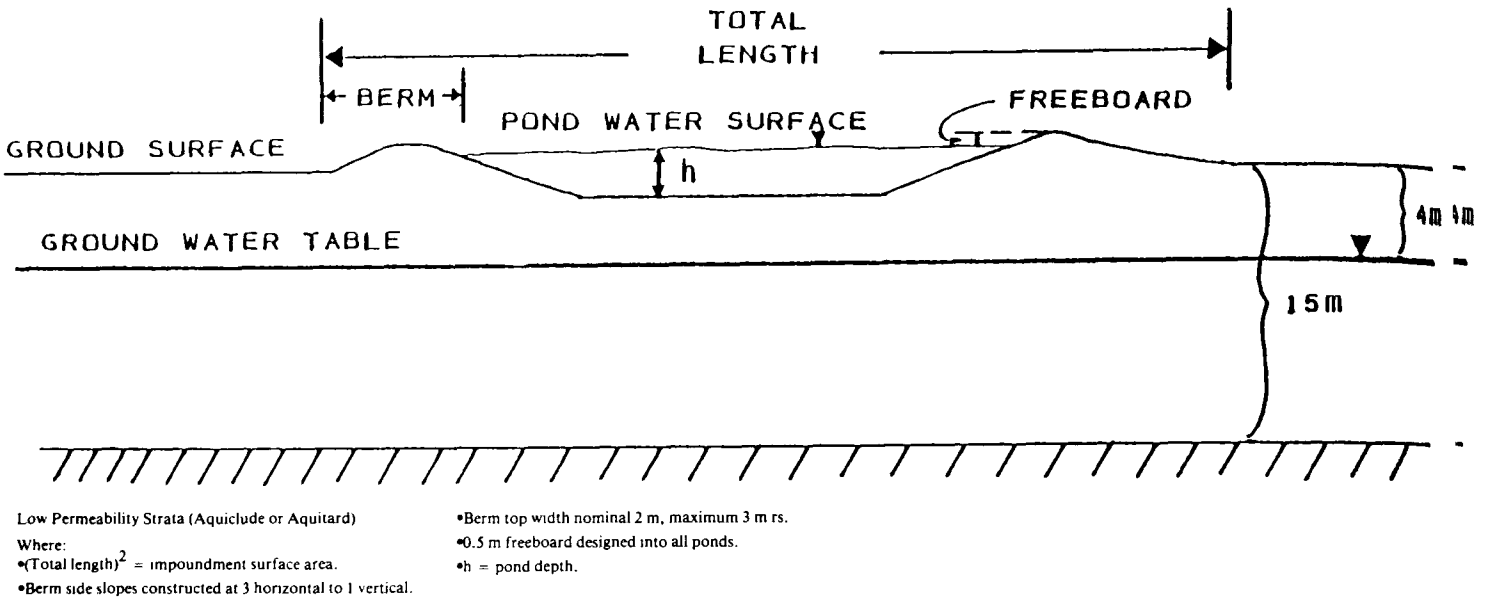


Figure 3.
Side View of Surface Impoundment

UNIT OPERATION PROFILES

Thirty-five unit operations were identified which might be used as part of a remedial action effort at an uncontrolled hazardous waste disposal site. These operations are shown in Table III for both impoundments and landfills. Although there appears to be some overlap between the two lists, each operation was configured separately for the distinctly different design criteria and environmental conditions assumed in each site profile.

All of the unit operations shown were taken from the literature and only those for which the literature contained adequate conceptual designs and cost data were addressed. In some cases, a part of the necessary data was missing and was supplied by SCS.

Alternative Unit Operations

When a pollution problem exists, a number of unit operations may be used interchangeably. The following list gives some unit operations which may be used either conjunctively or as alternatives for each other:

For elimination of contaminated site runoff, and prevention of precipitation from entering a landfill or closed impoundment, the following are conjunctive or alternative unit operations:

- •Contour grading and surface water diversion
- •Surface sealing
- •Revegatation
- •Berm construction/reconstruction

For minimizing leachate formation, the following are conjunctive/alternative unit operations:

- •Contour grading and surface water diversion
- •Surface sealing
- •Grout curtain
- •Sheet piling
- •Slurry trench
- •Well extraction
- •Well point system
- •Chemical fixation

For the control of leachate/contaminated groundwater migration, the following are conjunctive/alternative unit operations:

- •Grout curtain
- •Grout bottom seal
- •Sheet piling
- •Well point system
- •Well extraction
- •Well injection
- •Underdrains

For gas (methane and other volatile hydrocarbons), the following are conjunctive/alternative unit operations:

- •Perimeter gravel trench
- •Gas migration control—passive
- •Gas migration control—active

COST COMPILATION

Once a remedial action unit operation had been defined in terms of its intended use (with respect to the landfill or surface impoundment site profiles) and the extent to which it can be used in conjunction with or as an alternative to other unit operations, the cost of the operation can be defined for each scale of operation associated with the site profile. To do this, the unit operation is broken down into component requirements. Each component is further defined in terms of sub-components (labor, materials and equipment) and costs are assigned to each component and sub-component. The assigned costs are in terms of mid-1980 dollars for U.S. upper and lower cost overages (for the continental 48 states), as well as for the example location of Newark, NJ.

Table III.
Unit Operations Used as Remedial Actions

Landfills

1. Contour grading and surface water diversion
2. Surface sealing
3. Revegetation
4. Bentonite slurry trench cut-off wall
5. Grout curtain
6. Sheet piling cutoff wall
7. Bottom sealing
8. Drains
9. Well point system
10. Deep well system
11. Injection
12. Leachate recirculation
13. Chemical fixation
14. Chemical injection
15. Excavation and reburial
16. Ponding
17. Dike construction
18. Perimeter gravel trench vents
19. Treatment of contaminated waste
20. Gas migration control—passive
21. Gas migration control—active

Impoundments

22. Pond closure and contour grading of surface
23. Surface sealing of closed impoundments
24. Revegetation
25. Slurry trench cutoff wall
26. Grout curtain
27. Sheet piling cutoff wall
28. Grout bottom seal
29. Toe and underdrains
30. Well point system
31. Well extraction system
32. Well injection system
33. Leachate treatment
34. Berm reconstruction
35. Excavation and disposal at secure landfill

After costs are assigned to each component, conceptual design capital and operating cost estimates are accumulated and allowances for overhead and contingencies are applied. Total and average life cycle costs are then computed for each unit operation.

Estimation of Component Costs

For the most part, the 1980 Dodge and Means Guides[4,6] were used to obtain the needed costs. The costs were then expressed in terms of metric units.

Regional adjustments indexes presented in the Dodge Guide[4] were used to modify the metric versions of the cost estimates for geographical differences. These indexes were applied to obtain revised material and labor costs for the U.S. low, U.S. high and Newark, NJ estimates. No index was applied to equipment costs, since it was assumed that equipment costs are the same nationwide.

Because the Dodge Guide[4] and Means[6] present costs differently, assumptions were made so that the regional adjustment indexes could be used for both texts. For example, in the Means, labor costs were not identified as a separate entry, but were included as part of installation. Thus, whenever the Means was used to present costs, the Dodge Guide Regional Adjustment Index for Labor was applied to installation costs.

Frequently, neither guide itemized costs into categories of labor, material and equipment but simply presented a "total" estimate. Depending upon which reference was used, the following rules were applied: in the Dodge Guide, if only a total cost was presented, an average labor/material index was applied to the unit cost; in the Means, the "total" costs include an overhead allowance of 25%. This allowance was removed before the labor/material index was applied. In all cases, costs were adjusted so that overhead allowances were not included at the subcomponent level.

As the scale of operation changed, the quantity of any one component required for a unit operation also changed. The cost of each component presented in the unit operation conceptual design cost tables typically includes the sum of costs for any material, labor or equipment subcomponents. These total costs for each component do not include overhead and contingencies.

Once all the components within a unit operation were costed, the costs were summed, giving a subtotal capital cost for the unit operation. This subtotal capital cost was then used to obtain an overhead allowance (always 25%), and a contingency allowance (between 10 and 40%, depending upon the unit operation). The subtotal capital cost was added to the overhead and contingency allowances to obtain the estimate of total unit operation capital cost. (See example below.) This method was used for all scales of unit operation.

Life Cycle Costing

Once total capital and operating costs were determined for lower and upper U.S. averages and for Newark, total and average life cycle costs were computed to ensure that any subsequent cost comparisons of unit operations could be equitably accomplished.

Although operation and maintenance (O&M) cost estimates are for 1980, as the first year of operation, O&M component quantity requirements were estimated to accurately reflect requirements for each of the first ten years of remedial operations. This ten-year life of the conceptual designs means that life cycle evaluation of operating costs only addressed subsequent inflation and appropriate discounting of these O&M component costs to their mid-1980 present values.

It was further assumed that capital costs would not be amortized and discounted, but would be considered as fully incurred in the first year of operation. As a result of these assumptions, average annual compounding inflation rates for electricity and for all other O&M components were derived using estimates from the April 1980 Survey of Current Business[1]. These inflation rates were derived as shown in Table IV.

In determining the present values of future expenditures, the March 1980 Gross National Product Implicit Price Deflator of 174.51[5] was similarly evaluated in terms of its 1972 base year to estimate an annual general inflation rate of 7.4%. To this, an assumed 4% social time preference rate was added to create a total annual discount rate of 11.4%. The life cycle cost methodology was then followed, in which inflated operating costs were discounted to their mid-1980 present values, and summed with total capital costs, to determine total life cycle costs over the ten-year life span of each unit operation. Average life cycle costs were then computed by dividing this total by the site profile's daily scale of operation.

The contract report of this work includes two tables for each unit operation, giving the cost of each component, plus overhead and contingency allowances, O&M costs and life cycle costs for a medium size landfill and impoundment. One of these unit operations is given as part of the costing example in Tables V and VI.

EXAMPLE UNIT OPERATION

An example of remedial action unit operation can be taken in the revegetation of a landfill (Unit operation 3, Table III). All other unit operations were derived similarly and reported in the same format in the contract report.

One such unit operation is described in Table V in general terms.

Table VI describes how the vegetation unit operation would be achieved in a medium size landfill operation. The component requirements and their associated costs when the revegetation unit operation is applied to the 5.41 ha landfill site are shown in Table VI. In this table both capital and O&M component requirements are identified and costed in terms of mid-1980 dollars.

The costs associated with each component may represent the sum of various labor, material and equipment costs incurred in accomplishing that component. For example, costs for the "mulching" component are for applying mulched hay over 5.41 ha. The labor costs, according to the 1980 Dodge Guide, are typically $85.20/ha ($34.50/acre). This number was adjusted for regional labor cost differentials and multiplied by the number of hectares involved; these labor costs ranged from $50 to $110. The value for Newark, NJ was $100. Material (hay) and equipment costs were added to these labor cost estimates seen in Table VI. A similar process was followed in costing each capital and O&M component.

Once all of the capital components had been identified and costed, allowances for overhead and contingencies were added to complete the capital cost portions of these estimates. In all unit operations, a 25% overhead allowance was assumed. This assumption is partly based on the fact that the Means construction cost guide[6] also assumes a 25% allowance for contractor's overhead. A contingency allowance to cover unforeseen cost additions was also applied to each capital cost subtotal. In general, the contingency allowance ranged from 10 to 40% depending on the extent to which the unit operation was expected to encounter unforeseen difficulties.

Each of the O&M component costs were escalated for future inflation and then discounted to their present values (in mid-1980 dollars). These present values were summed over a ten-year life cycle of future site maintenance and then added to the capital cost total to determine total life cycle cost. Average life cycle cost was computed by dividing this total by the landfill's former daily scale of operation.

APPLICATION AND LIMITATIONS

The contract report document, produced as a result of this review and update work, consists primarily of unit operation costs at the component and subcomponent levels, and average life cycle costs. By applying this cost information to the report's discussion of alternative or conjunctive unit operations, enforcement personnel will be able to configure and cost complete remedial action scenarios.

The following is an example intended to show how the report may be used to help develop an estimated cost for a remedial action scenario, involving a combination of unit operations. The estimated cost for the hypothetical remedial action is then calculated using the cost data presented in the report.

Hypothetical Problem

An abandoned hazardous waste site has been investigated and is found to be contaminated surface and groundwater. It is decided that the site must be isolated by: (a) preventing surface runoff from entering the stored hazardous waste, (b) preventing groundwater migration through the site, and (c) implementing a monitoring program to confirm the effectiveness of the steps taken. The unit operations required are as follows:

- Contour grading and surface water diversion
- Surface sealing
- Bentonite slurry trench cutoff wall. Monitoring is included in unit operation.

For example purposes, it is assumed that the hypothetical site has the following dimensions:

- Surface area = 4 ha

Table IV.
Derivation of Inflation Rates for O&M Inputs

Type of O&M Input	Electricity	All Other O&M Inputs
Related Published Cost Index:	Electric Power	Consumer Price (CPI-W)
March 1980 Index Value:	305.7	239.9
Average Annual Index % Increase Since Base Year (i.e., 12.75 years since mid-1967 when index equaled 100):	9.160%	7.104%
Assumed Future Inflation Rate	9.2%	7.1%

Table V.
Unit Operation 3—Revegetation

Use:
Revegetation helps to physically stabilize the earth material and reduce infiltration; it also serves to minimize erosion of the cover material by wind and water.

Configuration:
Revegetation involves first grading the landfill, covering it with a suitable, fertile soil, adding soil supplements, and then seeding.

Conjunctive Uses:
Contour grading and gas migration control systems are used as cost components.

Assume:
1. Entire surface of landfill is revegetated.
2. 0.6 m of clay and silt loam will be used for landfill cover.
3. Clay and silt loam are easily accessible; transportation costs are not included.
5. Native grasses will be used for seed.

- Site is square, 200 m each side
- Average depth of bentonite slurry trench cutoff wall must be 10 m to impervious material.
- Hydrological investigation indicates that bentonite slurry trench cutoff wall must extend around three sides of site to cut off groundwater migration through the site.

The procedure for estimating the cost of this hypothetical remedial action scenario is as follows:

1. Refer to the pertinent tables in the report, and list the components of the unit operations selected. This step is shown in Table VII, first column.
2. Refer to the price list in the appendix of the report, and determine what units will be required to measure the cost of each component. This step is shown in Table VII, second column.
3. Calculate the number of units of each cost component required for the site. This step is shown in Table VII, third column, for the hypothetical site used in this example.
4. Refer to the price list in the appendix of the report, and list the unit cost for each cost component required. A decision will have to be made on whether to use U.S. high, U.S. low, or Newark, NY costs. For this example scenario, U.S. high costs were used, and are shown in Table VII, fourth column.
5. The final cost calculation required multiplication of the number of units (Step 3 above) by the unit cost (step 4 above), as appropriate, and summation of the cost components to arrive at a total cost. For this example, see Table VII, fifth and sixth columns.

For the hypothetical remedial action scenario used here as an example, the estimated costs were calculated as follows:

Total capital cost	$1,277,100
Total O&M Cost, during 10 years	$ 128,700
Total 10-year life cycle cost	$1,405,800

CONCLUSIONS

The literature review verified that little has been done in estimating the cost of hazardous waste cleanup at uncontrolled or abandoned sites. Those sources which addressed remedial responses frequently followed a case-study or national, industry-wide approach; cost information, if provided, was too highly aggregated for costing separate remedial unit operations. Those sources which did develop cost estimates at the unit operation level frequently omitted critical components or allowed substantial overlap in the scope of each unit operation. This study has attempted to overcome such deficiencies, as well as to quantitatively bound the effects which scale economies and regional price differentials are expected to have on the costs of implementing 35 different remedial response unit operations.

The primary product of this study has been a costing methodology which was consistently applied to each of these unit operations. The resulting cost estimates would seem to lend themselves readily to: (1) comparing costs for alternative unit operations which perform the same function, or (2) computing combined cost estimates for unit operations which comprise a complete remedial response scenario. The problem with the first type of use is that such simple cost comparisons do not address technical differences in the capabilities or efficiencies of alternative unit operations which accomplish the same goal. Such differences depend on both the inherent configuration of each respective unit operation, and the environmental setting under which it is actually implemented.

Table VI.
Costs of Revegetation for Medium Size Landfill
(5.41 ha - 27,685 m³)

	Dollars		
Capital Costs	**Lower U.S.**	**Upper U.S.**	**Newark, NJ**
Area Preparation	3,710	6,440	5,760
Excavation, Grading & Recontouring of site	43,820	50,790	49,050
Hydroseeding	4,900	6,900	6,200
Mulching	1,450	2,080	1,860
Capital cost (subtotal)	53,880	66,210	62,870
Overhead Allowance (25%)	13,470	16,550	15,720
Contingency Allowance (10%)	5,390	6,620	6,290
Total Capital Cost	72,740	89,380	84,880
O&M Costs			
Grass Mowing (6/yr)	320	650	550
Refertilization (1 time/yr)	250	350	300
Total O&M Cost	570	1,000	850
Total Life Cycle Cost* (over 10 years)	77,550	97,810	92,050
Average Life Cycle Cost*			
Per ha	14,335	18,079	17,015
Per ac	5,796	7,310	6,880

*See text for methodology and assumptions

As comprehensive as the site profiles may be, they still represent a conceptual design of an environmental setting and are no substitute for actual site conditions when choosing among alternative unit operations. A subsequent report may address some of these qualitative considerations.

The problem with the second type of application is that the simple addition of unit operation costs, when configuring a complete remedial response scenario, ignores both real-world influences on conceptually derived costs and the minor joint effects of scale and agglomerative economies. More specifically, some scale economies may still be enjoyed when multiple unit operations all require similar component inputs. Agglomerative economies resulting from minor component overlap or redundancy may also occur when unit operations are combined into remedial response scenarios. Subsequent research should address these considerations.

Because complete remedial action scenarios for uncontrolled sites typically consist of several unit operations, much remains to be done, even from a conceptual design cost perspective, in identifying the most appropriate short- and long-term remedial scenarios. Such an effort might include a systematic evaluation to determine the most prevalent pollution problems occurring at uncontrolled landfill and impoundment sites. Once this set of

"typical" pollution cases has been determined, likely remedial action scenarios could be configured using unit operations developed in this study. The resulting composite cost estimates for these scenarios could be determined using unit operations developed in this study and then compared to determine the relative and absolute cost advantages of each alternative scenario.

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FORCED CLEANUP: A POLICE ACTION OR A MONEY JUDGMENT?

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INTRODUCTION

In September 1980, Black & Veatch of Michigan, Consulting Engineers, was appointed to the unique position of Circuit Court Receiver. Not only did this appointment come as a surprise, but also as an agent of the court, it gave the Engineer responsibility of undertaking compliance with a previously entered Court Order. Included were certain activities which had not been performed by the Defendant in accordance with the direction of the Court. These actions were in the case of the State of Michigan, *et al.* vs. Berlin & Farro Liquid Incineration, Inc., *et al.*; a case involving an uncontrolled hazardous waste site in Genesee County, Michigan.

In addition to making the appointment of a Receiver, the Court required the Defendant to deposit a cash bond to ensure payment to the Engineer for services to be performed. Work was to include isolation, stabilization and confinement of liquid hazardous waste, with related long-term monitoring to ensure compliance. The program was to cover design, methodology for implementation and performance of the work.

When the Engineers' recommended program was submitted to the Court for approval, the Defendant took action to recover the bond and transfer jurisdiction in the case to Federal District Court. There he was involved in bankruptcy proceedings. At issue was the clarification of whether the Circuit Court Order constituted enforcement action under the State's police powers or constituted a money judgment against the Defendant.

HISTORY

In 1971, the Berlin & Farro Liquid Incineration Company applied for and received from the State of Michigan a license to haul liquid industrial waste, as well as an air quality permit to install a liquid waste incinerator. The incinerator was placed in operation in late 1972 and the Company began accumulating wastes at the site.

Subsequently, community complaints led to an investigation by the Michigan Department of Natural Resources (DNR). The inspection revealed Berlin & Farro was operating in violation of various State Regulations. Formal Administrative Complaints were filed against the Company by the State in 1973.

In 1974, the DNR Air Quality Division conducted an intensive investigation of the incinerator and concluded it could continue to operate on an interim basis provided particulate control equipment was installed and certain procedures were followed during its installation. By this time, Berlin & Farro had accumulated a substantial amount of drummed liquid waste, installed several holding tanks both above and below ground, and constructed two large storage lagoons for liquid waste.

In March 1974, spills of industrial waste on the site were documented by the DNR while investigating compliance with previous orders. By May, a Consent Order was drafted by the Michigan Air Pollution Control Commission and a Pollution Incident Prevention Plan was submitted to the Michigan Water Resources Commission.

In November, several spills of liquid industrial waste again occurred on the property, resulting in contamination of a County Drain. But, by October, Berlin & Farro was making some progress in implementing its Pollution Prevention Plan and the Water Resources Commission provided a permit to allow continued storage of liquid waste on the site.

DNR investigations conducted early in 1975 showed the Company was not continuing to make good faith progress in meeting air, waste storage and sampling requirements. By August, the Company had accumulated over 2,300 drums (55 gal each) of liquid and solid waste on the site. An estimated 2.5 million gallons of bulk liquid waste was also being stored in the lagoons and underground storage tanks.

Several meetings were held by the DNR with the State Attorney General and Berlin & Farro attorneys in an attempt to reach some agreement on the air and water quality problems at the site. These efforts failed and in September 1975, an Emergency Order to Cease and Desist was issued against the Company by the DNR. This Administrative Order was to close the incinerator and revoke the liquid industrial waste hauling license.

Ten days after the Emergency Order was issued, Berlin & Farro attempted, but failed to have the Circuit Court restrain the DNR from enforcing its Order. Two months later the Company was served by the Department with an Order for hearing an administrative complaint. Early in December, a hearing took place and in February 1976, the hearing examiner issued recommendations which included reinstatement of the liquid waste hauler's license

and a permanent Cease and Desist Order for operation of the incinerator.

The Air Pollution Control Commission then acted, but in a somewhat less positive fashion. They issued a permanent Order to close the incinerator, unless proper air pollution devices were installed. In April, the DNR had restored the Berlin & Farro hauling license.

In June 1976, another spill occurred at the site, again contaminating the County Drain and a downstream creek. Various administrative and legal maneuvers continued well into 1977, when Berlin & Farro was implicated in other litigation as having received C-56 from the Hooker Chemical and Plastics Corporation. DNR personnel then attempted to sample soil, water, waste and sediment at the Berlin & Farro site. The Company refused to grant permission for entry and a search warrant was eventually obtained. Samples were taken from the site, drains, lagoons and nearby creek bed.

Results from the survey revealed that soils from the lagoon and surrounding areas were contaminated with extremely high concentrations of heavy metals (lead, nickel, chromium, copper and zinc), organochlorines and other organic compounds. Sediments in the County Drain contained concentrations of organochlorines higher than those found in the lagoon, with some values exceeding 27,000 mg/kg. Contamination of sediment in the drain and creek occurred downstream for over 15 miles.

Administrative efforts continued into 1979 when the Michigan Attorney General finally filed suit against Berlin & Farro *et al.* in Genesee County Circuit Court. This litigation led to a Preliminary Injunctive Order but the Company failed to comply with all its terms. As a result, in August 1980, the Genesse County Circuit Court issued a Contempt Order and fined Berlin & Farro $250 (maximum under Michigan law). The Court also ordered appointment of a Judicial Receiver to assure compliance with the previous Consent Order.

To appoint a Receiver, the Court requested the State to prepare a list of qualified firms and/or persons. The DNR provided the names of three engineering firms and one private individual, qualification and experience documents were solicited, and during a September 1980 hearing, the Court ordered the appointment of Black & Veatch of Michigan. Further, it ordered the defendant to post a $10,000 cash bond to cover the affairs of the Receiver.

RECENT EVENTS

Black & Veatch was directed by the Court to develop a program to assure compliance with a limited number of specific items from the Preliminary Injunctive Order. The items selected were determined during the September hearing and were mutually agreed upon by the State and Berlin & Farro.

For the most part, the expected results and to some extent, the methodology by which these items were to be completed were stipulated in the Order, e.g., "...shall erect a fence, at least six feet in height (including barbed wire topping), along the perimeter..." or "...shall deposit soils from the Site...on top of the sludges in order to minimize any potential odors to the extent possible." At the same time, some vagueness existed, i.e., was it to be a cyclone fence or stranded wire and how much cover was justified to minimize odor? The answers would have a significant effect on the cost.

The Court also directed Black & Veatch to include an implementation schedule in the program. Prompt enforcement was the goal. While the program was to provide for strict compliance, the Engineer was requested to consider alternatives which might provide satisfactory compliance at a lesser cost. A second hearing was to follow the Engineer's Report and provide a form for final negotiation of method, cost, contractors and schedule. At this point, Berlin & Farro continued to insist on the right to plan and determine compliance activities. The Court, on the other hand, appeared increasingly impatient and less responsive to the Berlin & Farro demands.

Black & Veatch submitted a report to the Court within three weeks. Since considerable earth work was to be involved, the impending winter made it apparent that rapid mobilization would be essential to ensure completion prior to frost. Failure would delay completion for at least six months.

But the Engineer apparently was not the only one busy. Only a few days after filing its Report with the Court, Black & Veatch was served with a Temporary Restraining Order. This notice came from the Federal District Bankruptcy Court in Detroit, Michigan. A hearing date was set and the work stopped. Since that time, no real progress has been made in resolving the continuing migration of pollutants from the site. What has occurred has been a variety of legal and bureaucratic actions aimed at achieving the long term goals of the participants.

SPECIAL CONCERNS

Rather than continue with the chronological discussion of historical facts, attention will now be focused on some of the more interesting factors which have evolved in this case. Some will be typical to many cases. Others will suggest a variety of complicated factors that make imaginative investigation and thorough planning essential to successful resolution of hazardous waste problems.

Money

The title of this paper makes reference to A Money Judgment. It is of little consequence whether or not this case involves a money judgment. Money has and will continue to be a key issue. It is probable the same will hold true in most other cases. Corrective costs are high and available sources of funds are limited. Defiance may have played a major role in the inactivity of the Defendant in this case but the cost of corrective action surely has been a major concern. Some progress was possible when Company resources were used in remedial activities. When cash distribution to the Receiver became an issue, the creditors objected and quickly reduced the Court's flexibility and enforcement.

The State frequently claimed that monies could easily be made available from Company assets (land) and State or

Federal funds. This unfortunately has not been the case. The problem with the Company assets has been complicated by the bankruptcy proceedings and even further by a legal technicality which will be discussed below. Statutory and political factors have also restricted ready allocation of governmental funds. Even appropriations to the Superfund are not likely to be directly applied to this project.

Jurisdiction

Jurisdictional questions have been far from simple. What started as an incinerator-air pollution question has developed into a water resources concern. Improper and uncontrolled storage rather than burning of the materials became the long-term issue. Action to rescind the incinerator license therefore had limited effect on environmental control.

Eventual litigation appeared to place the State Circuit Court in a position to enforce permanent cleanup. The role of the Federal Bankruptcy Court interfered with the effectiveness of this effort and has significantly delayed control of the pollutants.

Declaration of a Toxic Substances Emergency by the State of Michigan (only the second such declaration in the State's history) has shifted the responsibility for directing actions from the DNR to the Michigan Toxics Substances Control Commission (TSCC). This has resulted in the Commission initiating an entirely new program for permanent site cleanup. At the same time, it has been reported by the State that the Circuit Court continues to claim jurisdiction in the case and that it has indicated any program developed will be subject to review by its Receiver prior to authorization.

Liability

When initially considering cleanup responsibilities, the TSCC resolved to solicit the services of a consultant to develop various alternatives and recommend the "best" alternative for a permanent solution at the site. Through subsequent actions however, the Commission itself created definition of the alternatives and had an evaluation of these performed by an Environmental Protection Agency consultant.

An interesting liability question is raised. In performing as a Court Receiver, Black & Veatch concluded that their liability was limited to the execution of the Court Ordered tasks in a responsible and professional manner. The assignment did not include creation or evaluation of the final design concepts. Such was not the case in the TSCC plan. Their original plan called for the creation of concepts which could have had far reaching liability implications to the consultant who created them. The eventual action, which called for independent evaluation of the TSCC-created alternatives, still carries with it a far greater liability potential than many firms might be willing to prudently accept.

There is a similar concern for potential future liability on the part of a prospective recipient of the hazardous waste. One alternative calls for permanent burial of the Berlin & Farro materials at the Hooker Chemical Company "vault" in western Michigan. While there is a recognized presence of some Hooker wastes in this material, it includes many hazardous materials derived from other sources. If the Berlin & Farro waste were accepted, the leachate system at the vault might collect some of these other wastes and place Hooker in a position of future responsibility for treatment and disposal of materials it did not produce, a circumstance it would certainly not welcome.

Time

As pointed out in the historical summary, difficulties in this case were first identified in 1973. Over eight years later, little has been done to correct the environmental abuse at the site. Granted, action has been effective in halting an escalation of the problems but a real solution has yet to be implemented. This situation is extremely disappointing in view of the major actions taken: state administrative orders, Circuit Court Orders, appointment of a Court Receiver and a State Declared Emergency.

Initial efforts appear to have been directed toward control of the facilities while still operational. As problems became more pronounced, a shift in strategy seems to have occurred. The procedures called for in the Court's Preliminary Injunctive Order were clearly intended to secure the site to minimize immediate environmental degradation, rather than toward a permanent solution.

The more recent steps, in response to the emergency declaration by the TSCC, are now directed toward the original objective of a permanent solution. This direction will, of course, be accompanied by an increased cost of implementation. It would be speculative to suggest whether this vacillation in objectives was premeditated or circumstantial but it is probable that it will markedly affect both the time at which contamination is controlled and the point at which the case is eventually concluded.

Legal Constraints

The nature of the action often required in hazardous waste cases indicates that legal considerations become of paramount importance. In the case of Berlin & Farro, the State operated for some time under the misguided conception that funds would be reasonably available by liquidating the site on which the Company was operating. Unfortunately, the corporation held title to only a small portion (approximately ten acres) with the remaining property being held personally by the Company president, a private individual and not a party in the litigation. Ascess to the assets was further complicated by the bankruptcy proceedings.

Enforcement power does not carry with it the automatic right of access to the property of the Defendant. Confusion and inaccurate public reporting developed regarding the ease with which investigations could be performed. This resulted in several instances of strained relations and implied threats. At one point, the Company president brandished a shotgun to prevent Court authorized seizure of a Company vehicle.

Two bonds were posted in this case. The first, a corporate guarantee bond has been placed on the list of

debtors to receive its share of the liquidated assets of Berlin & Farro preventing funds from becoming immediately available. Even the second, a cash bond in the hands of the Circuit Court, became temporarily unavailable for its intended purpose as a result of continued legal maneuvering.

CONCLUSION

Certain conclusions can be drawn from the experiences in this case. Hopefully they can be used beneficially in other hazardous waste projects.

- A change in certain statutes may be appropriate to better define which agencies or authorities have jurisdiction in various hazardous waste affairs. The need for protection of personal rights and a balance of powers prevent a clearly defined answer to this question.
- Participants in hazardous waste activities should give careful consideration to potential liability. Long-term risks could well overshadow the long-term benefits.
- A realistic assessment should be made at the onset regarding desired results and the time for accomplishment. Wasted effort and lost time will otherwise result.
- The entire hazardous waste arena is constantly faced with legal entanglements. Lack of attention to this fact may well result in a failure to meet the desired objective.

Finally, the question of A Police Action vs. A Money Judgment has yet to be clearly settled. While the bankruptcy Court eventually directed payment of the Engineer's fee in this case, the Order directing this action stated only "...that Black & Veatch be paid...". It did not provide a general determination of the issue. Rather the Court reaffirmed during its hearing that all issues involving disbursement of Company assets must come before an individual judgment, an action which certainly will encumber enforcement activities and make the ultimate decision academic.

TECHNICAL AND FINANCIAL ASPECTS OF CLOSURE AND POST CLOSURE CARE

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INTRODUCTION

Federal legislation and regulations have been developed to protect public health and environmental quality from harmful discharges of hazardous wastes. One of the specific requirements addressed by Federal law is the need to provide closure and post closure plans with assurances of financial capability to implement these plans. Federal law requires that owners of hazardous waste management facilities provide for proper closure of their facility. It also requires that the owner of the facility provide for post closure care, at a site where the waste remains after closure, for a period of 30 years. The purpose of these requirements is to assure the public that, if an incident occurs which could force an operational hazardous waste management facility to close, funds will be available to properly close the facility and assure no environmental or health impacts occur.

The regulations also specify that adequate funding must be available to assure closure and post closure care, as needed, and that such steps can be implemented and carried out with no financial burden being incurred by the public.

One aspect that is not addressed by this regulatory program is post closure care after the owner's responsibility has been terminated, i.e., what happens to a site after 30 years to assure environmental protection.

TECHNICAL ASPECTS

Closure is the period after wastes are no longer accepted, during which the owners or operators complete treatment, storage and disposal operations, dispose or decontaminate equipment and apply cover to or cap landfills. The purpose of the closure standards is to assure that all hazardous waste management facilities are closed in a manner that:

- Minimizes the need for post closure maintenance, and
- Controls, minimizes or eliminates to the extent necessary to protect human health and the environment, post closure escape of waste, leachate, contaminated rainfall or waste decomposition products to ground or surface waters or to the atmosphere. There are two types of closure and post closure requirements in the Federal rules:

A. General requirements which are applicable to all facilities, and
B. Specific technical requirements which are included in the facility-specific regulations.

The closure standards, specifically for the plan and cost estimate, assures the owner has considered the actions and costs that must be taken to properly close his facility. The regulations specify timing for the development and submittal of closure plans. Closure standards require that closure plans had to be developed by May 19, 1981 for existing hazardous waste management facilities, or during the development of a plan of operation for new facilities. During the interim status period, plans must be maintained on-site. These plans need not be submitted for regulatory agency review until they are submitted either prior to closure or to obtain a final permit.

If a facility is to close before a final permit is issued, the closure plan must be submitted to the EPA Regional Administrator, or authorized State at least 180 days before closure is anticipated to take place so the regulatory agency can review and approve the document and so the requisite public participation, with regard to plan actions, can be accomplished.

For those facilities in existence on November 19, 1980, the closure plan must be developed for all portions of the facility that were active on that date. If some areas were closed after this date and before the development of the plan, these areas must be properly closed in accordance with the closure standards. Partial closure is also a concept that can be utilized to reduce the financial requirements for facilities, generally landfills. This allows an owner to sequentially close areas of his facility. By minimizing the active portion of the facility, the necessary actions needed to meet the closure requirements are less and, hence, the costs needed to implement the plan are less.

The regulations also require the closure plans be revised when there is a change in the plan, including changes in activities, schedules or estimated cost for closing the facility. The cost estimates must be updated annually.

The closure plan is the cornerstone of the closure regulations. Closure plans must address the following basic elements including:

- How and when a facility will be closed
- An estimate of the maximum inventory of waste on-hand at any given time
- Decontamination activities

•Schedule of activities over the closure period
•Cost estimate to implement the plan.

The schedule for closure must address, at a minimum, three key dates:

•The final date of waste acceptance
•Dates for completion of specific activities
•The final date of closure completion.

A schedule would naturally begin with a 180 day notification prior to the beginning of closure. The second date would be the beginning of closure. An important requirement is all treatment and disposal of wastes on-site, must be accomplished within 90 days of closure. Closure must be complete within 180 days of the acceptance of the last waste shipment. This 180-day requirement may be waived if it can be shown that, realistically, more than one year is needed. An example of this situation would be closure of surface impoundments where stabilization of the sludge must take place before cover and vegetation can be placed.

The final date of completed closure is the date, after all activities have taken place, upon which separate certification can be made by an independent registered professional engineer and by the owner that closure has taken place in accordance with the closure plans, and is complete.

There are facility-specific requirements outlined in the Federal regulations and these are further addressed in guidance documents prepared by the U.S. EPA. These documents explain the facility-specific requirements and suggest methods for meeting them. They also provide outlines for the development of closure plans to meet the general and facility-specific requirements.

Post Closure Care

While closure requirements impact all hazardous waste management facilities, post closure care requirements impact those only where the wastes remain after closure, i.e., hazardous waste disposal facilities which include landfills, land application facilities and seepage facilities. Post closure is the period after closure during which owners, or operators of disposal facilities, must conduct certain monitoring and maintenance activities.

Post closure care consists of, at least, groundwater monitoring and reporting in accordance with the regulations and maintenance of monitoring and waste containment systems. In addition, facility security provisions may be required to remain operable during the post closure care period or a portion thereof. The circumstances, during which security would be required, is where an opportunity exists for the accidental encroachment on the facility by people, or animals which could result in adverse health or environmental impacts.

The post closure care period begins upon the certification by an independent registered professional engineer that closure has been completed. No agency action is required to initiate the post closure care period. As with the closure requirements, the post closure care plan must be submitted 180 days before closure is anticipated to begin.

Post closure owner responsibility extends for a period of 30 years. Activities must be structured over this 30-year period to assure there are no adverse impacts resulting from the site on human health and the environment. There is a provision allowing application to the appropriate regulatory agency for a shortening of the 30-year timeframe. Criteria have been established to evaluate if foreshortening the post closure care period would still continue to provide for no adverse human health, or environmental impacts.

One of the methods EPA has used to attempt to assure the facility will be safe after post closure owner responsibility has terminated, is land use controls consisting of a notice to the local land authority, generally a zoning board. This notice must include a survey plan with the dimensions of the landfill cells or other disposal facility specifications with respect to permanent benchmarks; it must be submitted within 90 days after closure is complete. This survey plan must be developed by a registered land surveyor and must include the type, location and quantity of hazardous waste disposed of in the facility. In addition, the owner must record a notation on the deed for the property that will notify any potential purchaser of the past use and current and future use restrictions for the facility as a result of the activities that have taken place at the facility. The regulations require post closure use of the facility cannot disturb the integrity of the final cover, liners or other components of the containment system.

As with the closure, the post closure plan is the cornerstone of the post closure requirements. Its basic purpose is to assure the owner has considered the actions and the associated costs, to provide for post closure care.

Some of the plan development requirements are the same as for post closure plans: the how and why must be specified, the activities and frequencies to assure appropriate post closure care must be identified, a schedule must be developed, and cost estimates must be provided. Plan revisions are allowed and, in fact, needed where the schedule activities, or cost estimates change.

The plan describes the basic activities that must take place during post closure care. These include monitoring and maintenance activities. Monitoring of groundwater is the primary monitoring requirement. Continuation of the groundwater monitoring system utilized during the active life of the facility must be continued, sometimes at a less frequent rate. In addition, inspection and maintenance activities must be conducted to assure the integrity of the facility. Specifically, the following activities must be included in the inspections and maintained if the need arises:

•Run-off control structures
•Settlement (through maintenance and use of benchmarks)
•Erosion damage
•Gas control facilities
•Leachate management facilities
•Groundwater monitoring system

After the activities and schedules have been established, cost estimates must be prepared to implement the plan. Ground rules for cost estimates are briefly addressed in the section on Financial Aspects.

FINANCIAL ASPECTS

Four topics are discussed below under the financial aspects of closure and post closure care. These include:
•the basic rules for estimating the costs of the activities necessary to implement the closure and post closure plans;
•the financial mechanisms that can be utilized to meet the financial responsibility requirements;
•the timing for implementation of this RCRA requirement and,
•the current regulatory situation regarding the provision of financial assurance to the regulatory agencies.

In developing estimates to implement the actions outlined in closure and post closure plans, four different techniques can be used:
•The experience of the owner or operator
•Contractor estimates of the actions
•Cost estimating handbooks
•Work-ups from labor, materials and equipment requirements.

Experience to date has shown owner/operator experience generally provides the least costly of the different techniques.

As indicated above, the estimates to implement the plans are made in current year dollars and must be updated to account for inflation. These updates must be annual and for this purpose a standard tool to gage inflation over the past year has been selected by the U.S. EPA. This is the "Implicit Price Deflator for Gross National Product" which is developed by the Bureau of Economic Analysis in the U.S. Department of Commerce. This document is published monthly, and is available from the Bureau of Economic Analysis. Further, since it is a regulatory requirement, U.S. EPA regional personnel should have ready access to this information.

The actual index is developed in a ratio manner by dividing the deflator for year "X" by the deflator for year "X-1". This ratio is then multiplied by the estimate to result in a revised total dollar figure needed for the accomplishment of the closure and the post closure requirements. The financial assurance mechanism must then be modified to assure that adequate funds are available to implement the closure and post closure plans.

Basic Cost Estimation Rules

Basic rules for estimating closure costs are outlined below:
•Costs must be based on the activities described in the closure plan
•The estimate must be made when the closure costs are most expensive, i.e., when the maximum extent of operations is the greatest and there is the largest anticipated on-site inventory of waste materials
•Costs can be based on the owner or operator conducting the closure activities which allows the owner/operator to take advantage of the depreciated value of equipment used in closing a facility
•All pertinent costs must be identified and included in the cost estimate
•Costs are estimated in the year of preparation and inflation factors are considered on an annual basis using the index described above.

The ground rules for estimating costs for post closure activities are only slightly different from those in the closure sequence. The largest single difference is the cost must be based on contracting for the provision of services needed to implement and carry out the closure plan. Other ground rules include:
•Cost must be based on the activities described in the post closure plan
•Cost must reflect the care for the total area of hazardous waste containment
•Cost must be complete and include all the pertinent costs
•Cost estimate must cover the entire 30 year time period required for post closure owner responsibility.

Financial Mechanisms

As required by the hazardous waste regulations, owners or operators of hazardous waste management facilities, must establish financial assurance for closure and, where necessary, post closure to assure the plans can be implemented at any point in time and the funding needed for the plan implementation will be available. The following options are available for providing financial assurance for closure and post closure care:
•Trust fund
•Surety bond guaranteeing performance
•Stand-by letter of credit assuring funds
•Combination of the above.

These methods are outlined specifically in the *Federal Register*, January 12, 1981.[5] States' requirements may vary from the Federal requirements, but they must be at least as stringent as the Federal requirements in providing financial assurances. Examples of the mechanisms are also provided in the January 12, 1981, *Federal Register*.

TIMING OF REGULATIONS

The regulations were scheduled to be effective on July 13, 1981. However, because of concerns raised regarding the limited range of mechanisms promulgated by U.S. EPA in January, the U.S. EPA has extended the comment period and, subsequently, extended the effective date until October 13, 1981.

Basic concerns regarding the mechanisms promulgated in January, centered around the lack of a self-insurance mechanism and a financial test mechanism to meet the financial assurance, and liability requirements as required by the law. The concerns expressed by the industrial community were very specific. The U.S. EPA has indicated it is looking into, and most likely will develop, mechanisms for self-insurance and for a financial test so that a firm can provide for self-insurance to meet the financial assurance, and liability requirements. EPA agreed there was no point in initiating and acquiring much more costly mechanisms outside a firm if, in fact, the ability to insure oneself was going to be promulgated at some point in the

future. There are other concerns regarding the need for separation of, or duplicate closure and post closure mechanisms, as well as the ability for a corporate entity to provide financial assurances for multiple sites using one "umbrella" mechanism.

One of the basic underlying concerns regarding the mechanism selected and utilized under this program, revolves around tax considerations. If EPA allows insurance to guarantee closure and post-closure funds, then the funds set aside through insurance premiums would be tax deductible as business expense. However, if these funds were placed in a trust, there would be tax liability to this money. The regulated community sees this as being an undesirable situation since they would be taxed for money they could not utilize in their day-to-day business.

U.S. EPA anticipates the issue will be resolved in a fashion so the revised regulations can be published before the October 13, 1981 deadline.

CONCLUSION

The depth and breadth of events that must take place in this one sub-rpogram of the hazardous waste program illustrates the complexity of the entire program. Hence, great care must be taken in analyzing and meeting the requirements specified by the State and Federal programs.

The basic purpose of the Federal requirements for hazardous waste sites is to show that the owner or operator has adequately considered, and planned for the closure and post closure technical and financial requirements. The technical requirements are needed for both the interim status standards, as well as for obtaining a RCRA permit. The financial assurance requirements are also needed for both interim status and RCRA permits; however, the implementation has been delayed until at least October 13, 1981.

The importance of careful cost estimates for closure and post closure care cannot be over-stressed. These requirements can have a direct financial impact on a firm and, therefore, must be analyzed in conjunction with the closure and post closure plans to minimize exposure.

As specific as these rules appear to be, because each facility is unique, there is a capability for innovative, and creative rule interpretation to allow for minimization of exposure under these regulations. Such decisions may often mean the expenditure of capital costs as opposed to long term operation and maintenance costs. Cost analysis should be readily employed to assure the most cost effective long term solution for closure and post closure.

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PRACTICAL CONSIDERATIONS FOR THE PROTECTION OF PERSONNEL DURING THE GATHERING, TRANSPORTATION, STORAGE AND ANALYSIS OF SAMPLES FROM HAZARDOUS WASTE SITES

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INTRODUCTION

Uncontrolled hazardous waste sites can present a spectrum of potential health, safety and environmental hazards. Detailed information regarding each site is necessary before comprehensive plans can be developed and safely implemented to mitigate hazards presented by the uncontrolled waste. Acquisition of detailed site specific information can involve serious potential risks.

In this paper, the authors present practical suggestions for the protection of investigators in exploring, sampling and evaluating uncontrolled hazardous waste sites. Also considered are factors related to protection of the public. First a generic approach to hazard control planning is presented. This is followed by discussion of a composite case study based on real experiences in several waste exploration and analogous hazard situations.

GENERIC APPROACH TO HAZARD CONTROL PLANNING

Occupational exposures to hazards associated with waste site exploration and evaluation can be controlled or avoided. Success in prevention of adverse exposures depends on detailed planning, training and execution following principles of industrial hygiene, safety and occupational medicine. The discussion which follows presents a logical sequence of assessment and planning activities which has been developed and applied in actual waste site projects.

Preliminary Hazard Assessment

The first step in assessing potential hazards at a waste site is to collect and evaluate all known and available information regarding the site. Each site presents a unique matrix of risks. Among the important variables which define relative risk are: (1) materials deposited at the site, (2) type and integrity of hazardous material containers, (3) hydrogeological and topographical features of the site and (4) the period during which deposits were made at the site. To help assure that all useful information is acquired, a list of informational categories (Table I) with some specific examples has been developed. In practice, Table I can be used as a basic checklist during documentation, search and site visit activities.

The second step in preliminary hazard assessment is the identification of information which has relevance to the specific site but is uncertain or unavailable. The items in Table I can also be useful to this analysis. The objective here is to identify all potential hazards or gaps in known information which could reasonably affect safety in activities to be conducted on or off the site. Caution must be observed to prevent undue biasing of this analysis by facts which are known about the site. For example, at some sites a great amount of descriptive information may be available. The importance of missing information may be difficult to appreciate.

To avoid overly conservative assessment of potential hazards, a third closely related effort should accompany step two. This effort should try to logically eliminate potential hazards or data gaps from serious consideration when there is good reason to believe they have no im-

Table I.
Important Features of Uncontrolled Hazardous Waste Sites

Waste Parameters	Site Characteristics
Sources/volume/form	Topography
History of waste deposits	Geology
Dates	Hydrology
Sources of waste	Climatology
Type and quantity of waste	Wildlife (reptile, animal, insect)
Sources of additional information	Ground cover
Containment/confinement of waste	History of sampling/exploration
Waste containers	Accessibility
Types, age, condition	Security
Designed confinements	Adjacent tenants
Pits, lagoons, cells, trenches, cover	
Uncontrolled practices	
Open dumping	**Related Considerations**
Open burning	Nearby population centers
Flooding/evaporation/percolation	Hospital facilities
Hazardous properties	Ambulance service
Physical and chemical properties	Fire district
Flammability, corrosivity, reactivity	Utilities available/proximity
Potential toxicity	Industrial equipment rental
Acute, chronic	Law enforcement

portance. For example, a site may be known to contain only hazardous wastes from building demolition (e.g. asbestos) and junk transformers (e.g. PCB's). In this case, organophosphate pesticides could be eliminated from consideration since there is no logical evidence that they would be present at the site. Similarly, serious consideration of buried drums of flammable solvent and other unlikely hazards could be rejected.

The fourth step in the preliminary hazard assessment is to obtain descriptions of the site exploration, waste sampling and other activities which are proposed. A list of several types of activities which may be required in exploring and evaluating a waste site prior to development of remedial action plans is given in Table II. The initial focus of this effort should be the equipment and procedures to be employed on site. Next, this analysis should consider offsite activities which will be required to support the proposed project. Transportation of waste samples to a laboratory and their analysis are examples. It is important that anticipated procedures be described together with the rationale for their selection.

Table II.
Site Reconnaissance, Exploration, Sampling and Evaluation Activities

Surveying
- Plat, elevations, grid
- Water table elevation
- Metal detection
- Surface probing
- Marking, staking, flagging

Access
- Timber and brush removal
- Surface grading
- Road construction
- Water pumping/diversion

Security
- Fencing, barricades, signing
- Offshift site and equipment protection

Sampling/Exploration
- Core/well drilling
- Excavation/trenching
- Drum/container sampling
- Gathering of soil, waste, water, air, vegetation, biological samples
- Disposal of excess sample material, washings, etc.

Sampling Handling/Analysis
- Identification and logging
- Packaging
- Storage
- Aliquoting
- Extraction
- Filtration
- Chemical analysis
- Waste disposal

Inspection/Maintenance
- Personal protective items
- Support system (compressors, generators)
- Hygiene facilities
- Exploration equipment

Shipping/Receiving
- Labelling, packaging and shipment per DOT regulations
- Items handled
  - Equipment
  - Supplies
  - Samples
  - Clothing
  - Wastes

The fifth step in the preliminary hazard assessment is the simultaneous consideration of potential hazards and the activities proposed to be conducted on and off site. The purpose of this exercise will be to identify situations where hazardous exposures of research personnel, subcontractors or the public may occur. The interface between each activity and each known or accepted potential hazard must be considered. Prediction of both "probable" and "worst case" exposures is very important to this analysis. Examples of several "worst case" incidents which could occur both on and off the site are presented in Table III.

An attempt should be made to describe the logical consequences of uncontrolled exposure incidents. Could a fire or explosion occur? Could personnel be exposed to high airborne concentrations of toxic contaminants? Could personnel be splashed with toxic or corrosive materials? These are examples of questions which require probable and worst case answers. Thoughtful organization of data from this step in the analysis can help to highlight important areas of uncertainty and high hazard situations.

Exposure Control Program Development

Having identified probable and worst case exposures which may occur in work on or off the site, plans can be formulated for protection of personnel. Experience has indicated that a broad range of protective measures may be applicable to different sites or to distinct activities planned for a single site. For each waste site scenario, the objective is to provide a program of protection which offers a reasonable margin of safety to exposed employees.

Table III.
Examples of Worst Case Incidents

Fire and/or explosion of flammable or combustible solvents or pesticide mixtures
Explosion of waste containers containing shock, pressure or heat sensitive materials
Penetration or rupture of compressed gas cylinders (buried or at the surface) containing toxic materials
Penetration of protective gear by toxic liquids, gases or vapors
Penetration of protective gear by equipment movement, flying debris, or contact with sharp objects
Interruption or contamination of supplied breathing air
Excavation and surface cave-ins
Equipment rollovers
In transit leaking or rupture of sample containers
Rupture or leakage of sample containers while in storage
Violent reaction of waste samples with analytical reagents
Medical emergency in hazardous area (e.g. heart attack)

In waste site work as in other occupational settings, feasible engineering, administrative and work practice exposure controls should be applied to reduce reliance on personal protective clothing and equipment. Contrary to the opinions of some, the self contained "moonsuit" approach to employee protection should not always be necessary to provide a reasonable margin of safety.

Job hazard analysis is a useful approach to identifying potential exposures and required controls. Where serious potential hazards are indicated, careful review of the factors which dictate the need for maximum protection should be made. In some cases, extreme caution may be dictated by the absence of information which could be safely acquired with reasonable cost and effort.

In other situations, incompatibilities may arise from inappropriate combinations of equipment, procedures and hazards. Substitution of alternate methods (e.g. a change in drilling equipment and procedure) or limiting the use of a method (e.g. no drilling at coordinates where metal detectors indicate the possible presence of buried drums and cylinders) may reduce or eliminate these incompatibilities. In some situations, freedom to substitute techniques may be limited by legal or contractual constraints. However, where improved safety may result, the impact of

Table IV.
Sample Schedule of Personal Protective Items by Work Activity

Work Activity	Safety spectacles with side shields	Safety belt and life line	Knee-high, safetytoe, impervious boots	Impervious work pants	Impervious work blouse	Midlength impervious work gloves	Half-facepiece, air-purifying respirator	Air supplied safety helmet/hood	Self contained breathing apparatus
1. Initial survey of site	X	*	X			X	X		
2. Metal detection survey	X	*	X			X	X		
3. Site clearing and preparation	X		X	*	*	X	X	*	*
4. Core drilling and core handling			X	X	X	X		X	X
5. Mound exploration			X	X	X	X		X	*
6. Final survey of site	X		X	*	*	X	X	*	
7. Rescue, repositioning of support systems		*	X	X	X	X			X

*Clothing or equipment which may be required based on site conditions.

these constraints should be discussed with the sponsoring group so that reasonable compromises can be achieved.

When personal protective clothing and equipment are necessary to supplement other exposure controls, they should be selected in a logical, objective manner. Decision logics to select respiratory protection devices are available from the National Institute for Occupational Safety and Health (NIOSH), the American National Standards Institute (ANSI), respirator equipment manufacturers and others. Similar decision logics are becoming generally available for other forms of protective clothing and equipment (e.g. gloves, boots, body coverings). Suggestions for protective clothing and equipment ensembles usage in common waste site work are given in Table IV.

Whenever heavy reliance is placed on protective clothing and equipment, it must be remembered that no protective system is one hundred percent effective. A number of probing questions must be answered. Will the scheme of protection afford adequate safety in the event of probable and worst case circumstances? Is the information being sought worth the risk? How will erosion of the planned safety margin be detected?

In addition to selection and use of protective clothing and equipment, a variety of support activities and facilities are necessary to complete the hazard abatement plan. Categories of support items which may be required at specific sites are given in Table V. Fortunately, many field applicable emergency abatement and personal hygiene support items are now commercially available. Examples would be portable chemical toilets and hand washing stations and portable eye-wash fountains. These and other items can be relied on for control of routine work hazards and minor emergencies.

Hazard control planning should also include provisions for major accidents. Emergency plans should address serious injuries, fires, explosions, spills, releases and other adverse events. A list of several elements which should be included in emergency planning is given in Table VI.

Control Plan Implementation

Implementation of hazard control plans should involve a variety of training and rehearsal sessions. Additionally, physical examinations, clinical tests and other procedures may be required. A list of pertinent training and examination items is found in Table VII.

On-site, full-time safety and health supervision is highly recommended where significant potencial hazards exist. No hazardous work should commence until all hazard control systems and facilities are set up and checked out.

Table V.
Site Exploration Support Facilities Equipment and Services

Facilities
- Chemical toilets
- Handwashing station
- Protective clothing and equipment storage
- First aid station
- Lunch tables/benches
- Temporary office
- Lockers
- Water coolers

Equipment
- Emergency shower(s)
- Eye-wash fountain(s)
- Communications equipment
  - Telephone
  - Public address system
  - Siren/horn
  - CB radio
  - Voice actuated tape recorder and radio communication
  - Fire alarm
- SCBA units
- Stretcher
- Electrical generator
- Air compressor
- Clothes washer
- Clothes dryer
- Meteorological station
- Water pumps
- Fire extinguisher(s)

Emergency Services
- Fire department
- Ambulance
- Medical care
- Law enforcement

Utilities
- Electricity
- Potable water
- Telephone
- Sanitary sewer

Site Security
- Fences/gates
- Lighting
- Guard station
- Security officers
- Intruder alarm

Other
- Freight pickup/delivery
- Industrial equipment rental
- Fuel delivery

Each site exploration procedure should be tested in a no hazard area with the scheduled hazard control measures in effect. Any problems encountered should be satisfactorily resolved before work is performed on the waste site. Work on the site should proceed from areas of relatively low hazard to areas of greater hazard.

COMPOSITE CASE STUDY

This section describes practical lessons which have been learned in waste site and other projects involving analogous work situations. The information gained from several projects has been combined to form a composite case study so that a broad range of experience can be discussed as well as protecting provileged information regarding specific waste sites.

Site Description

The hypothetical waste site to be evaluated is located approximately ten miles outside a small industrial center in the western United States. The total site encompasses 320 acres of basically level land. A marsh extends from within the site to the east. A drainage ditch defines the northern boundary of the property. Vegetation at the site consists of grasses, reeds, bushes to 4 ft and trees to 40 ft high and 0.5 ft in diameter.

Waste disposal at the site began in the 1930s. Industrial development accompanying World War II increased use of the site during the 1940s. During the period 1940 to 1975, the local municipality and several nearby industries intermittently used the site. One local company provided records of waste which they deposited there. Other companies used the site at various times; some of these are no longer in business.

Table VI.
Elements of Emergency Plan

Anticipated emergencies
- Weather extremes
- Fire and explosion
- Work accidents
- Medical emergencies
- Civil disobedience/unauthorized entry to site

Established procedures/ responsibilities
- Communications
  - Weather service
  - Fire department
  - Hospital/industrial clinic/ physician
  - Ambulance service
  - Law enforcement authority
- Rescue/extrication of injured or ill
  - Supervisor and employee action
  - Outside support
- Fire suppression/control
  - Supervisor and employee action
  - Outside support
- Medical care
  - First aid
  - Outside medical support
- Site evacuation
- Site security
- Evacuation of adjacent properties

Table VII.
Examinations, Training and Rehearsals

Examinations/Histories
- Hearing
- Vision
- Pulmonary function
- Medical history
- Employment history
- Physical examination
- Clinical tests

Training/Rehearsals
- Emergency and routine communications
- First aid (CPR, EMT)
- Respiratory protection use, limitations, inspection, maintenance
- Emergency equipment (deluge shower, eye-wash)
- Rescue of ill or injured
- Site evacuation
- Use, limitations and care of protective clothing and equipment
- Site surveying, sampling and exploration procedures
- Sample identification, packaging, storage, shipment
- Laboratory procedures
- Disposal of hazardous materials
- Fire fighting

Physical evidence indicates that wastes have been deposited in scattered locations on approximately 100 acres. Waste has been buried on dry ground and submerged in the marsh to depths of 15 ft. Liquid wastes have been discharged into pits for evaporation, burning and/or percolation. Drummed waste litters an 0.5 acre area. It is suspected that similar waste has been piled on the site and covered with earth to form mounds.

Work Assignment

The site will be evaluated in phases. Results of each phase will be considered in planning successive phases. Phase I work, discussed here, involved the following tasks and information:

(1) Location of all waste disposal areas
(2) Core drilling of dry land waste disposal areas and adjacent ground using a 50 ft grid pattern

(3) Core sample analysis by RCRA procedures
(4) Sampling and analysis of groundwater and marsh water
(5) Excavation of waste mounds with photographs and description of their contents
(6) The small area where drummed waste resides on the ground surface is to be roped off and left undisturbed.

Project Chronology

The following major activities were performed:
(1) An interdisciplinary project team was assigned and project organization established
(2) Available information was reviewed and a list of desired information prepared
(3) A preliminary reconnaissance visit to the site was conducted including discussions with several waste generators
(4) A comprehensive plan to perform the work assignment was prepared including an integrated health and safety plan
(5) Required equipment, clothing, etc. were assembled, fitted and tested
(6) Project employees were examined, trained and rehearsed in planned activities
(7) A project base was established at the site
(8) Planned activities and safety procedures were rehearsed with all project personnel including subcontractors in clean areas at the site
(9) Preliminary and indepth site work was performed
(10) Core and water samples were shipped to the laboratory
(11) Laboratory analyses were performed
(12) A technical report was prepared.

In the remaining sections of this paper, highlights of safety and health activities are presented.

Site Reconnaissance

The site was observed and photographed from undisturbed areas surrounding the waste site and from well established roads through the waste disposal area. Reconnaissance personnel wore impervious boots and gloves, eye protection, safety helmets, and half-facepiece air-purifying respirators while in or near waste disposal areas. No samples of waste or water were gathered or any waste disturbed. Detector tubes were used to indicate the possible presence of classes of vapors and gases.

Project Work and Hazard Control Planning

Project team members including safety and health personnel worked together to identify potential hazards, formulate plans for conducting required work, and integrating safety and health considerations into all phases. Key elements of the comprehensive safety and health plan were:
(1) Job hazard analysis for all project activities with identification of activity specific control measures
(2) Consideration of routine and worst case exposure possibilities and formulation of procedures for normal work and emergency action
(3) Specification of field and laboratory support services and equipment, facilities and safety supervision
(4) Purchasing, assembly and testing of all protective systems before traveling to the site
(5) Medical examination and training of in-house and contractor personnel prior to waste site work
(6) Establishment of a base facility at the site complete with safety, hygiene and emergency systems prior to initiating site work
(7) Full-time safety and health supervision of all work
(8) Rehearsal of all site exploration and sampling work in clean areas before entering contaminated areas
(9) Rehearsal of all sample gathering, packaging, storing, aliquoting, analysis and waste disposal procedures prior to handling real samples
(10) Rehearsal of emergency actions
(11) Post medical examination and debriefing of all project personnel

Description of Base Facility

A base facility was established on an access road upwind and equidistant to most areas of waste exploration work. The facility included a trailer-mounted emergency shower, hygiene facilities, stores of protective clothing and equipment, rescue equipment, first aid supplies, portable power generators and communications equipment. Lunch tables, chemical toilet, equipment cleanup, inspection and repair facilities were also provided. Direct communication lines and message relay systems were established with the local hospital, fire department, ambulance service and private emergency assistance group. The base facility was manned by an experienced safety and health professional. This person had authority to stop work at any time if unacceptable risks or failures arose.

Preliminary Survey of Site

Prior to sampling, core drilling and excavation of the site, a preliminary survey and mapping was performed by employees working in pairs wearing impervious suits, gloves, boots, safety helmets, eye protection and air-purifying respirator. Metal detectors were used to locate buried metal (possible waste drums). A narrow metal rod was used to probe for "drum graves" or other areas of weak surface support. Later, no core drilling would be performed where metal was detected or infirm ground was discovered. These precautions helped to reduce the potential for penetrating a waste drum with the core drill and also potential upsets of the drilling equipment.

Core Drilling and Mound Exploration

An independent drilling contractor was engaged to core drill the site. A two-man team was thoroughly trained in all sampling and safety procedures. A geologist sampled, described and packaged core segments. During the advance into the site, drilling and retreat from the site these men wore impervious boots, gloves and air-supplied helmet with vortex tube cooler. Air-supplied helmets were selected after consideration of probable and worst case core drilling incidents. This analysis indicated only a re-

mote chance for exposure to contaminant concentrations near an IDLH (immediately dangerous to life and health).

Compressed air was supplied from a gasoline fueled, rotary air compressor with 100 ft^3/min capacity at 100 psig. The compressor was fitted with a high temperature shutdown device. Inlet air was drawn from an elevated air intake. Compressed air was regularly checked for compliance with Class D breathing air requirements and continually filtered for removal of particulates and organics. Condensate was removed at the compressor and at multiple drip legs in the pressure hose system. An air hose, 1 in. in diameter connected the compressor to two dual outlet pressure/flow regulation and filtration units. Each helmet was supplied with 100 to 200 ft of air hose (3/8 in. diameter).

A microphone attached to a portable recorder was installed inside the geologists helmet so that descriptions of core samples could be tape recorded. This microphone was also connected to a two way radio. The on-site safety supervisor maintained the air compressor, tested air quality, maintained radio contact with the geologist and directed advance and retreat activities. He also supervised disrobing and hygiene practices. Air-supplied helmets and support equipment were thoroughly inspected, cleaned and repaired as necessary each day.

The safety supervisor remained in sight of and in radio contact with core drilling. Air horns were available for signalling and alarm. The base camp was equipped with a self-contained breathing apparatus (SCBA) which could be used for rescue after calling for and confirming that outside help was on the way. Back up SCBA rescue assistance could be on-site in less than 15 min.

Mound exploration was performed using the same ensemble of protective clothing and equipment. A backhoe was used to open selected mounds from the upwind side. Photographs were taken, descriptions recorded and overburden replaced.

Groundwater and Marsh Water Sampling

After all core drilling was complete and slotted screen casings installed, water samples were obtained from core holes. Depth to water measurements were also made and later combined with survey information to describe the water table on the site. During water sampling from core holes the same protective ensemble used in preliminary survey of the site was employed.

Marsh water samples were gathered by wading into the marsh at the periphery of the waste deposit. Chest waders, impervious gloves, goggles and half-facepiece air-purifying respirator were used. A safety harness and attended lifeline were also worn.

Sample Handling, Transportation, Storage, Analysis and Disposal

The waste and water sampling and analysis program was planned, critiqued and rehearsed before any samples were collected. Provisions for documented chain of custody were built into the system. Laboratory space for sample storage and analysis was dedicated prior to site work.

Selected segments of core samples were deposited in numbered, one quart, glass jars with threaded, Teflon® - lined closures. Similar jars were used for water samples. After closure, jars were cleaned of surface contamination and additional identification attached. Soil and waste samples were stored in a freezer on site. Water samples were refrigerated.

Sample jars were placed in protective plastic mesh and packed in ice chests filled with vermiculite and "Blue Ice." Chests were sealed and marked in compliance with Department of Transportation regulations. Samples were conveyed to the laboratory by Federal Express or as truck cargo with returning team members.

At the laboratory, technicians wearing gloves, apron, goggles and half-facepiece air-purifying respirators unloaded sample chests into freezers and refrigerators. This ensemble of protection was worn during all work with the samples in designated, restricted access laboratories. Later individual samples were removed to a fume hood, opened, an aliquot withdrawn for analysis and the remainder returned to storage. All extractions, filtrations, etc. were performed in laboratory fume hoods. Diluted wastes were deposited in 55-gal drums and disposed as hazardous waste.

CONCLUSIONS

Each waste site project has unique requirements for personal protection. The basic approach to hazard control planning presented here should have wide application. As experience is gained in this area, more comprehensive checklists and decision logics can be developed to facilitate hazard control planning.

The need to train personnel, rehearse proposed work and critique work practices and protective systems cannot be overemphasized. Well trained personnel appreciate potential hazards and the limitations of protective systems. They will endeavor to minimize exposure and challenge to their protective equipment.

Field and laboratory supervision by qualified safety and health professionals is vitally important. Both work situations demand full understanding of potential hazards and protective options. Proper inspection and maintenance of protective systems can only be assured by qualified persons. Conditions at any site are subject to change. Methods to quantify changes in potential hazard are limited. Persons who recognize the potential impact of changing conditions and are willing to halt work until proper accommodations can be made are indispensable.

Exploration of uncontrolled hazardous waste sites is essential to development of remedial action plans. It can be done safely with proper information, planning and execution. Each waste site experience can contribute to improved methods if properly evaluated at its conclusion.

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INTRODUCTION

EPA and contractor personnel at hazardous substance cleanup operations face the risk of direct chemical exposure or exposure to chemical-caused hazards such as fire, explosion or oxygen depletion. Many of the perils of entry, assessment and cleanup of hazardous waste sites have been recognized and addressed by numerous authors, but a number of important safety topics have yet to be adequately covered.

This paper describes a project that: (1) identifies specific hazardous substance cleanup tasks that require improved safety guidance and (2) provides monographs containing the best available safety guidance for selected topics. Two of the safety monographs produced as a result of the project are summarized. The monographs are: (1) air quality monitors and (2) medical surveillance for hazardous materials cleanup personnel.

IDENTIFICATION OF SAFETY TOPICS

The purpose of this project was to identify significant safety topics related to hazardous materials cleanup that had not been satisfactorily addressed by previous investigators or adequately covered in current or draft EPA manuals. The topics identified were then reviewed and, with the EPA Project Officer's concurrence, the most worthy were researched and written up in the form of monographs. The approach employed consisted of (1) conducting an exhaustive survey of safety literature, (2) evaluating EPA current or draft safety documents and (3) soliciting comments from field personnel on potential safety topics.

Safety Literature Survey

An extensive literature survey was conducted on safety procedures, techniques and equipment used in the control and/or cleanup of hazardous materials. In addition to examining pertinent books, report, manuals and other printed materials, there were numerous personal communications. Staff members of government agencies, trade organizations, professional associations and private companies, who are knowledgeable in the area of controlling hazardous materials or cleaning up uncontrolled hazardous waste sites, were contacted.

EPA Safety Documents Review

Thirteen EPA draft and published safety guidance reports were reviewed to develop a preliminary list of safety topics that required additional attention (Table I). A comparison matrix was prepared for the documents as part of the reviewing process and a summary report was written. Three of the manuals are clearly more complete than the others:

(1) Personnel Protection and Safety Training Manual, EPA Course No. 165.2 (A8)
(2) Hazardous Materials Incident Response Operations Training Manual, EPA Course No. 165.5 (A9)
(3) Hazardous Waste Site Investigation Training Manual, (A10).

These manuals are collections of a number of monographs, reports, sections of other manuals and ANSI, OSHA/NIOSH, CFR documents as well as commercial catalogs that were assembled for EPA training courses. In fact, several EPA documents (or sections thereof) cited in Table I can be found in Manuals A8, A9 and A10.

In addition to having produced the safety documents cited in Table I, the EPA is involved in other efforts to establish sound safety procedures for use during hazardous waste site investigations and hazardous substance cleanup activities. The EPA signed a Memorandum of Understanding (MOU) in December 1980 with the USCG, OSHA and NIOSH. The MOU objectives include development of a comprehensive guidance manual that will establish procedures to protect workers involved in investigating and cleaning up hazardous waste sites and responding to emergencies involving hazardous substances.

Another EPA effort that will provide safety information and guidance for worker health involves the preparation of 29 monographs on "Technical Methods for Investigating Sites Containing Hazardous Substances." This work is being sponsored by the EPA's Discovery and Investigations Branch, Hazardous Sites Control Division.

Final Selection of Safety Monograph Topics

From the review of the cited EPA safety manuals/memoranda and other available safety literature, a preliminary list was assembled of safety topics to be emphasized in the study. The topics were:

- Air quality monitors

Table I.
Summary of Draft EPA Manuals/Procedures Relevant to Safety Procedures in Hazardous Materials Cleanup

	Document Title	Prepared by	Status
A1.	Agency-wide Policy Order 1440.1 Respiratory Protection	Office of Occupational Health and Safety (OOHS)	Sent out for review by EPA subunits, 10/80
A2.	EPA Occupational Health & Safety (OHS) Manual, Chapters 1-7	AA for Planning & Management, OOHS	Issued to EPA employees on September 12, 1977
A3.	EPA OHS Manual, Chapter 8, Laboratory Use of Toxic Substances	OOHS	Sent out for review by EPA subunits, 9/80
A4.	EPA OHS Manual, Chapter 9, Hazardous Waste Site Investigations and Emergency Spill Responses	OOHS	Sent out for review by EPA subunits, 9/80
A5.	EPA Safety Manual for Hazardous Waste Site Investigations--Draft, 1979	OOHS and National Enforcement and Investigation Center (NEIC)	Draft, 1979
A6.	Oil & Special Materials Control Division's Draft Interim Safety Procedures	Environmental Response Team at the request of the Superfund Implementation Task Group	Circulated to various EPA subunits for comment on January 2, 1981
A7.	Field Health and Safety Manual	U.S. EPA Region IV	Published October 1980
A8.	Personnel Protection and Safety Training Manual for EPA Course No. 165.2	U.S. EPA, Hazardous Response Support Division and the National Training and Operational Technology Center	In use on recurring basis for training course
A9.	Hazardous Materials Incident Response Operations Training Manual, EPA Course No. 165.5	U.S. Environmental Protection Agency, Hazardous Response Support Division and the U.S. Coast Guard	In use on recurring basis for training course
A10.	Hazardous Waste Site Investigation Training Manual	Field Investigation Team (FIT) National Project Management Office, Ecology and Environment, Inc. under EPA Contract No. 68-01-6056	Has been used in training courses
A11.	Hazardous Waste Site Safety Procedures	Richard D. Spear, Chief Surveillance & Monitoring Branch, Region II, U.S. EPA	Memo of 5/21/80 that outlines Interim HWS Safety Procedures
A12.	Memo on Update of OOHS/ERT Activities	Robert C. Magor, Ph.D., Director, Office of Occupational Health & Safety (PM-273)	This memo indicates level of sophistication that has been achieved in OOHS evaluation of protective equipment (5/10/79)
A13.	Environmental Protection Agency FY-1980-81, Medical Monitoring Program Guidelines	OOHS	Appended to A10

- Medical surveillance
- Criteria for selection of protective clothing
- Personnel and equipment decontamination
- Index of operational and procedural manuals (to simplify location of appropriate safety information)
- Criteria for delineating the "hot line", and
- Odor detection for respirator canister failure (detection of an odor typically signals either a leaking facepiece or failure of the adsorbent canister.)

Based on the results of the survey of EPA and other safety literature, it was determined that a monograph on air quality monitors should be produced and work was initiated. Due to time and budget constraints, some topics could not be addressed in monographs. To prioritize the remaining topics, comments were solicited from a selection of EPA Regional personnel and private contractors with hazardous material handling and/or clean up experience and responsibilities. A synoptic matrix of their comments and suggestions relative to the proposed monograph topics appears in Table II. Two of the six suggested topics—the index of operational and procedural manuals, and medical surveillance—received a consensus endorsement. Personnel and response equipment decontamination received somewhat less support. The remain-

Table II.
Responses to Suggested Safety Topics

Topic	Synoptic Comments by Interviewee A	B	C	D	E	F	G	Consensus
1	Has reservations about training people to use odor detection as method. Desensitization is a problem. Avoids problem by using fit test and fresh canisters.	May be too dangerous; not too excited about this idea.	No need for study of odor detection; foolish to train people.	Would like to see a cross-reference chart or index for respirators and canisters. Not excited about odor detection.	Foolish and impractical. Some odors deaden the senses. Too subjective a test.	Subjective; many different odors, many similar odors exist. Sensitization is a factor. Some chemicals do have characteristic odors; perhaps pilot study called for.	Not enthusiastic about this idea.	Negative
2	Hot line varies with wind, concentration and containment. NFPA guidelines are sufficient. Use of programmable calculator might be nice.	Every spill is different so zones will vary. Also approaches by government and private companies vary. Not too excited about idea.	Coast Guard HACS program can be used to provide distances for hot line and evacuation within half hour of input. This topic is, therefore, redudant.	Prefers to use air monitoring devices although dispersion modeling can be used for spills.	Has an SOP that uses operational parameters to pragmatically delineate hot line; not enthusiastic about computer program.	Hot line is arbitrary in field; no visible contamination oftentimes. Safety manual for hazardous waste site investigation is used by teams. Not enthusiastic.	Determination of perimeter should be provided.	Mixed
3	Full range of clothing is currently employed by TATs. Development of criteria is more difficult than it is worth.	Uses almost exclusively throw-away clothing. Doesn't think a sophisticated criteria is required for his region.	E&E has program with NIOSH to develop criteria; therefore, probably not necessary.	Assumes worst case and uses "moon suit" when hazard unknown. Rarely uses anything less than splash protection, face mask, hard hat and rubberized boots. Hygienist makes decision on clothing protection.	The currently used 4 levels of protection are adequate for site assessment, not for cleanup. Decision to downgrade should be up to hygienist/toxicolngist.	Uses clothing appropriate to TLV, IDLH and skin contact factors. Uses Noyes chemical data book, a repetition of CHRIS. Considers present techniques adequate.	People do not pay attention to protective clothing or its selection until it is too late.	Mixed-Negative
4	Must search a multitude of materials; should identify best reference sources available. Sympathetic with idea.	Believes this to be a good idea. Could include aspects of OHM-TADS and list by chemicals.	Uses computer tie-in to OHM-TADS to get full printout in half hour. Also, TAT has 1/2" document from 40CFR117. It might be OK to develop an index, though.	Supports idea of an index. Manuals can be identified and selected by various subject tabulations.	Only experience will properly show the advantages and disadvantages of the many manuals.	Likes a modification of this - terse, brief explanations re differences between manuals; abstracts could be used.	Johns Hopkins University has done some work on this subject.	Positive
5	Uses annual public health service checkups for response personnel.	Doubts a medical program is practical. Personnel would not pay proper attention to results.	Considers this an important topic that should be investigated.	Believes this topic is a good one.	Uses a good medical surveillance program determined by hygienist/toxicologist for baseline and followup.	Establishing baseline is important, but not often done, for first responders. This info is required.	Believes further research in this area is justified.	Positive
6	Sample requisition by EPA staff can result in equipment contamination; depot decontamination is suggested. Interested in idea.	Not much involvement with decontamination and therefore not much need for this item.	Uses soap/water washdown. Also uses disposable clothing, whenever possible. Believes further research of topic is indicated.	Expressed no comment on this topic. (Proprietary considerations may be involved.)	Recommends good medical surveillance with depot-level decontamination and proper training.	Currently uses a procedure for scrub-down in conjunction with wash and rinse water containment. Not enthusiastic.	Believes this topic requires further research.	Mixed-Positive
7	Would like an index for proprietary chemicals and for specific materials not to be flushed with water.	Would like to see less documents and a greater expenditure for resources to respond to spills.	Interested in representative drum sampling and moving deteriorating drums safely.	Interested in chemical reactivity tabulations. Also, likes info on neutralization and gas/liquid immobilization for field operations.	No other topics suggested.	Would like an index for synonyms and a cost rate for disposal of drummed wastes.	No other topics suggested.	

Topics: 1 - Odor Detection of Respirator Canister Failure
2 - Criteria for Delineating the "Hot Line"
3 - Criteria for Selection of Protective Clothing
4 - Index of Operational and Procedural Manuals
5 - Medical Surveillance
6 - Personnel & Response Equipment Decontamination
7 - Others (to be suggested by interviewees)

ing topics received mixed reviews, except for odor detection of respirator canister failure, which received a uniformly negative response.

With the aid of the interviewees' comments, the final list of safety monographs was developed. The list includes:

(1) Air Quality Monitors
(2) Medical Surveillance for Hazardous Materials Cleanup
(3) Selection of Personnel Protective Clothing for Hazardous Materials Cleanup
(4) Personnel & Equipment Decontamination
(5) Index of Operational Manuals for Hazardous Materials Cleanup

The "hot line" criteria topic received a positive response, but it was not addressed by this project since another EPA project* is investigating criteria for evacuation distances for hazardous substances derailment incidents. The "hot line" is directly related to evacuation distances and it was decided to address the topic only once, in the other project.

*EPA Contract No. 68-03-3014, Task 10 (Phase II), TMS-2, is developing a Fire Control Handbook for Hazardous Substances.

Two safety monographs produced by this effort and further described in abridged fashion in the following sections of the paper are Air Quality Monitors and Medical Surveillance for Hazardous Materials Cleanup.

AIR QUALITY MONITORS

Combustible and/or toxic gases or vapors and oxygen-deficient atmospheres may be encountered with lethal results if proper protection is not provided. Hazardous materials cleanup personnel must ascertain accurately and efficiently what atmosphere conditions prevail in order to take safe and corrective action. This responsibility requires that response personnel use portable monitoring devices that are extremely reliable.

A search of available product literature, however, reveals a bewildering array of different air quality monitors, employing various principles of operation, packaged in many sizes and shapes, with a host of operating characteristics and selling for a variety of prices. To assist response personnel in selecting an appropriate air quality monitor, an evaluation of commercially available monitors was conducted. The price of the air quality monitors was not a consideration in the evaluation.

Only those devices capable of monitoring hazardous gases or vapors on a continuous and quantitative basis were considered. Thus, detectors that indicate the presence of a substance by discrete sampling were eliminated, whereas monitors that possess the ability to quantitatively sense fluctuations in gas or vapor concentrations over a period of time were included.

Evaluation

A desk-top analysis was conducted of commercially available devices for the monitoring of combustible and/or toxic gases or vapors and oxygen levels. Thirty basic design configurations, representing models currently produced by 18 different manufacturers, were evaluated.

The gas-phase monitoring devices were segregated into three categories characterized by the gas system being monitored: (1) oxygen, (2) combustible gas or vapor and (3) toxic gas or vapor (as represented by H_2S and CO). The toxic gas or vapor category was limited to H_2S and CO monitors for two reasons. First, many toxic gas monitors are capable of detecting numerous gases. A complete desk-top evaluation and comparison of all monitor/gas combinations was considered unworthy of the time and cost it would require. Second, a fair comparison of toxic gas monitors could only be made between monitors for which there was performance data on the same gas(es).

Unfortunately, there was no gas for which performance data were available for all toxic gas monitors. However, data was available for H_2S and/or CO for each monitor, so the toxic gas monitors were evaluated in two groups depending upon whether CO or H_2S monitoring data was available for the instruments. Those instruments for which performance data existed for both CO and H_2S were evaluated in both groups.

Fifteen instrument parameters were identified as the most important for the intended use of the monitors. A tabulation of the 15 specifications and qualifications, including solid-state electronics and the degree of skill required for operation, for each combustible gas vapor monitor are given in Table III. Similar tables were prepared for the toxic gas/vapor (H_2S and CO) and oxygen monitoring devices.

The evaluation was accomplished by applying to each specification or qualification a factor that relates the importance of that particular parameter to the features desired in the final product. Thus, rating criteria were established to reflect differences in the various devices and weighting factors were assigned to each particular specification so that each device was rated in accordance with the criteria. (See Table IV for evaluation rating criteria.)

Conclusions

With the device specifications and qualifications identified and the evaluation criteria established, individual ratings were determined for each device specification. By summing all the individual ratings for a particular device, an overall rating for the device was obtained. Overall ratings for the top-rated devices in each of the four device categories are as follows. Among oxygen monitors, the Dynamation O_2-25, Energetic Ecolyzer 400 and Biomarine OM325R all received the highest ranking with identical scores of 245. Ranked second with a score of 235 was the Gastech Model 1641.

Among combustible gas monitors, the Century OVA-128 was ranked highest with a score of 258, followed by the Dynamation LCD-Combo with a score of 240. Rating totals in the H_2S toxic gas monitor category show high values of 225 for the HNU's PI-101 and 214 for the Interscan Model 1170. For the CO toxic gas monitor category, the Enmet CGS-100 was highest rated with 219, while the Gastech EC-231 was second with 216.

Presumably, any of the highly rated devices can be used for the specific monitoring application for which it was intended. However, it must be remembered that the desk-top evaluation relied almost exclusively on manufacturer's product literature and on telephone conversations with the manufacturers or their representatives. An independent experimental and/or field evaluation of the various monitors would provide better data on which to base the evaluation. It is quite possible that monitor ratings developed from first-hand field evaluation could differ from those derived from a desk-top or literature evaluation. Moreover the assembled information is dated and therefore subject to change with time.

MEDICAL SURVEILLANCE FOR HAZARDOUS MATERIALS CLEANUP

A monograph has been produced describing a medical surveillance program for hazardous materials cleanup personnel. The program is a test protocol designed to supervise the health and well-being of the hazardous material cleanup team members. Medical surveillance programs for hazardous materials cleanup personnel are directed at

Table III.
Combustible Gas/Vapor Monitors—Operating Specifications

Instrument* (Operating Principle)	Volume/ Weight (in^3/lbs)	Setup Time (min)	Temp. Range (°C)	Operating Range(s) (ppm)	Accuracy (% F.S.)	Minimum Detection (% F.S.)	Alarms#	Intrinsically Safe	Calibration Medium/ Time (min)	Interferences	Response Time, 90% (sec)	Operating Period (hrs)	Remote Readout
GasTech Inc. Johnson Instrument Division													
Model 1314** (CC)	248/8	1	-8 to 43	0-100% LEL Toluene 0-500 ppm Organic Vapor (OA)	±10	<1	A/V/F (Bat, Det)	Yes	Toluene/ 5-10	Poisons - silicones, lead vapors	5	8	No
Model 1641*** (CC)	344/8	1.5	0 to 40	0-100% LEL Methane	±5	2	A/V/F (Bat, Det)	Yes #	Methane/ 5-10	Argon, helium	4	6	0-1 V
Dynamation Inc. LCD Combo** (CC)	84/3	<2.5	-9 to 49	0-100% LEL Methane	±2	1	A/V/F (Bat, Det)	Yes #	Methane/ 5-10	Poison - silicones and lead vapors (filter will stop most)	5	9	0-2 V
Enmet Corp. CGS-100*** (SS)	224/6.5	10	-10 to 50	0-50% LEL Methane (OA)	±3	<1	A/V/F (Bat)	Yes	Methane/ 5-10	None (while detecting total comb.)	30	10-14	No
Century Systems Corp. OVA-128 (GC/FID)/	425/12	1	0 to 55	0-10 ppm 0-100 ppm 0-1000 ppm	±1	<1	A/F (Bat, Det)	Yes	Methane/ 5-10	None (while detecting total comb.)	2	8	0-5 V
Infrared Industries, Inc. IR-711 (IR)/	227/9	5	0 to 50	0-100% LEL propane, 0-1000 ppm JP-5	±5	2.5	A/F (Bat)	Yes	Propane, JP-5/5-10	Compounds containing CH bond	5	5-8	0-100 mv
International Sensor Technology AG6000** (SS)	167/5	0.5	0 to 40	0-100% LEL Methane	±5	3	A/V/F (Bat)	Yes	Methane/ 5-10	H_2, Methyl Mercaptans	20	10	No
Scott Aviation/Div. of A-T-O Inc. Model O-17 (CC)	126/5	Instant	0 to 43	0-100% LEL Hexane	±10	5	A/F (Bat)	Yes	Hexane/ 5-10	Poisons - silicones, lead vapors	5-10	4-6	No
Energetics Science/Div. of Becton Dickinson & Co. Ecolyzer 400** (CC)	432/8	1	-18 to 40	0-100% LEL Methane	±1	1	A/V/F (Bat, Det)	Yes	Methane/ 5-10	None (while detecting total comb.) Poisons silicones, silicates, lead vapors	15	10	No
Mine Safety Appliances Co. Model 260** (CC)	263/<10	5	0 to 40	0-100% LEL Pentane	±10	10	A/V/F (Bat)	Yes	Pentane/ 5-10	Poisons - silicones, silicates, lead vapors	<20	8-9	No
Biomarine Industries, Inc. Model 902** (CC)	561/9.5	< 5	-15 to 40	0-100% LEL Hexane	±5	10	A/V/F (Bat)	Yes	Hexane/ 5-10	Poisons silicones, lead vapors	4	16	No

* All devices are of solid-state construction and require average skill on the part of the operator. Operating Principle code: CC = Catalytic Combustion, SS = Solid State, GC/FID = Gas Chromatography/Flame Ionization Detector, IR = Infrared Absorption.
** Also equipped to monitor either toxic gases or oxygen.
*** Also equipped to monitor both toxic gases and oxygen.
/ This principle of operation is sensitive to the C-H bond and, therefore, the corresponding device will respond to most, but not all, combustible gases/vapors.
# A/V/F = Audio/Visual/Failsafe; Bat = Battery Check; Det Detector Check.
# Not determined by independent assessment.
OA = Others available.

employment qualifying, general health maintenance and prevention or early detection of harmful effects of hazardous substances. In the case of adversely affected member(s) of the cleanup team, this may require medical intervention and removal from the cleanup team.[2] The objective of this monograph is to describe and document the elements that comprise a reasonable medical surveillance program for hazardous materials cleanup personnel. The described elements are based on state-of-the-art medical methodology and the proposed medical surveillance program is expected to be tailored to specific applications as required by the user organization. Also, medical surveillance programs should be designed to secure maximum preventive benefits at minimal cost and inconvenience.

A medical advisory board sponsored by the organization responsible for the hazardous materials cleanup should have the responsibility of developing a medical surveillance program and evaluating its results. The board should be empowered to make recommendations based on its review of the examinations performed on personnel.

Two examinations that are commonly performed[2] are:
- Preplacement
- Periodic

Preplacement/Pre-Employment Examinations

Preplacement examinations serve an essential function in health surveillance by providing an historical record of

previous exposures, information on the state of health prior to joining the team and a baseline for comparisons with later health observations. Preplacement examinations are used to ensure that workers are physically able to use personal protective equipment.[2] Employment and medical history and a physical examination consisting of physical and biological monitoring are elements of the preplacement examination and should be tailored to the specific hazards of the job under consideration.

Periodic Examinations

A periodic examination is a tool that can be used to detect incipient disease, physiological changes, biochemical deviations or evidences of absorption of toxic agents and to establish interim reappraisals.[3] Periodic examinations consist of periodic baseline examinations (comprehensive) and hazard-oriented surveillance examinations (limited).

The periodic examination provides two primary services: (1) maintains a continuing record of the general health status of the team members and (2) provides an epidemiological record, followup analyses and/or examination for possible latent effects of exposure to some hazardous substance(s).

Periodic examinations would be similar to pre-employment/preplacement examinations. However, the emphasis would be on possible exposures that had occurred since the previous examination. An example of the physical/biological parameters that a periodic examination could investigate[4] for possible exposure of a response team member to selected hazardous substances is shown in Table V.

The hazard-oriented surveillance examination is developed to screen for exposures that may occur during a hazardous material cleanup operation, such as at an uncontrolled hazardous waste site. Hazardous materials cleanup personnel may be exposed to toxic chemicals that may or may not have been identified from the onset of the response action.[2] Based on the premise that hazardous materials response team members could be operating in situations where the hazards are unknown, three points should be made:

(1) It is not economically feasible to test the team members for all hazardous substances if they were exposed to unidentifiable numbers and types of chemicals in question.[2]
(2) There are no general tests that can be used to screen for organics or inorganics generically. The tests are chemical-specific and the biological pathway examined would be dependent on the type of chemical in question.[2]

Table IV.
Evaluation Rating Criteria

Volume/Weight				Solid State		Setup Time (min)		Skill		Temperature Range: Lower Limit (°C)		Temperature Range: Upper Limit (°C)		Operational Range(s)		Accuracy (% F.S.)	
in^3		lbs															
0-750	15	0-5		Yes	15	0-10	15	Average Ability	10	<-30	15	>70		>2 Ranges	15	≤ ±2	20
751-1500	13	6-15				11-20	10			-20 to -30	12	60 to 69		2 Ranges	10	±3 to ±5	15
1501-2250	11	16-30		No	0	21-30	5			-10 to -19	9	50 to 59		1 Range	5	±6 to ±10	10
2251-3000	9	31-45				31-60	1	Greater Technical Ability	0	0 to -9	6	40 to 49				>±10	5
3001-3750	7	46-60				>60	0			>0	0	<40					
>3750	5	>60												Add 5 if factory allows options for range(s).			

Minimum Detection: O_2		Minimum Detection: Combustibles		Minimum Detection: H_2S and CO		Alarms		Intrinsically Safe		Calibration Procedure		Calibration Procedure		Calibration Time (min)	
0-0.5%	10	<1% LEL	10	1 ppm	10	Audio	5	Yes	20	Contained gas unnecessary	14	Calibration gas introduced with syringe and glass container	6	0-5	6
0.6-1.0%	5	1%-2% LEL	6	1-2 ppm	6	Visual	5			Direct cylinder attachment to monitor	12	Calibration gas introduced with permeation tube and instrument	4	6-10	5
		>2% LEL	4	>2 ppm	4	Failsafe: Detector	5	No	0	Calibration gas introduced with bag and cylinder	10			11-20	4
						Battery	5			Calibration gas introduced with syringe and cylinder	8	Calibration gases plus external computer for computations	2	21-30	3
														>30	2

Interferences				Response Time (Sec)		Operating Period (Hr)		Remote Readout	
Oxygen		IR absorption	22	Photoionization	10	0-10	30	>16	25
None	20	Hydrocarbons with similar frequencies to the material being monitored		Many organics (materials with ionization potential equal to or less than the energy level of the UV source)		11-20	24	12-16	20
Interferents <2500 ppm	10	Colorimetric	22	Electrochemical	5	21-30	18	8-11	15
Interferents >2500 ppm	0	Strong reducing agents		Unsaturated hydrocarbons, C_2H_5OH, H_2, NO		31-60	12	4-7	10
Toxic & Combustible Gases*		Catalytic combustion	20			61-90	6	<4	5
GC/FID	30	Silicones, lead vapors, (poisons)				>90	0		
None stipulated, very specific if gas known.		Solid state	17						
IR absorption with microprocessor (Used by the MIRAN-80)	30	Marcaptans, H_2							

Remote Readout	
2 Ranges	10
1 Range	5
None	0

* Because of the wide disparity in product information on interferents, allowance has been made for interferents generally associated with specific principle of operation by subtracting the effect of the interferents from the maximum allowable (30) according to the following schedule: major single interferent, -5; small interferent family, -8; large interferent family, -10.

Table V.
Biological Parameters Affected by Selected Hazardous Substances[4]

	Medical/Occupational History	Periodic Exam (depends on annual exposure rate)	Physician Certification	EKG	Chest X-ray	Pulmonary Performance	Lab Exams:	Urinalysis	Sputum Cytology	Urine Cytology	Complete Blood Count	Blood Chemistries:	SGOT (Serum Glutamic Oxaloacetic Transaminase)	SGPT (Serum Glutamic Phosphoric Transaminase)	Alkaline Phosphatase	Total Bilirubin	GGTP (Gamo Glutamo Transpeptidase	Lead
Asbestos	x	x	x		x	x			x									
Beryllium	x	x	x		x	x												
Carcinogens (other classified)	x	x			x			x		x	x		x	x	x	x	x	
Lead	x	x	x					x			x							x
Ozone	x	x	x		x	x												
p-tert-Butyltoluene	x	x	x	x							x							
Styrene	x		x															
Toluene	x	x			x	x		x			x							
Trichloroethylene	x	x	x	x		x		x			x							
Vinyl Chloride	x	x	x		x	x		x					x	x	x	x	x	

Table VI.
Health Effects and Medical Surveillance for Selected Airborne Contaminants (Partial List)[3]

Airborne Contaminant	Health Effects	Medical Surveillance
Acetone	Irritation of respiratory tract and mucous membranes; narcosis; dermatitis	Interval history
Alumina	Lung overload; no fibrosis	Interval history
Ammonia	Irritation or respiratory tract and mucous membranes	Chest X-ray; lung function
Antimony Pentachloride	Gastrointestinal and heart disorders; respiratory irritation	EKG; Chest X-ray; lung function
Asbestos	Fibrosis of lung; bronchogenic carcinoma; mesothelioma; cancer of stomach, colon and rectum	Chest X-ray; lung function; sputum cytology (OSHA requirement—annual medical surveillance)
Bauxite (may contain silica)	Lung overload	Chest X-ray; lung function
Beryllium	Fibrosis of lung; dermatitis	Chest X-ray; lung function; skin inspection
n-Butyl alcohol	Irritation of respiratory tract and mucous membranes; narcosis; dermatitis	interval history
Butyl Cellosolve (2-Butoxy Ethanol)	Irritation of respiratory tract and mucous membranes; narcosis; dermatitis; red cell hemolysis	Complete blood count
Cadmium Oxide	Pulmonary edema; fibrosis of lung; kidney damage	Chest X-ray; lung function; cadmium and protein in urine; urinalysis
Carbon Dioxide	Asphyxiation	None
Carbon Monoxide	Asphyxiation; disturbed consciousness	Interval exam; carboxyhemoglobin if intoxication suspected

(3) Field monitors can be used to evaluate the type and concentration of chemicals on site that the team might be exposed to indirectly.

Personal monitoring and area monitoring (manual and automatic) are the most common techniques used to determine an exposure to atmospheric chemicals. However, both are subject to significant errors. Biological monitoring may be useful to validate the atmospheric monitoring. Also, exhaled air analysis can be used to measure exposure to industrial chemicals.[3] A partial list of potential health effects, type of medical surveillance and industrial hygiene considerations required for several specific airborne contaminants is given in Table VI.[3] The usual approach in determining that a chemical insult to the body has occurred due to exposure to a hazardous material involves medically observing changes, either from the norm or a previous baseline, in a person's health.

During a response action, response team members should be carefully observed by the on-scene coordinator, on-site industrial hygienist or medical personnel and fellow team members. The first warning signs of toxic effects from a hazardous exposure are often observed by a fellow worker.[5] Finally examinations on the termination of employment are desirable since they document the health status then and provide evidence of any changes that have occurred during the employment period. This does not rule out the possibility that effects may show up at a later date.

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INITIAL SITE PERSONNEL PROTECTION LEVELS BASED ON TOTAL VAPOR READINGS

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INTRODUCTION

The EPA Environmental Response Team (ERT) was established in October 1978 to provide technical assistance to On-Scene Coordinators (OSC), Regional Response Teams (RRT), EPA Headquarters and other Regional Offices, as well as other governmental agencies at spills of hazardous materials and at uncontrolled hazardous waste sites. In this paper, the author describes the procedures used by ERT in selecting the appropriate level of personnel protection during the initial assessment and operational phase. Personnel protection is categorized into three levels and criteria for selection is based on potential total vapor exposure.

The objective of using total atmospheric gas/vapor concentrations for determining the appropriate personnel protection level is to provide a numerical criteria for selecting Level A, B, or C protection. Until atmospheric contaminants are specifically identified and personnel protection selected based on toxicological properties, total gas/vapor concentrations provide a numerical value that can be used as a guide for selecting personnel protection equipment.

Although total gas/vapor concentration measurements are useful to a qualified professional for the selection of protection equipment, caution should be used in the interpretation of this data. The response of an instrument to several gas/vapor contaminants does not provide the same sensitivity as measurements involving a single contaminant. Since total vapor field instruments see all contaminants in relation to a specific calibration gas, the concentration of an unknown environment may be over estimated or under estimated.

When carcinogens or other highly hazardous substances are suspected, the protection level should not be based solely on the total gas/vapor criteria, rather the level should be selected on a case-per-case basis weighing heavily on potential exposure and chemical characteristics of the suspected material.

FACTORS FOR CONSIDERATION

In utilizing atmospheric gas/vapor concentrations as a guide for selecting a level of protection, a number of factors should be considered:

1. The uses, limitations, and operating characteristics of the monitoring instruments must be recognized and understood. Instruments such as the photoionizer and Organic Vapor Analyzer (OVA) do not respond to all substances that may be present or may respond differently to identical substances when compared to one another. Therefore, experience, knowledge, and good judgment must be used to compliment the data obtained with this instrumentation.
2. Hazardous other than detectable toxic gases/vapors such as non-detectable gases (i.e., phosgene, HCN, chlorine, etc.,) liquid/solid particulates, explosives, combustibles, radiation, oxygen deficiency, and other harmful conditions may exist in the atmosphere or on the site.
3. The risk to personnel entering an area must be evaluated against the need for entering. Although this assessment is largely a value judgment, a conscientious assessment of the variables involved and the risk to personnel must be balanced against this need for site entry.
4. The knowledge that carcinogens or other highly toxic substances are involved or suspected requires that gross levels not be the sole factor in determining the level of protection. Other factors which must be taken into consideration are exposure, chemical characteristics of known/suspected materials, instruments, weather conditions, etc.
5. Functions which need to be performed on-site must be evaluated. Based upon total atmospheric gas/vapor concentrations, Level C protection may be judged adequate. The work functions to be performed such as moving drums, opening containers, bulking of materials and other operations that increase the probability of exposure may require a higher level of protection.

CRITERIA

The criteria for relating Levels of Protection to total atmospheric concentrations are:

Level C	0-5 ppm above background
Level B	5-500 ppm above background
Level A	500-1000 ppm above background

Level A Protection

Level A protection provides the highest degree of protection against hazards due to inhalation, skin and eye

irritation, if the inherent limitations of the personnel protective equipment are not exceeded. Yet Level A protection does present the highest potential for heat stress. Cooling vests/suits have demonstrated some degree of relief to body temperature build-up. The range of 500 to 1000 ppm total gas/vapor concentrations in air is based on the following criteria:

- Since Level A will provide protection against air concentrations greater than 1000 ppm for most substances, an operational restriction of 1000 ppm is established as a warning to:
  - Take into consideration analytical instrumentation sensitivity to wind velocity, humidity, temperature, etc.
  - Evaluate the calibration and/or sensitivity error associated with the instrument(s).
  - Evaluate the need to enter environments greater than 1000 ppm.
  - Identify the specific constituents contributing to the total concentration and their associated toxic properties.
  - More precisely determine the concentration of the individual constituents that make up the total concentration.
- A lower limit of 500 ppm (for Level A) total gas/vapor concentration in air is selected as the value to upgrade from Level B to Level A in order to fully protect the skin and/or eyes until qualitative and quantitative determinations can be made of the constituent products and skin and/or eye hazards excluded.
- The range of 500-1000 ppm total concentration is sufficiently conservative to provide a safe margin of protection due to instrument error, calibration and sensitivity, unanticipated transient concentrations, and protection against highly hazardous substances that could account for the total concentrations.

Experience with properly operating portable field equipments for measuring total gases and/or vapors has demonstrated levels approaching 500 ppm have not routinely been encountered on hazardous waste sites. High concentrations have only been encountered in closed buildings, at openings to containers or when working in the spilled contaminants.

A decision to require Level A should also consider the negative aspects of this high level of protection, i.e., higher probability for accidents due to cumbersome equipment, increased resources needed and the physical stress caused by heat buildup in fully encapsulating suits. These factors need to be carefully evaluated and balanced against the reasons for utilizing Level A.

Level B Protection

Level B protection is the minimum level of protection required for initially entering an open site where the type(s), concentration(s) and presence of airborne gas/vapors are unknown. This level of protection provides a high degree of inhalation, skin and eye irritation or absorption protection. Although a small portion of the body (neck and head) are exposed, primarily liquid/solid materials have the highest potential of causing acute or chronic effects due to exposure of this area. The use of a hooded chemical resistant jacket would further reduce the potential for exposure to this area of the body. Although the potential for heat stress is not as high as Level A, it can be a major problem. Cooling vests/suits have demonstrated some degree of relief to body temperature build-up.

A limit of 500 ppm total atmospheric gas/vapor concentration readings on portable field instruments has been selected as the upper restriction on the use of Level B. Although Level B personnel protection would provide adequate protection against most substances at concentrations higher than 500 ppm, an upper limit of 500 ppm is selected as the decision point for a careful evaluation of the risks associated with higher concentrations.

Considerations:

- Analytical instrumentation sensitivity to wind velocity, humidity, temperature, etc.
- Calibration and/or sensitivity error associated with the instruments.
- The probability that substance(s) present are cutaneous or percutaneous.
- The necessity for entering higher concentrations in Level B.
- The work function to be done and the increased probability for exposure.
- Qualitative and quantitative identification of the specific components.

Level C Protection

This level provides the same high degree of skin protection as Level B, but lesser inhalation and/or eye protection. A relatively low (0-5 ppm above background) ambient concentration has been established as the range for wearing Level C protection equipment. An upper limit of total vapor concentration of 5 ppm (above background) has been selected primarily based on the use of a full-face air purifying gas mask with canisters and requirements as to its constraints and limitations. These are:

- MSHA/NIOSH approved air-purifying devices should only be worn in atmospheres where the substances have been identified or the potential of exposure is highly unlikely.
- Substances must have good warning properties.
- Continuous air monitoring must occur for the atmospheric contaminants identified.
- Appropriate, approved canisters must be used.
- Sufficient oxygen (at least 19.5% of air at sea level) must be present.

Full-face, air purifying devices will provide respiratory protection against most environmental vapors greater than 5 ppm; however, until qualitative and quantitative information is available about the substances, concentrations greater than 5 ppm indicate a higher level of respiratory protection should be used.

PROTECTION EQUIPMENT

Since exposure factors vary from one situation to another, it is impossible to develop a specific safety procedure that will be appropriate for all situations; ERT

limited the selection of protective equipment to three general categories. Although total gas/vapor monitoring is the primary screening mechanism used, the protection levels indirectly address protection against three possible routes of exposure (inhalation, skin absorption/irritation, and ingestion).

Level A—Personal Protection Equipment

- Positive Pressure SCBA (MSHA/NIOSH approved) operated in the positive pressure mode
- Totally Encapsulating Suit (boots and gloves attached, cooling vest when applicable)
- Gloves—Inner (tight fitting and chemical-resistant)
- Boots—Chemical-protection, steel toes and shank. Depending on suit boot construction, worn over suit boot
- Gloves—Outer, chemical resistant. Depending on suit construction, worn over suit gloves. May be replaced with tight fitting, chemical-resistant gloves worn inside suit gloves.
- Underwear—cotton, long-john type
- Hard Hat—(under suit)*
- Disposable protective suit, gloves, and boots. (Worn under or over encapsulating suit)
- Coveralls (under suit)*
- Two-way radio communications

*Optional

Level B—Personal Protective Equipment

- Positive Pressure SCBA (MSHA/NIOSH approved), operated in the positive pressure mode
- Hooded, two-piece chemical-resistant suit (cooling vest when applicable)
- Gloves—Inner, tight fitting, chemical-resistant
- Boots—Outer (chemical-resistant, heavy rubber disposables)
- Boots—Inner (chemical-resistant, steel toe and shank)
- Two-way radio communications
- Hard Hats*
- Face Shield*

*Optional

Level C—Personal Protective Equipment

- Full-face gas mask, air-purifying respirator (MSHA/NIOSH approved)
- Chemical-resistant clothing
- Overalls and long-sleeved jacket or coveralls; hooded two-piece chemical splash suit (when applicable—hooded disposable coveralls)
- Gloves—Outer (chemical-protective)__
- Gloves—Inner (tight fitting, chemical-resistant type)
- Cloth or disposable coveralls—inside chemical protective clothing, cooling vest when applicable*
- Escape pack
- Hard Hat* (face-shield, optional)
- Boots—Outer (chemical-protective heavy rubber throwaways)
- Boots—Inner (chemical-protective, steel toe and shank)
- Two-way radio communications

*Optional

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HAZARDOUS SUBSTANCE SITE AMBIENT AIR CHARACTERIZATION TO EVALUATE ENTRY TEAM SAFETY

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INTRODUCTION

Because of the wide variety of ambient conditions that may be encountered in investigation and remedial action activities on hazardous substance sites, a means of determining the potential dangers is essential in order to protect worker health and safety. A number of airborne toxic chemicals have been found at the boundaries of hazardous substance sites (Table I).[1]

The air emissions from hazardous substance sites are complex because there is usually no single point source on a site and because concentrations of toxic chemicals decrease rapidly as they diffuse and disperse in the atmosphere.[1] In addition, explosive or oxygen-deficient atmospheres may exist, and radiation may be encountered.

Depending on the nature of the site, the information necessary to assess the hazard potential may be obtained by researching existing data sources. However, in many cases, a variety of equipment may be required to characterize and monitor the ambient air, both on-site and at the site boundaries. The goals of such an ambient air characterization scheme are as follows:

(1) To qualitatively and quantitatively define the hazards due to airborne pollutants on hazardous substance sites
(2) To locate specific areas of a site upon which to focus the investigation and remedial action activities
(3) To monitor the surrounding community for any adverse environmental impact that work on the site may cause

The data obtained from the air characterization study is used to develop a personnel protection plan that allows workers to perform site activities in the lowest level of protective gear consistent with maintaining their health and safety.

In this paper, the author discusses the equipment that can be used to define the hazards associated with hazardous substance sites. The actual selection of specific personnel protective gear based on the analytical data generated by the air characterization is beyond the scope of discussion but several references detailing selection criteria are included.

PRELIMINARY HAZARD ASSESSMENT

Before work is initiated at a hazardous substance site, detailed background research should be conducted to ascertain what chemicals, hazards, special requirements, etc., may be associated with the site. Possible sources of information are state, county and municipal agencies, including the federal and state EPA.

All site waste generator records should be reviewed, including inventories, shipment manifests, and permits. Personal interviews with site personnel, public officials, and private citizens may be helpful.

The most valuable information, of course, is the results of any air monitoring or sampling that has been performed. In addition, data on the waste composition may provide information on potential airborne pollutants. It may be desirable to perform an offsite preliminary inspection, since many times a simple visual reconnaissance can go a long way in terms of defining probable hazards.

Table I.
Examples of Predominant Species Found in Air Near Hazardous Waste Sites.[1]

	Maximum concentration observed at each dumpsite, ug/m^3			
	Love Canal Niagara Falls, N.Y.	Kin Buc, Edison, N.J.	Elizabeth, N.J.	Other
Benzene	5703	1550	234	10
Toluene	1472	2600	325	64
o-xylene	73		79	20
m+p-Xylene	140		225	41
Acetaldehyde		245		
Benzaldehyde		56		
Isopropyl ether		120		
Phenol		10		
Ethyl acetate		232		
Ethyl ether		35		
Dimethyl ether		10		
Naphthalene		6100		117
Ethyl benzene				282
Methyl isobutyl ketone		444		
n-Pentanal		38		
Chloroform	172	266		1.5
Methylene chloride	10	1250		
Dibromomethane		63		
Dichloroethane		57		
Tetrachloroethane	1140	22		
Trichloroethane	73	500		2.0
Trichloroethylene	270	93	218	4.5
Tetrachloroethylene	1140	394	95	1.8
Carbon tetrachloride	5	20		
Vinyl methyl ether		5000		
Vinyl isopropyl ether		13000		
Vinyl chloride				110000
Chlorobenzene	240	50	16	
Dichlorobenzene	100	34		158
Chlorotoluene	6700			
Dichlorotoluene	159			
Trichlorobenzene	74	1		
Trichlorotoluene	44			
Bromoxylene		50		
PCB's				300

Source: Reference 1

Once the background data are assembled, a preliminary hazard assessment is performed, generally requiring an interdisciplinary scientific approach by individuals with training in chemical, biological and radiological safety and health and experiences in determining and implementing a personnel protective equipment program. The task is not entirely quantitative, since many subjective professional judgments are required.

Each site is unique, posing specific problems and requiring individual attention. For example, the site may be known to contain a hazardous chemical; however, if the site is properly managed and the hazardous chemical adequately contained, there may be only a minimal threat to worker health and safety.

AIR MONITORING EQUIPMENT

In many cases, the information obtained from the background research either is not sufficient to define the site hazards or indicates that the hazard potential is great enough to require specific personnel protective equipment. Both instances necessitate the use of a variety of equipment to characterize and monitor the ambient air so that the appropriate level of personnel protection can be chosen.

Continuous monitoring is also required since workers may encounter hazards such as explosive atmospheres or high levels of radiation for which no protective equipment is available. Continuous monitoring would also allow the selection of the minimum amount of protective equipment consistent with maintaining worker health and safety.

The air monitoring equipment described in this paper can be conveniently divided into two categories:

- Direct reading instruments, which provide a "real time" readout of the concentration of pollutants, and
- Collection media, which collect and concentrate the pollutants for subsequent laboratory analysis.

A list of equipment which is sufficient to evaluate entry team safety and to determine and implement a personnel protection equipment program for hazardous substance site workers is given in Table II.

With the exception of explosive and/or oxygen-deficient atmospheres, there is no way to reliably predict the health effects of exposure to hazardous substances based on the readout of a single direct reading instrument, unless the instrument can quantitatively respond to all of the substances present at any given instant. This is especially true for entry into sites where little or no background information exists, since the hazards are undefined and on sites where "dynamic" activities such as drum opening, sampling, drilling, etc., are in progress.

Hazardous substance sites may contain a number of pollutants in levels below the detection limits of direct reading instruments but still can cause synergistic health effects. Moreover, many toxic substances such as particulate organics and metals simply cannot be determined by a direct reading instrument.

The effects of personnel exposure to these types of substances must be carefully determined, especially for long-term site activities involving repeated exposure. For example, gamma radiation is relatively easy to detect in the field but low-level alpha or beta radiation is not. The health effects of human exposure to low levels of alpha and beta are potentially more severe than exposure to a much higher level of gamma radiation. Thus, the determination of the effects of exposure must be made by a health physicist and cannot be determined solely by a single instrument reading.

Table II.
List of Equipment for Ambient Air Characterization.

Hazard	Direct Reading	Collection System
Explosive atmosphere	Combustible gas indicator	Not used
Oxygen-deficient atmosphere	Oxygen level meter	Not used
Toxic atmosphere	1. Portable photoionization detector (PID) 2. Portable flame ionization detector (FID) w/gas chromatograph (GC) option 3. Colorimetric tubes	Sampling pumps in conjunction with absorption tubes, filters, and impingers
Radioactivity	1. Radiation survey meters (alpha, beta, gamma) 2. Passive monitors (alarms)	Dosimeters (film badges)

See References 2 and 3 for criteria for use of combustible gas indicators and colorimetric tubes.

As another example, direct reading instruments such as the photoionization detector (PID) and the flame ionization detector (FID) are very useful in locating "hot spots" —those areas of a site that contain significant levels of volatile chemicals. However, in order to determine the health effects of direct exposure, and ultimately personnel protection levels, the specific chemicals must be identified.

For a positive chemical identification, air samples are collected for laboratory analysis; the air contaminants are concentrated on a collection medium by passing ambient air through it. Since this type of air sampling is expensive, the value of an extensive background research is apparent. For sites with insufficient background data, it may be cost effective to perform work activities using full protective gear, while observing personnel for signs of stress. Once again, the subjective professional judgment of an individual experienced in the implementation of a personnel protective program is essential.

Explosive and Oxygen-Deficient Atmospheres

Explosive and oxygen-deficient atmospheres are unique in that the hazards associated with them can be determined by using direct reading instruments, provided that the operator is experienced and trained in field use of the instruments. For explosive atmospheres a combustible gas indicator is used. Although there are many commercially available units, most test for the concentration of explosive gases and vapors by measuring the heat produced by the combustion of a test sample. The readout is usually expressed as a percent of the lower explosive limit (% LEL), a dimensionless quantity defined as the lowest concentration of a gas or vapor by volume in air

which will explode or combust when there is an ignition source present.

The National Institute for Occupational Safety and Health (NIOSH) considers the action level for limitation of work in explosive areas to be 10% LEL, unless precautions are taken to prevent ignition sources. A reading of 20% LEL is considered IDLH (immediately dangerous to life and health) and requires evacuation regardless of what precautions have been taken. Also, work activities cannot be performed in atmospheres where the concentrations of gases or vapors exceed the upper explosive limit (UEL), which is the concentration of a gas or vapor by volume in air above which an explosion will not occur if there is an ignition source. Evacuation is necessary if UEL concentrations are detected, since dilution by air can easily create an explosive situation. Gear is not available for protection against the explosion hazard; immediate evacuation is the only recourse.

Oxygen-deficient atmospheres can be determined by using a commercially available oxygen level meter. A typical unit works on the principle of selective penetration of a membrane by oxygen with a subsequent reaction with an electrolytic reagent. The readout is generally directly in percent oxygen (% O_2).

NIOSH requires that an external air supply, usually a self-contained breathing device (SCBA), be used for work in atmospheres with less than 19.5% oxygen. Severely oxygen-deficient atmospheres indicate the presence of significant quantities of pollutants. Note that combustible gas indicators may not function properly in severely oxygen-deficient areas and should be used with an oxygen meter.

Radioactivity

There are three types of radiation that can be encountered on hazardous substance sites: alpha, beta and gamma. Human exposure to each type of radiation causes unique health effects, which are related to the received dose.

Sources of gamma on hazardous substance sites include hospital wastes, which may contain materials such as cesium, cobalt, and radium. Gamma radiation is easily detected using a variety of instrumentation, since it is in the form of electromagnetic energy and therefore travels relatively long distances. Because gamma is penetrating external radiation, there is no convenient means of protecting workers from exposure; if gamma radiation is detected, personnel should be evacuated immediately and appropriate government agencies contacted.

Alpha and beta radiation, however, travel much shorter distances than gamma and are therefore much more difficult to detect, since the monitoring device must be placed close to the source. Alpha sources are common and include substances such as thorium, radium and uranium. Biological laboratory wastes may contain beta sources, including radioactive carbon, phosphorus and sulfur. Since alpha and beta radiation are particulates and tend to adhere to clothes and boots of site workers, monitoring devices that will detect their presence should be used to screen personnel as personnel leave the site.

Although the external hazards due to alpha and beta radiation differ, protective clothing is available. The greatest danger is in the inhalation or ingestion of alpha or beta particles. An air-purifying respirator fitted with a radionuclide canister will in most cases offer protection against radioactive particulates. Adequate decontamination facilities must be available, however.

For field work, personnel should be equipped with a portable alpha/beta/gamma survey meter. Lapel-sized passive radiation monitors which respond with an audible alarm when the wearer encounters gamma are recommended for at least one team member. In addition, a dosimeter, which provides an indication of the total whole body exposure to radiation over an extended period of time, should be worn by all onsite personnel. Dosimeters are typically distributed to workers upon site entry and are worn on the lapel, underneath any protective clothing.

Toxic Atmospheres

When workers are engaged in activities on a hazardous substance site, Federal safety and health standards[4] dictate that they be protected against any respiratory danger. Personnel must wear an SCBA until the ambient air is fully characterized. It is desirable to use the lowest level of respiratory protection possible (i.e., the air-purifying respirator or no respiratory protection at all), since the addition of protective gear generally increases worker stress. Thus, the air monitoring program must provide the data necessary to determine respiratory protection.

The problem of cutaneous and percutaneous chemical hazards must also be addressed. Skin protection must be worn if there is any possibility of systemic injury, skin irritation, or death resulting from contact with an airborne gas, liquid, or particulate. Typically, the following information regarding all airborne pollutants is obtained in order to specify protective gear:[5]

- The chemical identity, the airborne concentration, and the physical state of each pollutant
- Permissible exposure limits of each pollutant
- The vapor pressure and equivalent ppm of each pollutant
- Warning properties for a gas or vapor
- Eye irritation potential for each pollutant
- The LEL, UEL, and IDLH concentration for each pollutant

One of the methods of determining the need for respiratory protection is to compute the "equivalent exposure"[6] based on the first three parameters in the table above. The calculations involved in computing the equivalent exposure are complex and are best left to the industrial hygienist who has experience in determining acceptable risk levels. Many factors in addition to those above enter into the selection of specific personnel protection and are beyond the scope of this discussion.*

Direct reading instruments such as the PID, the FID and colorimetric tubes are used to locate "hot spots" (areas of high air contamination) and in some instances provide

*See References 4, 5, and 7 through 14 for information on selecting protective equipment and determining the toxicological effects of exposure to hazardous substances.

a tentative identification of volatile inorganic and organic chemicals. Hot spots are important since they define the areas of the site that may contain significant quantities of chemicals.

Air sampling pumps for volatile organics are usually placed on the hot spots. Direct reading instruments can also be used to monitor the ambient air for dramatic changes in quality that may occur as a result of activities such as drilling, drum opening, etc. because these instruments provide a real time readout of pollutant levels.

The PID is a non-specific vapor/gas detector. It uses the principle of photoionization to detect a wide variety of volatile chemical compounds. The readout is in parts per million (ppm), references to a specific calibration standard. It does not respond to the common constituents of air, including methane.

The flame ionization detector (FID) in conjunction with a gas chromatographic (GC) column is used to detect and to tentatively identify volatile organic chemical compounds. In the "survey mode" it functions as a non-specific total hydrocarbon detector, with a readout in ppm, referenced to a specific standard, usually methane.

In the "GC mode" the unit can determine the "retention time" of an unknown chemical compound. The retention time is the length of time necessary for the chemical to pass through the GC column. By comparing the retention time of the unknown with the retention time of known standards, a tentative qualitative/quantitative identification of the unknown can be made.

Since specific chemical standards and calibrated columns are needed, an idea of the nature of the unknown is needed prior to the GC analysis. Thus, the importance of background research is demonstrated, since a prior knowledge of the air characteristics allows the selection of analytical standards for the GC.

Colorimetric tubes provide a means of qualitative/semi-quantitative identification of volatile organic and inorganic chemicals. The sample is drawn into the tube by means of a hand-operated pump. Since the reagents in each tube react with a specific chemical compound, prior knowledge of the chemicals expected is necessary for selection of the tubes. At a minimum, tubes for hydrocyanic acid, phosgene and hydrogen sulfide should be used on sites investigated.

For positive identification of all the pollutants that may be present, various collection media are used in conjunction with sampling pumps. Sampling pumps are commercially available in a number of configurations, but for general site characterization, an intrinsically safe "NIOSH" pump is recommended. This type of pump is portable, battery operated, and sufficiently lightweight so that it can be worn by personnel. Typical collection media include activated carbon, Tenax GC, XAD-2, silica gel and Florisil tubes, membrane and glass fiber filters, polyurethane foam plugs and impingers containing selected reagent solutions. Specific applications for these media, including the typical laboratory analysis required are given in Table III.*

*For a complete listing of methods and collection media for air sampling, see References 15, 16 and 17.

Table III.
Specific Applications for Collection Media Including the Required Laboratory Analysis.

Pollutant	Collection Media	Laboratory Analysis
Volatile organics	Carbon tubes Tenax tubes XAD-2 tubes Silica gel tubes	Gas chromatograph/mass spectroscopy (GC/MS)
Particulate organics	Glass fiber filters	GC/MS
Pesticides (including PCBs)	Florisil tubes Polyurethane plugs Glass fiber filters	GC/MS GC/Electron capture
PBBs	Glass fiber filters	GC/MS
Metals	Membrane filters	Atomic absorption (AA)
Volatile inorganics	Impingers/reagent solutions	Wet chemical methods
Particulate inorganics	Membrane filters Glass fiber filters	Wet chemical methods
Cyanides	Filters/impingers	Wet chemical methods

As previously mentioned, pump placement for volatile materials can be determined by using the PID, the FID and colorimetric tubes to survey the site for hot spots. In general, pumps are placed in selected work areas, as well as near drums, leachate ponds or streams, surface water impoundments, lagoons, areas with visibly contaminated soils and in the headspace of groundwater monitoring wells. Upwind and downwind sampling points are recommended.

Once personnel protection has been determined, air monitoring is still necessary. For example, assume that an air-purifying respirator has been determined to be adequate for a worker involved in drilling operations. Since drilling may result in a spontaneous release of toxic substances, a means to determine if the air quality has changed is necessary to insure that the respirator will protect the worker. In this situation, a FID or a PID can be used to give a real time readout of pollutant levels. A combustible gas indicator/oxygen meter combination should also be used to determine if an explosive situation has been created. If the drilling operations are long term, it would be desirable for the worker to wear a sampling pump fitted with a carbon or Tenax tube so that his/her total exposure can be monitored. Real-time monitoring should also be used for drum opening and staging, sampling, excavating, draining of tanks and lagoons and related remedial action activities.

Environmental Monitoring

Environmental monitoring also can be performed using the equipment discussed in this paper. Of particular concern is the impact that site work activities have on the surrounding community, since new hazards may be created. In general, the highest concentrations of toxic pollutants will occur directly over the site, close to the point source. A reasonable assumption is that the concentrations will decrease as the pollutants migrate offsite. Thus, if a complete air monitoring program for personnel protection has been initiated, the values measured onsite can be considered worst case.

Several models have been developed to predict the air emissions from sites.[18, 19, 20] However, offsite monitoring may be required, since in many cases workers spend a good deal of time at the site boundaries. A common mistake is to remove protective gear, as if the site boundary somehow limits pollutant migration. This type of site boundary monitoring is an integral part of evaluating overall site safety.

CONCLUSION

Entry into a hazardous substance site involves potential exposure to a number of hazards. It is essential that the risks associated with these hazards be determined such that protective measures can be taken to maintain worker health and safety. A hazard assessment is necessary and should precede any site work. Background research for site specific information as well as on-site air characterization will supply the quantitative data needed to perform the assessment. A personnel safety plan should be designed based on these data.

In addition to the quantitative data, many qualitative judgments enter into the determination of an effective and efficient safety plan. Perhaps the most important factor is determining if the physiological and psychological stresses caused by wearing protective gear are greater than the risks of direct exposure to hazardous substances. Therefore, individuals with training and experience in hazard evaluation and the implementation of a personnel protection plan are as necessary as the monitoring equipment used to characterize the ambient air.

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SHAKEDOWN AND PERFORMANCE TESTING OF THE EPA-ORD MOBILE INCINERATION SYSTEM

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INTRODUCTION

The EPA's mobile incineration system was designed and constructed under the Office of Research and Development's program to demonstrate the feasibility and practicality of destroying/detoxifying hazardous substances and wastes that have been improperly discarded at landfills, spilled onto soil or stored in above-ground containers. The basic purpose of the incinerator is to allow cleanup to take place totally at the affected site, thus avoiding both transport and the ever present institutional barrier that an area will become a permanent destruction site.

The system is purposely over-designed to accommodate diverse situations and can be further modified to handle unique situations. It is expected that private interests will make use of the plans, specifications and reports to construct and use versions that are more dedicated to particular, defined problems where the research potential is not required.

Those skilled in the art will readily determine what changes should be made and will, undoubtedly, be able to reduce both construction and operating costs. As an example, operating cost savings can be achieved by better utilization of waste heat.

SYSTEM DESCRIPTION

The mobile incineration system is mounted on three 45-ft air-ride suspension trailers for permit-free hauling over Interstate Highways and improved roadways, as well as for short-distance travel over unimproved roads or terrain to a suitable setup site. The system is self-contained, except for consumable supplies (water, fuel, chemicals and power, which preferentially will be supplied by commercial lines, but can be furnished by auxiliary diesel generators).

To conform to applicable regulations and operating permit requirements, gaseous emissions are continuously monitored or intermittently sampled to the extent required and all solid and liquid wastes are collected, analyzed and treated, as necessary, before disposal. The system was specifically designed to meet the stringent requirements (40-CFR-761) for the incineration of polychlorinated biphenyls (PCBs), namely, minimum residence time of 2 sec at 2200 °F at 3% excess oxygen, and attainment

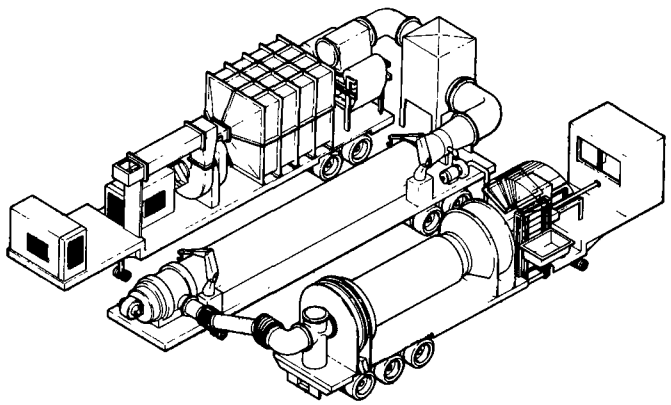

Figure 1.
Mobile Incineration System. Trailer #1 (lower right) showing control booth, solid feed mechanism and kiln with ducting to Trailer #2 (center) showing secondary combustion chamber and flue gas quench with ducting to Trailer #3 showing particulate filter, mass transfer scrubber, induced draft fan with diesel drive and base of stack, and diesel-electric unit.

of a combustion efficiency of 99.9% along with such related requirements as limitations on the release of particulates and acid gases, destruction and removal efficiency and rapid shutdown in the case of malfunction or failure to meet the criteria of 40-CFR-761.

The principal unit on Trailer No. 1 is a 52-in. ID by 16 ft long A.P. Green "Kast-O-Lite 30 in.* refractory-lined kiln having specially designed double layer, leaf type, stainless steel seals packed with graphite-impregnated packing and rotated by a hydraulically driven motor with speed and pitch adjusted to regulate the residence time of solids. The effective volume is 236 ft^3. Firing is with two tilted 4 in. Maxon burners with proportioned air control. Controlled tuyere (excess) air is also provided to accommodate atomizer injected liquids, pumpable sludges and ram fed solids.

The hopper-fed ram has an adjustable stroke and frequency. Liquid and solid wastes will be homogenized separately to ensure homogeneous composition and heat value, since variations in feed composition can lead to highly objectionable combustion transients. Liquid and solid wastes can be fed into the kiln concurrently. Tempering water is injected into the kiln to control temperatures and maximize throughput.

The first trailer also has a motor-powered hydraulic system, forced air blower and the required piping and instrumentation. Thermocouples are mounted to record temperature (the maximum is 1800°F) and an oxygen concentration meter monitors the exit gas.

The second trailer is designed to support the secondary combustion chamber (SCC) which has the same bore and refractory as the kiln, but is 36 ft long. The SCC is surrounded with a shroud through which cooling air is passed. The second trailer also has two Maxon burners and is designed to meet the 40-CFR-761 requirements for PCB incineration.

Gases pass from the kiln, whose primary purpose is to initiate combustion and to insure that hazardous substances are fully volatilized from any solids, through "inconel" ducting—designed to handle misalignment and temperature-induced dimensional changes. A swirl plate at the entrance to the SCC aids development of turbulence (the design Reynolds number is greater than 30,000). The temperature and oxygen concentration are continuously monitored at the end of the SCC. The residence time is computed from feed and temperature data. The SCC trailer has its own air supplies and the necessary instrumentation and control equipment.

The SCC terminates in a gas flow measuring venturi alloy nozzle that conducts the flue gas to a quench elbow equipped with water spray nozzles that drop the gas temperature to approximately 180°F and remove some particulates and acid gases.

The gas/vapor is ducted to a ground-level, baffled sump and then ducted upwards to the first element on the third trailer, namely, a "CHEAF" particulate remover, also fabricated from an "Inconel" alloy. The CHEAF collects particulates on a sprayed fiberglass belt that is pulled through and re-rolled automatically when the pressure drop (approximately 40 in. W.C.) exceeds a set-point as the belt becomes plugged with particulates (down to the 0.3 μ range).

The gas/vapor then enters a cross-flow caustic mass transfer unit ("Ceilcote") (MX) packed with "Telerettes" and scrubbed with sodium carbonate or caustic soda as required. Fluid levels in the quench tank, CHEAF and MX sumps are controlled, pH is measured and makeup water or alkaline fluid is added as required. A demister section is incorporated into the MX. The 150 hp diesel-driven induced draft fan can develop the equivalent of 70-90 in. W.C. for use at mile-high altitude sites and consists of an "Inconel" shaft and 36 in. impeller with a SS 316L housing.

A controlled reflow duct connects the exit of the fan to the inlet of the CHEAF to maintain the correct pressure drop across the CHEAF. The flue gas from the fan passes through a sound suppressor and the stack, which has ports for the flue gas sampling that is required by regulations. The nominal gas flow is 7200

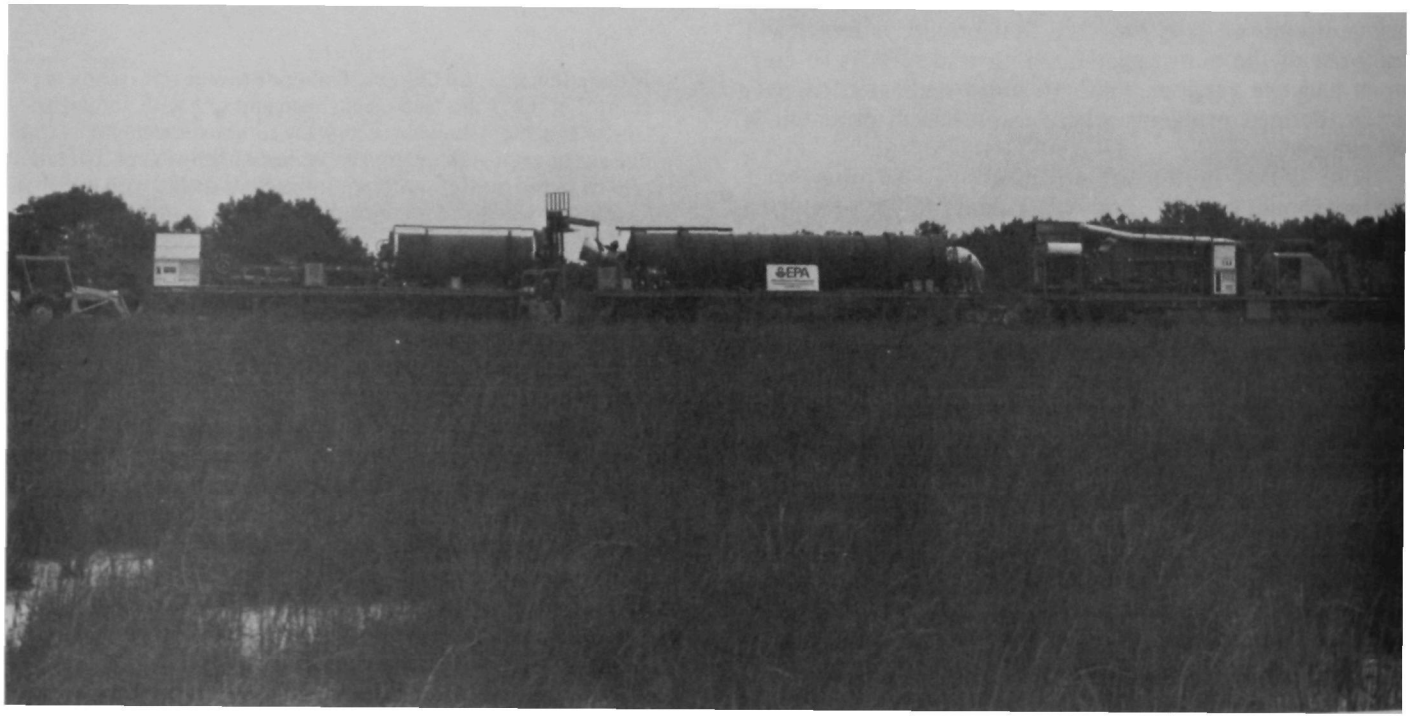

Figure 2.
Field assembly of Mobile Incineration System showing (left to right) Trailer #1 with feed and kiln, Trailer #2 with secondary combustion chamber and venturi quench and sump, and Trailer #3 with particulate filter, mass transfer unit (scrubber), open control panel, draft fan and drive, and electric power supply. (Back-hoe at far left used in assembly.)

scfm. The instrumentation and interlock system on Trailer No. 3 is the most complex.

The system is designed to accept as feed those substances cited pursuant to Sections 311 and 307 of the Clean Water Act, along with materials designated under the Resource Conservation and Recovery Act. The feeding of inorganic salts, which tend to flux the kiln refractory, and of heavy metals, which form volatile oxides or halides, must be controlled; data gathering on this aspect is an integral part of the continuing shakedown/testing.

SYSTEM TESTING

At the time this paper was written, shakedown was essentially complete, i.e., the pumps, valves, switches, interlocks, etc. have been tested singly and as a system, but without firing the system.

The current test plan has five major phases, each of which involves extensive sampling and analysis:

(1) commercial fuel oil burn,
(2) burn of fuel oil spiked with iron oxide particles,
(3) incineration of fuel oil spiked at increasing levels of dichlorobenzene,
(4) combustion of fuel oil spiked with increasing concentrations of PCBs (or Aroclors) and
(5) incineration of an oil-based waste leaching from a local landfill.

Federal and State of New Jersey permits are both required, as is assent from the municipality in which the test is conducted. Local residents have visited the facility and will participate in a public hearing.

The main purpose of the fuel oil burn is to establish baseline data. Extensive gas sampling, for example, with the modified method 5 system and/or SASS train, will be replicated. The presence of polychlorodibenzodioxins (PCDD) and polychlorodibenzofurans (PCDF) will be carried to the limit of detection. All wastes will be analyzed and continuous or intermittent measurements (as required) will be made on carbon dioxide, carbon monoxide, hydrochloric acid, sulfur oxides, nitrogen oxides, total hydrocarbons, polluting organic hazardous chemicals (POHCs), particulates, etc.

The test with iron oxide-spiked fuel oil will assess the efficiency of the particulate removal capability of the system. Many factors were taken into account in choosing a very fine iron oxide. Subsequently, testing is planned with metal soaps, metal alkyls and metal aryls.

In the third phase, orthodichlorobenzene will be added to fuel oil in concentrations of 1, 5 and 25% to assess DREs, chiefly.

In the fourth phase, based on the outcome of the preceding chlorinated aromatic chemical tests, actual samples of PCBs or PCB-containing fluids will be fed at concentrations of 0.05, 1, 10 and 20%. A planned fifth phase will be based on the effective incinerability of an oily waste leachate contaminated with priority pollutants.

In all these tests, the system will be first brought to temperature, which requires 16-24 hours, and then operated as long as is required to collect meaningful samples. The system will then be idled (not fully cooled down) until the next phase is to be intiated. Excluding tests on a proposed leachate, the test series will require 45 days. The data are expected to yield a definitive array of combustion and operating conditions that can be adapted for use in detoxifying other hazardous substances.

Since the mobile incineration system is a research unit, provision has been made for the incorporation of modifications, especially in air pollution control, should these be indicated.

ACKNOWLEDGEMENTS

The basic system was fabricated by MB Associates (now Tracor-MBA), San Ramon, California, under EPA contract 68-03-2515. Especial mention should be made of the contribution of R. Tenzer, Wm. Mattox, P. Kirkegaard, Wm. Ford, D. McKown, and their associates.

The major part of the system was delivered in September 1980 to an on-site operating unit in Edison, N.J., namely, the Environmental Emergency Response Unit (EERU) (a contractor-operated facility), for completing assembly, undertaking shakedown, conducting tests and performing field demonstrations. EERU was operated by Mason & Hanger-Silas Mason Company, Inc., under Contract No. 68-03-2647 until June 1981. Thanks are due to M. Sproul, G. Campbell, V. Manolio, F. Brown and the Mason & Hanger home office staff (Lexington, KY) that prepared most of the P&I diagrams and initiated installation of the instrumentation and control equipment and the various lines (electric, hydraulic, fuel, compressed air).

EERU is now being operated by IT Enviroscience under Contract No. 68-03-3069. ITE has current responsibility for completion of assembly, shakedown, field testing and operation. The contributions of C. Steuwe, C. Pfrommer, S. Anicito, A. Sherman and R. Miller, on site, and of R. Novak, R. Lovell and many others at ITE headquarters (Knoxville, TN) are acknowledged.

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HISTORY AND BENCH SCALE STUDIES FOR THE TREATMENT OF CONTAMINATED GROUNDWATER AT THE OTT/STORY CHEMICAL SITE, MUSKEGON, MICHIGAN

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INTRODUCTION

Hazardous leachates and contaminated ground and surface waters are often associated with unsecured industrial waste storage and disposal sites. Numerous problems are encountered in the cleanup of such a site. One major problem is identifying the most effective treatment technology for the contaminated stream. Contributing to this problem are:

(1) The inability to characterize completely the contaminated stream due to technical and economical limitations
(2) The paucity of information on the effectiveness of techniques for treating the broad spectrum of organic and inorganic compounds frequently present in these streams.

Therefore, the U.S. Environmental Protection Agency began a project now being conducted by Touhill, Shuckrow and Associates, Inc. (TSA) to evaluate techniques for concentrating hazardous constituents of aqueous waste streams. A literature review, desktop evaluation and laboratory bench scale experimental studies form the basis for judging the potential of numerous candidate technologies.

During the course of this project, a part of the laboratory experimental work was carried out at Cordova Chemical Company, present owners of the Ott/Story Site, using groundwater contaminated by prior operations. This site provided an opportunity to interface research activities with development of a treatment system for a high priority problem site.

In this paper, the authors provide a brief background on the site history, a method selection of candidate treatment technologies and summary of results of the experimental studies.

SITE HISTORY

During 1957, Ott Chemical Company began production of various organic chemicals in Dalton Township, Michigan, north of the City of Muskegon.[1] Many of the organic chemicals produced used phosgene as a raw material. At the time of plant startup, Michigan State Water Resources Commission permitted Ott Chemical Company to discharge wastewaters into seepage beds, provided that certain limitations on the types and amounts of substances disposed were adhered to and that the discharge was monitored regularly and results reported to the state.

Permit Violations

Beginning in 1957 and continuing through 1967, permit violations were evident. Initially, chlorides and phenols were detected in monitoring and water supply wells. Ott Chemical Company attempted to mitigate pollution problems, by using a groundwater purge system to contain the contaminated plume on company property, and by reducing contaminant concentrations in their discharges to the seepage beds. The State permitted discharge of purged groundwater to a nearby creek, provided there was no impairment of stream's beneficial use.

Although the remedial action program reduced contaminant concentrations going into groundwater and limited pollution migration, other problems became evident. Fish tainting because of purge water discharge was observed in the nearby creek, and other groundwaters in the area were polluted by stored or disposed wastes.

In recognition of the continuing and spreading problem and the fact that remedial actions were not successful completely, the State began, in 1965, water quality investigations to document the extent of contamination. At least 40 organic chemicals, some of which are considered to be hazardous, were identified in the groundwater.

Remedial actions continued but in 1968 the State ordered discontinuance of direct discharge of process wastewaters to the groundwater. Although cooling water discharges were still permitted to be discharged to the seepage beds, treatment of process waters prior to discharge to the Muskegon River was required. Nevertheless, wastes stored on site and spilled in the plant area continued to exacerbate and spread the problem. In 1974, process wastes and purged groundwater were connected to the municipal wastewater treatment system.

Up to 1976, attempts to improve waste handling practices at the site continued. Some of these efforts included: waste incineration, development of spill prevention measures and plans for deep well disposal. However, control of the contaminated groundwater plume was not accomplished and the pollutants continued to migrate toward residential water supply wells down-gradient from the plant site. A small nearby trout system became severely degraded by contaminated groundwater exfiltration.

Ownership Change

Solutions to the contamination problems were hindered, to some extent, by operating entity and ownership changes between 1965 and 1973. In the 1972-1973 period, Story Chemical Company became owner of the facility. Ultimately, during 1976, Story Chemical Company filed for reorganization in Federal Bankruptcy Court, abandoning the plant site in September 1977. Site abandonment caused additional concern because of 23,000 pounds of phosgene gas left in two containers on site.

In October 1977, Cordova Chemical Company purchased the facility, and cooperated with the State in site cleanup, including providing funds to furnish an alternate water supply for the area. In return, the state agreed to limit the new owner's liability for previous problems.

In 1979, groundwater contamination was found at a depth of 30 m, and the contaminated plume was 400 m wide. Furthermore, wells in the area were deemed unpotable and residents were advised to use bottled water for drinking.

Ott/Story operations left a number of unresolved concerns. In particular, large volumes of organic chemical migrating through soil and ground and surface water continued to have an adverse environmental impact. It was within this context that bench scale studies were conducted to uncover suitable treatment methods for decontaminating polluted groundwater.

Table I.
Treatment Process Trains

Process Train Sequence	Ancillary Processes	Waste Type
Biological followed by carbon sorption	pH adjustment, coagulation, settling before biological for heavy metal control. Clarification, filtration before carbon for solids removal	High TOC, low in toxics (to biomass)
Carbon sorption followed by biological	pH adjustment, coagulation, settling before carbon to reduce solids loading	High TOC, high in toxics (to biomass
Biological with powdered activated carbon included	Biophysical system proceeded by coagulation and clarification to minimize heavy metals and solids loading	High TOC, high in toxics
Membrane followed by biological	pH adjustment, clarification and filtration before membrane to prevent membrane fouling	Membrane removes high molecular weight organics and inorganic ions; biological removes remaining organics
Stripping followed by carbon sorption	pH control before stripping. Clarification and filtration before carbon for solids removal	Stripping to remove volatile organics and reduce organic load to carbon; carbon to provide further organic removal

LITERATURE REVIEW/DESKTOP EVALUATION

Results of the literature and desktop evaluation have been reported elsewhere.[2, 3] The following list of candidate concentration technologies was developed:

BIOLOGICAL TREATMENT
CARBON ADSORPTION
CATALYSIS
CENTRIFUGATION
CHEMICAL PRECIPITATION
CRYSTALLIZATION
DENSITY SEPARATION
DIALYSIS/ELECTRODIALYSIS
DISTILLATION
EVAPORATION
FILTRATION
FLOCCULATION
ION EXCHANGE
RESIN ADSORPTION
REVERSE OSMOSIS
SOLVENT EXTRACTION
STRIPPING (AIR AND STEAM)
ULTRAFILTRATION

The processes that had the greatest range of applicability included:

BIOLOGICAL TREATMENT
CHEMICAL COAGULATION
CARBON ADSORPTION
RESIN ADSORPTION
STRIPPING
MEMBRANE PROCESSES

It also was concluded that these unit processes would have to be assembled in process trains (containing more than one of these unit operations) to achieve the degree of treatment required at most sites. Five possible process trains were formulated (Table I). These trains do not represent the only possible configurations; however, they do provide broad range applicability to a wide variety of contaminants.

These process combinations were developed with data from single compound studies. Actual treatability of multi-compound streams generally will require bench-scale studies using actual wastewater. Because of the specific contaminants at the Ott/Story site, chemical coagulation and membrane processes were judged to have limited application and were not studied in the laboratory.

BENCH SCALE STUDIES OF UNIT PROCESSES

In laboratory bench scale studies, individual unit processes were examined first; then process trains were evaluated. Wastewater used in these studies was contaminated groundwater at the Ott/Story Site collected from two wells located in the contaminant plume. For a portion of the studies, an equal volume composite of water from these two wells was used; in other studies the water from each well was used separately. Analyses of the composite sample and water from the separate wells are shown in Table II. Although the water from well W-17d has a much lower total organic carbon (TOC) concentration, it con-

Table II.
Groundwater Quality at the OTT/Story Site

	Composite Sample (50% OW-9 & 50% W-17d)	Well OW-9	Well W-17d
Conventional Pollutants:			
pH	9.3 - 12	9.6 - 1105	9.5 9.6
COD (mg/l)	5400	5200 - 8300	1600 2600
TOC (mg/l)	400 - 1500	1500 2400	171 730
NH_3-N (mg/l)	64	40 163	7.9 16
Major Priority Pollutants: (in µg/l)			
Vinyl chloride	ND - 32,500	ND	ND - 5,240
1,1-dichloroethylene	5 - 6,570	ND - 2600	ND
1,1-dichloroethane	60 - 19,850	ND - <0.1	ND 6,570
1,2-dichloroethane	350 - 111,000	>500 - 2000	3,670 >1000
Benzene	ND 7,370	600 - 900	>5000 25,000
1,1,2,2-tetrachloroethane	5 1,590	ND - <1	ND - 1,590
Toluene	5 5,850	3,300 5,600	3,610 - 7000

tains many of the same organic priority pollutants as well OW-9, frequently at similar concentrations.

Results of many of these experimental studies have been described in detail elsewhere.[2, 4, 5, 6] In this paper, a brief summary is presented.

Steam Stripping

Continuous flow, steam stripping experiments were conducted using a composite sample. The TOC concentration in the stripper bottoms ranged from 300 to 400 mg/l and appeared to be independent of the overhead: feed ratio. Overhead TOC concentration approached 3500 mg/l at an overhead:feed ratio of 0.06. The average TOC reduction between feed and bottoms was 34%.

These results indicate a major constraint associated with steam stripping, i.e., it is necessary to further treat a bottom waste stream having a flow only slightly less than the feed flow. Because the TOC concentration appeared to be independent of system flow rates and feed TOC levels over the ranges examined and because additional treatment of the bottoms would be necessary, steam stripping would likely be a costly, yet only moderately effective, concentration process.

Adsorption by Granular Activated Carbon and Resin

Batch isotherm studies were used to evaluate various sorbents and operating conditions. Then continuous flow granular activated carbon (GAC) studies were conducted off pH 9.3 to 10.0, using Filtrasorb 300 GAC.

In continuous flow studies three or four glass columns arranged in series with sampling ports located at the influent and effluent ends of each column were used. Each column was 122 cm by 2.5 cm (ID) and contained 91 cm of GAC. The system was operated in a downflow mode at a loading rate of approximately 1.35 l/m^3s (2 gal/min/ft). This provided an empty bed contact time (EBCT) of approximately 15 min. per column.

Influent TOC concentration varied substantially, ranging from 316 to 950 mg/l. Generally, after only 3 to 10 bed volumes (BVs), TOC removal decreased to 50%. TOC leakage reached 90% after about 200 to 240 BVs were processed and continued at this level until up to 500 BVs had been processed. As would be expected, effluents from columns 2 and 3 were intermediate between columns 1 and 4. Column performance data correspond to batch sorption study data.

The difference between treatabilities of the composite groundwater and waters from the individual wells is shown in Figure 1. Organic materials in W-17d (as reflected by TOC concentration) were more readily sorbed by GAC than was TOC in the composite groundwater or OW-9 groundwater.

Continuous flow resin adsorption studies were conducted on the composite sample using XE-347 carbonaceous resin. Again, these continuous runs were preceded by batch isotherm studies.

Three columns similar to those used for GAC studies were charged with 792 to 835 cm^3 of resin and were operated at loading rates of 2.95 to 3.79 BV/hr. EBCT ranged from 6 to 20 min.

Breakthrough characteristics were similar to those of the GAC studies except that XE-347 TOC removal declined more rapidly. TOC removal diminished to 50% after about 5 BV were processed and appeared to stabilize at about 10% for at least 120 BV.

Biological Treatment

Several attempts were made to acclimate an activated sludge culture to raw groundwater. All attempts, however, were minimally successful. Neither a conventional activated sludge nor a commercial microbial culture could be acclimated. A light colored, filamentous biomass which settled poorly appeared to be indigenous to the water and inhibited a healthy biomass.

Approximately 80% TOC reduction was achieved; however, stripping due to aeration appeared to account for about two-thirds of this removal. Addition of trace elements and nutrients, and pH adjustment to pH 7.0 to 7.5 did not aid microbial acclimation to raw ground-

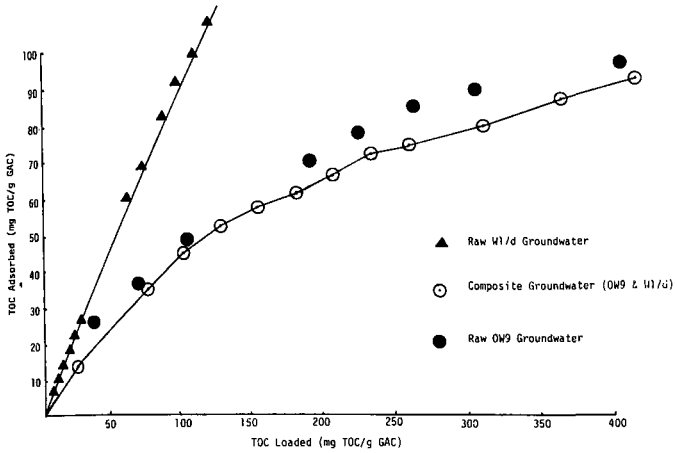

Figure 1.
TOC Adsorption by GAC

water. Addition of powdered activated carbon (PAC) at aeration chamber concentrations of approximately 10,000 mg/l also did not aid acclimation to raw groundwater or improve TOC removal or mixed liquor appearance.

BENCH SCALE STUDIES OF PROCESS TRAINS

Granular Activated Carbon/Aerobic Biological Treatment

Because of the apparent toxicity of groundwater to biological processes and the rapid breakthrough of TOC in adsorption systems, a process train consisting of granular activated carbon (GAC) followed by activated sludge (AS) biological treatment was investigated. It was expected that GAC would protect the biological system from toxic materials while organics leaking from the GAC would be degraded or stripped during the biological process.

Carbon pretreatment of raw groundwater permitted development of a culture of aerobic organisms capable of further treating GAC effluent. In excess of 95% TOC removal was realized by this process during the period when TOC removal by the GAC exceeded 30%. After this initial period, process train performance declined as carbon performance declined. Data indicate that:

(1) Some fraction of TOC which initially is sorbed by carbon begins to leak through the system after a short period of operation
(2) The fraction of TOC which leaks through the carbon system is not toxic to the biological system but does not appear to be removed or reduced either biologically or by air stripping associated with AS aeration
(3) Operation of the biological process at hydraulic retention times ranging from 4 to 16 hr, with or without powdered activated carbon, or with or without Phenobac seems to have little impact on process performance (based upon TOC removal)
(4) Overall system performance was maintained at 75-85% TOC removal (effluent TOC of 100 to 185 mg/l) for about 21 days (46 retention times for biological system and 110 BVs for carbon).

As shown in Table III, organic priority pollutant analyses conducted during operation of the GAC/AS System indicated that almost all of the organic priority pollutants detected in the raw groundwater were removed consistently to less than the level of detection (0.01 mg/l) by the system. Additionally, the AS process completely removed the few organic priority pollutants leaking through the GAC system even during the phase of operation when overall TOC removal was declining. Analysis of biological sludge showed no organic priority pollutants at a 0.01 mg/l detection level.

Granular Activated Carbon/Anaerobic Treatment

A GAC/upflow anaerobic filter (UAF) system was investigated using the composite groundwater and water from well OW-9 (both high TOC waters). UAF performance declined as GAC performance declined. Changes in UAF organic loading rate did not appear to affect UAF performance.

Overall, the performance of the GAC/UAF process train was slightly poorer than the GAC/AS process train achieving a maximum TOC removal of 81% when treating the composite groundwater. During this period TOC removal averaged 66% and ranged from 38 to 81%. The average TOC removal by the GAC process was 31% with a range of 10-46%; the average TOC removal by the UAF process was 50% with a range of 12-67%.

GAC/Trickling Filter Treatment

The GAC/TF process train was investigated because operation was expected to be easier and less energy intensive than activated sludge and also less likely to induce stripping of volatile organic compounds.

An unseeded trickling filter provided little or no removal of TOC from GAC pretreated groundwater. A new filter, initially seeded with activated sludge recycled for about four weeks, developed a significant biomass on the filter media. Although TOC removal was substantially better than for the unacclimated system, performance was poorer than achieved by the GAC/AS process train. Moreover, as GAC performance steadily decreased, anaerobic conditions developed in the TF.

Granular Activated Carbon/Anaerobic/ Aerobic Biological Treatment

The GAC/UAF treatment process discussed earlier was modified by the addition of an activated sludge process. When TOC leakage from the GAC process was considerable, the aerobic process reduced the UAF effluent TOC by 50% or more. Otherwise, little additional TOC removal was achieved by the AS process. The process train provided TOC removals of 86 to 100%. The importance of GAC pretreatment was demonstrated when,

Table III.
TOC and Priority Pollutant Data for Granular Activated Carbon/Activated Sludge Process Train (mg/l)

Compound	Raw Groundwater 9-16-80	GAC Effl. 9-16-80	Raw Groundwater 9-23-80	GAC Effl. 9-23-80	AS Effl. 9-24-80	GAC Effl. 10-1-80	AS Effl. 10-1-80
TOC	637	380	929	604	90	770	183
Total Cyanide	NA	NA	0.11	0.21	0.23	0.23	0.20
CN	NA	NA	0.05	0.05	0.05	0.05	0.05
Total Phenol	NA	NA	16	0.16	0.10	0.10	0.10
Methylene chloride	2.1	0.029	14	0.01	ND	0.16	ND
1,1-Dichloroethene	1.6	ND	0.06	0.01	ND	ND	ND
1,1-Dichloroethane	2.4	ND	0.17	0.02	ND	ND	ND
Trans-1,2-dichloroethane	0.06	ND	0.04	ND	ND	ND	ND
Chloroform	9.8	ND	0.70	0.06	ND	ND	ND
1,2-Dichloroethane	72	ND	25	1.4	ND	0.05	ND
1,1,1-Trichloroethane	7.6	ND	0.39	0.04	ND	ND	ND
Trichloroethylene	0.06	ND	0.03	ND	ND	ND	ND
Benzene	1.2	ND	1.5	0.02	ND	ND	ND
1,1,2-Trichloroethane	0.11	ND	0.07	ND	ND	ND	ND
Perchloroethylene	0.49	ND	1.9	ND	ND	ND	ND
Toluene	2.3	ND	0.97	0.05	ND	0.01	ND
Chlorobenzene	0.23	ND	0.29	ND	ND	ND	ND
Phenol	0.025	ND	0.028	ND	ND	ND	ND
2-Chlorophenol	0.040	ND	0.036	ND	ND	ND	ND
2,4-Dichlorophenol	0.010	ND	0.010	ND	ND	ND	ND
1,2-Dichlorobenzene	0.085	ND	0.077	ND	ND	ND	ND
Dibutyl phthalate	ND	ND	ND	ND	0.05	ND	ND

NA—not analyzed
ND—not detected
No other priority pollutants detected at 0.01 mg/l detection limit

within one day after carbon pretreatment was terminated, UAF process performance declined markedly. Results from this series of tests indicated that:

(1) As the UAF process became acclimated, its performance improved and it accounted for a larger share of TOC removal.
(2) As the carbon column performance declined, UAF performance also declined.
(3) Generally, the AS process provided minimal TOC removal. Aerobic biodegradation, stripping or adsorption onto mixed liquid solids were negligible. However, a normal appearing, well-settling activated sludge biomass, albeit one with a relatively low MLSS (mixed liquor suspended solids) and low sludge production, was observed.
(4) As TOC leakage from the carbon column increased, overall system performance declined; however, the amount of removal attributable to the aerobic process increased.
(5) The overall system, under the operating conditions studied, generally did not perform as well as the GAC/AS train, i.e., it did not maintain low effluent TOC levels ($<$ 50 mg/l) for as long as the GAC/AS train. However, both systems appeared to be able to maintain effluent TOC levels below 100 mg/l for equivalent duration.

Ozonation Treatment Studies

The effects of ozone (O_3) pretreatment were evaluated using O/AS and O_3/GAC/AS process trains. Ozonation conditions were as follows:

- Air served as ozone source.
- O_3 dose—2g/hr.

•O_3 flow rate—2 liters/minute.
•Batch O_3 contact time—1 hour/3 liters of groundwater.

The process trains involving ozone pretreatment did not perform as effectively as the other trains studied thus, suggesting little benefit to pre-ozonation (in terms of TOC removal aside from that attributed to stripping during ozonation). TOC removal by the O_3/AS train ranged from 37 to 60% while removal by the O_3/GAC/AS train ranged from 42 to 88%.

While little change in TOC concentration may occur as the result of ozonation alone, ozonation might be expected to enhance either the biodegradability or adsorption of organics. However, pre-ozonation did not appear to improve the performance nor increase the longevity of carbon treatment on the basis of TOC breakthrough.

CONCLUSIONS

Desktop evaluations identified a number of concentration technologies that may be applicable for treating hazardous leachates and contaminated ground and surface waters. The most promising, broadly applicable technologies were:

•Adsorption : carbon and resin
•Biological treatment (aerobic and anaerobic)
•Biophysical treatment
•Chemical coagulation
•Membrane processes
•Stripping : air and steam

These unit operations then were studied separately and in combinations using groundwater from an actual hazardous waste contamination site.

Carbon pretreatment of the raw groundwater permitted development of both aerobic and anaerobic biological processes apparently by removing pollutants toxic to the biological processes. Highest TOC removals were achieved with an activated carbon/aerobic biological (activated sludge) system. However, as the carbon performance declined, so did that of the rest of the system. The GAC/anaerobic biological process train performed somewhat more poorly than the GAC/activated sludge system. Studies of ozonation did not imply any advantage as a pretreatment operation. The process of ozonating yielded TOC removals similar to that achieved by air stripping.

ACKNOWLEDGEMENT

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DESIGN OF A TREATMENT SYSTEM FOR HAZARDOUS RUN-OFF

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INTRODUCTION

On July 30, 1979, the State of Pennsylvania requested that the U.S. Environmental Protection Agency (EPA) conduct an on-site assessment of an abandoned mine drainage tunnel, known as the Butler Tunnel, from which an unknown discharge was entering the Susquehanna River. Approximately 500 to 1,000 gal/day of oily sludge, along with an assortment of cutting oils, aromatics, substituted phenols, alkyl resins and short and branched chain hydrocarbons were being discharged from the tunnel. This discharge was traced to an alleged illegal dumping of millions of gallons of toxic wastes into an abandoned coal mine through a sewer borehole at Dupont, Pennsylvania, two miles inland from the river.

Roy F. Weston, Inc. was retained by EPA to determine alternative approaches to treatment and/or decontamination of the toxic oily material that might be found in coal mine pools being drained by the tunnel, as a result of exploratory drilling (by other EPA contractors) at Pittston, Pennsylvania. In addition, Weston was to conduct a similar investigation on the Butler Tunnel. For both of these investigations, the consultant's work was to include physical and chemical characterizations of the contaminated material, and an evaluation of disposal techniques for treating the wastes.

The project had four phases:

Phase I: pertinent available data on mine pool wastes were to be collected and reviewed. Analytical protocols for characterization of the mine pool wastes were to be developed. Potential alternatives for concentration and disposal of the wastes were to be determined.

Phase 2: data from treatment studies previously performed on the effluent from the Butler Tunnel were to be evaluated. Supplemental treatment studies, if necessary, were to be recommended. Alternative methods for temporarily treating the effluent were also to be recommended.

Phase 3: waste samples collected from the mine polls were to be analyzed. Cost estimates were to be developed for feasible treatment alternatives.

Phase 4: supplemental analytical and treatability studies on the Butler Tunnel effluent were to be performed, which were necessary to recommend a temporary treatment scheme for the tunnel's effluent.

Reports summarizing the results of Weston's overall project as well as an overview of the over all clean-up operation have been presented elsewhere.[1, 2]

The purpose of this paper is to present a description of the treatment process train which was designed to remove hazardous pollutants from the Butler Tunnel effluent. The development of the design basis, results of treatability studies, the design and costs for installation and operation of the equipment are presented.

CHARACTERIZATION OF TUNNEL DISCHARGE

Since August of 1979, when the Butler Tunnel clean-up program was initiated, samples of the Butler Tunnel discharge were systematically collected and analyzed for oil and several classes of toxic organic chemicals. These included analysis for dichlorobenzenes, disctyephthalate, alkylphenols, toluene, xylene, ethylbenzene and naphthalene. After a period of preliminary screening of the effluent, dichlorobenzene (DCB) was chosen as an indicator parameter in order to reduce the analytical load to a manageable level. In addition to these analytical data, the discharge flow rate from the tunnel to the Susquehanna was measured.

Presented in Figure 1 is the cumulative distribution of flow rates from the Butler Tunnel from August 1979 to April 1980. As indicated, the flow rates during this period ranged from approximately 1 mgd to greater than 12 mgd. Statistically, on 20% of the days the flow rate was less than 3.0 mgd, on 40% of the days it was less than 6.0 mgd and on 80% of the days it was less than 12.0 mgd.

Presented in Figures 2 and 3 is a comparison of the oil and DCB loads (lb/day) discharged versus the flow rate (mgd) of the discharge on the same day. During this period, the lowest flow which could be accurately measured was 2 mgd, therefore this flow rate was assumed for days on which the flow rate was reported as "less than 2 mgd." A review of Figures 2 and 3 shows that the most significant discharges of oil and DCB, in terms of lb/day to the Susquehanna River, occur when the tunnel flow rate is low. The sensitivity level for oil was estimated to be 1.0 to 1.5 mg/l.

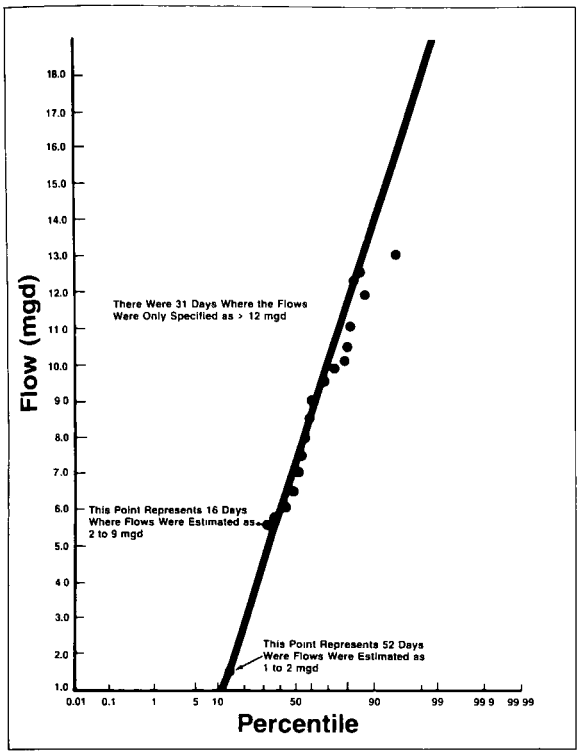


Figure 1.
Cumulative Distribution of Flows
Pittston, Pennsylvania (Butler Tunnel)
August 1979 to April 1980

The results of priority pollutant analysis of a sample of the tunnel effluent are presented in Table I. On the day that this sample was collected, the discharge was in excess of 12 mgd. These data confirm that the Butler Tunnel has been contaminated by various solvents and other organic species. Review of the data in Table I shows that the base-neutral extractable fraction represents approximately 90% of the total organics reported on the table.

TREATMENT REQUIREMENTS

In general, the analysis of the data for the Butler Tunnel discharge confirmed what was previously suspected. The principal contaminants in the discharge are oil and dissolved organics.

Regulations governing the quality of this discharge are found in Chapter 93—Water Quality Standards, of the Pennsylvania Code, Title 25—Environmental Resources. Review of this chapter indicated that there were no specific water quality criteria for the principal contaminants in the Butler Tunnel discharge. Therefore, Section 93.8—Development of Specific Water Quality Criteria for the Protection of Aquatic Life, requires that 96-hour continuous flow bioassays be run, using the methodologies referenced in Subsection 93.8e of Chapter 93. However, during the analytical program, bioassays were not run. Therefore, it was assumed, based on conversations with EPA, that treatment of the Butler Tunnel wastes for oil and organics, such as those in Table I, would be required to levels which represented reasonable reduction of the initial concentrations.

TREATABILITY INVESTIGATION

While developing the preliminary treatability plan, various specific aspects of the overall emergency program were considered including:

1. In order to successfully treat, for all the contaminants in Table I, it would probably be necessary to use activated carbon. Alternatives to activated carbon which were initially considered, but then rejected, included:
   - •Air stripping of the organic species—while this might be reasonably effective on those species found in the volatile fraction in Table I, it would probably have little effect on the base-neutral extractable fraction, which represented around 90% of the total organics present.
   - •A low-level biological system—this was rejected because of the low values for BOD_5 in the raw waste; also the significant area requirements that would be needed to treat the probably flow rates required. (The available space for on-site treatment was limited to an area of 250 ft x 70' on a ledge overlooking the mouth of the tunnel.)
2. If activated carbon was to be used, then it would be necessary to minimize any fouling problems due to oil, or material which periodically sloughed from inside the tunnel. For this reason, Weston decided that solids separation facilities were necessary before the activated carbon system and that it would also be necessary to

Table I.
Organic Analysis (GS/MS)
Butler Tunnel
March 20, 1980
Pittston, Pennsylvania

A. Base-Neutral Extractables (μg/L)	
1,2-Dichlorobenzene	164.0
Naphthalene	7.6
Diethylphthalate	13.4
Bis (2-Ethylhexyl) Phthalate	192.9
B. Acid Extractables (μg/L)	
None detected	
C. Volatile Fraction (μg/L)	
Methylene Chloride	1.6
Trans-1,2-Dichloroethylene	6.5
Chloroform	1.3
1,1,1-Trichloroethane	3.4
1,1,2-Trichloroethane	16.7
Trichloroethylene	6.8
Benzene	1.3
2-Chloroethylvinyl Ether	2.1
D. Pesticides	
None detected	

periodically inject chlorine, for disinfection of the activated carbon.

3. If activated carbon was going to be used, pH adjustment of the raw wastewater may be necessary.

To implement the treatability plan, the following tests were run:

- Activated carbon isotherms.
- Chlorine demand.
- Titration curves.

In order to economically conduct this preliminary work, DCB was chosen as an indicator parameter for analysis of the isotherms.

Presented in Figure 4 is an isotherm run on the tunnel effluent. As indicated in the figure, activated carbon may be used to treat the Butler Tunnel wastewater to DCB equilibrium concentration of less than 10 μg/l. To establish chlorine residual of 2 mg/l, a chlorine dosage of 8 mg/l was required. To adjust the pH of the raw wastewater from 4 to neutral, approximately 40 mg/l of caustic (50 mg/l as $CaCo_3$) was required.

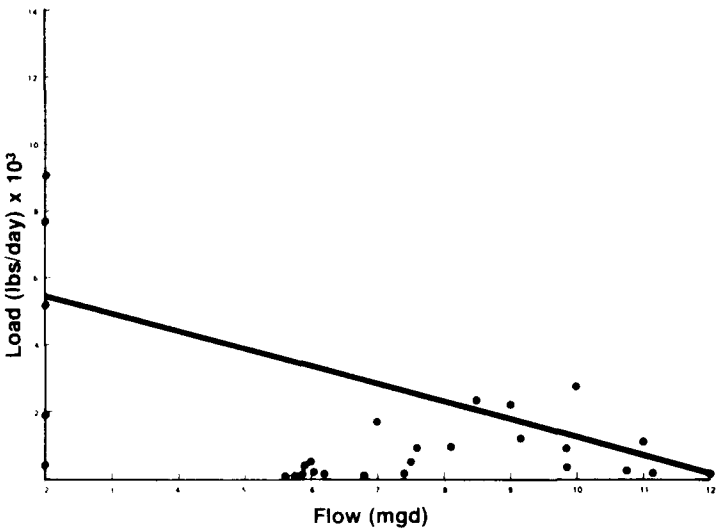


Figure 2.
Oil Load
Pittston, Pennsylvania (Butler Tunnel)
August 1979 to April 1980

PROCESS DESIGN

As a basis for its concept design, Weston used the results of its data analysis and treatability tests and, in addition, incorporated the following factors:

- Based on conversations with the EPA project officer, it was decided to investigate designs for two flow rates—
  - The most significant discharges of contaminants from the Butler Tunnel have occurred on days when the flow rate was 3.0 mgd and 6.0 mgd. The reasons for this are:
  - The construction of facilities much in excess of 6.0 mgd might be prohibitive from an economic point-of-view.
- The limitations on available land area, for an on-site facility.

Presented in Figure 5 is the general process flow diagram for the Butler Tunnel treatment system. As indicated

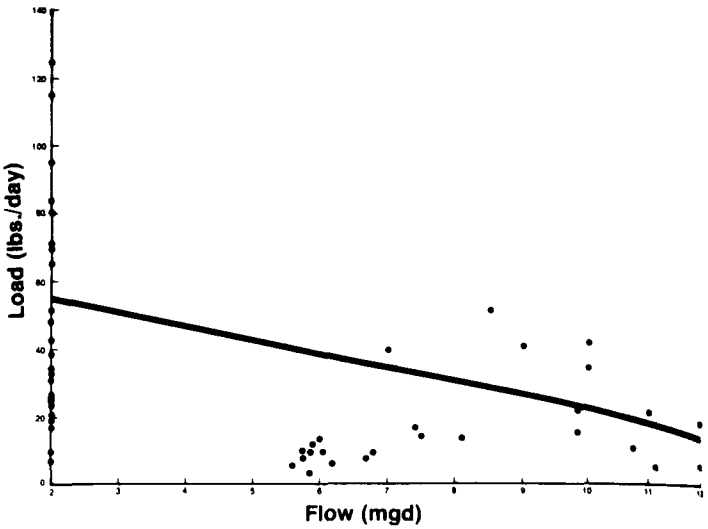


Figure 3.
DCB Load
Pittston, Pennsylvania (Butler Tunnel)
August 1979 to April 1980

in the diagram, the Butler Tunnel discharge would be treated in the following sequence:

- Water from the tunnel will flow into a wet well through a bar screen that will remove large solids. This wet well will be constructed at the mouth of the Butler Tunnel, below the ledge. The west well will have an emergency overflow provision to the Susquehanna River, so that flows in excess of the design flow can be bypassed.
- Water will be pumped from the wet well to a flow division box. The purpose of the flow division box is to divide the flow before being fed to several corrugated plate separators, operating in parallel, that will remove suspended solids and floatable oils. It will be important in the final design of the facility to select lift pumps, whose operation will keep oil/water emuisions to a minimum.
- As described above, the corrugated plate separators will remove solids and floatable oils; these two streams will be sent to holding tanks prior to ultimate disposal. Corrugated plate type separators were selected over other types of separators because they will minimize the land area required for the unit operation.
- After treatment by the separators, the wastewater will go through a pH adjustment step (to a final pH near 6.5-7), flow through another flow division box and then to parallel trains of activated carbon adsorbers.
- The preliminary design contraints for the carbon adsorbers were 30 minutes contact time and 3 gal/min/ft^2 application rate. Commercially available adsorbers were considered first; however, in order to satisfy these design constraints and to allow for mobility and accessibility at the site, more land area was required than was available. For this reason, Weston recommended the construction of four adsorbers—two trains with two stages each. Each adsorber would be compartmented into quadrants with a common centerwell. The compartmentalization will allow for backwashing facilities of reasonable capacity and size to be designed.

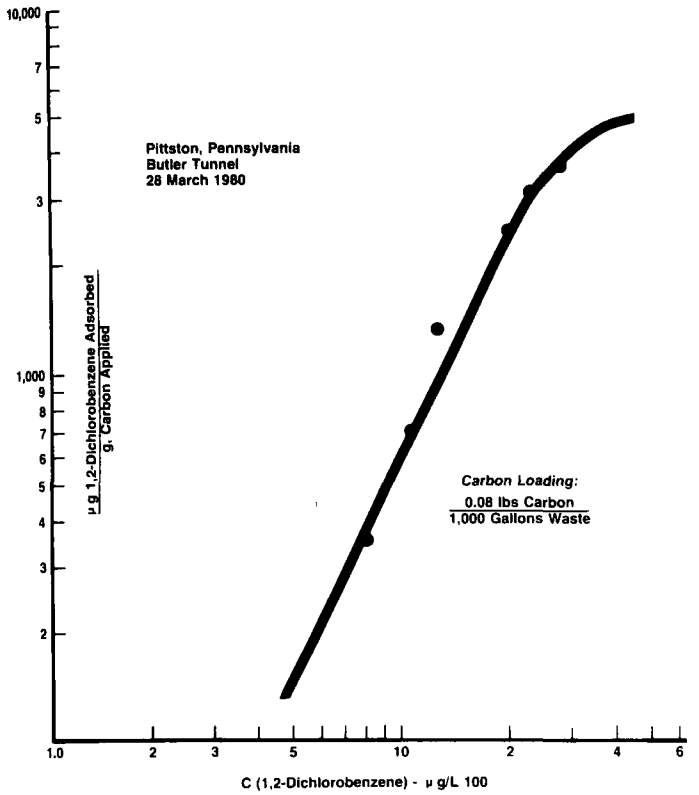


Figure 4.
Carbon Isotherm for 1,2-Dichlorobenzene on Carbon Filtersorb 300 in Butler Tunnel Wastewater

- After being treated in the carbon adsorbers, the flow will go to an effluent sump which will be used to store backwash water, and also to allow for chlorination of effluent prior to discharging to the Susquehanna River. Additionally, the operator will be able to chlorinate the influent to the carbon adsorbers periodically, to minimize bacterial growth on the adsorbers.
- Water used for backwash will go to a backwash receiving tank. This tank is necessary to handle the surges in the flow during backwash. After entering the backwash receiving tank, the water will be retained so that solids and oil can be separated from the bulk of the water. These solids and oil will be separated and sent to the sludge and oil holding tanks respectively.
- Oil from the oil holding tank will be pumped on a periodic basis into tank trucks for transport to an acceptable waste oil disposal facility, such as Rollins in Bridgeport, New Jersey.
- For the purpose of this design, the consultant has assumed that solids to be disposed of, will also require disposal as a hazardous waste. Such disposal is expensive (estimates are typically $125/ton); therefore, a centrifuge has been included to dewater the solids prior to disposal.

Presented in Figure 6 is a proposed equipment arrangement site plan that Weston developed for the 6.0 mgd design case. As can be seen by this figure, the proposed 6.0 mgd facility will occupy all available space.

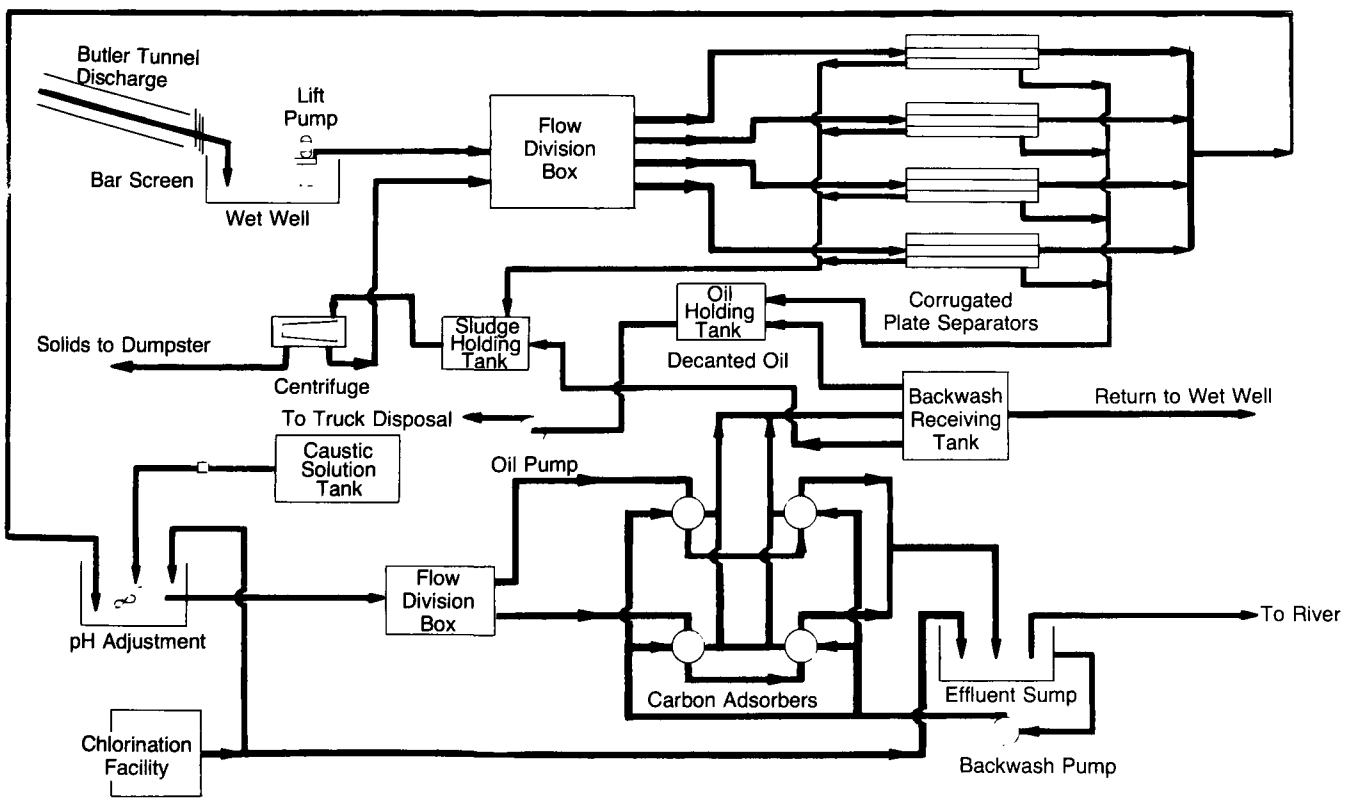
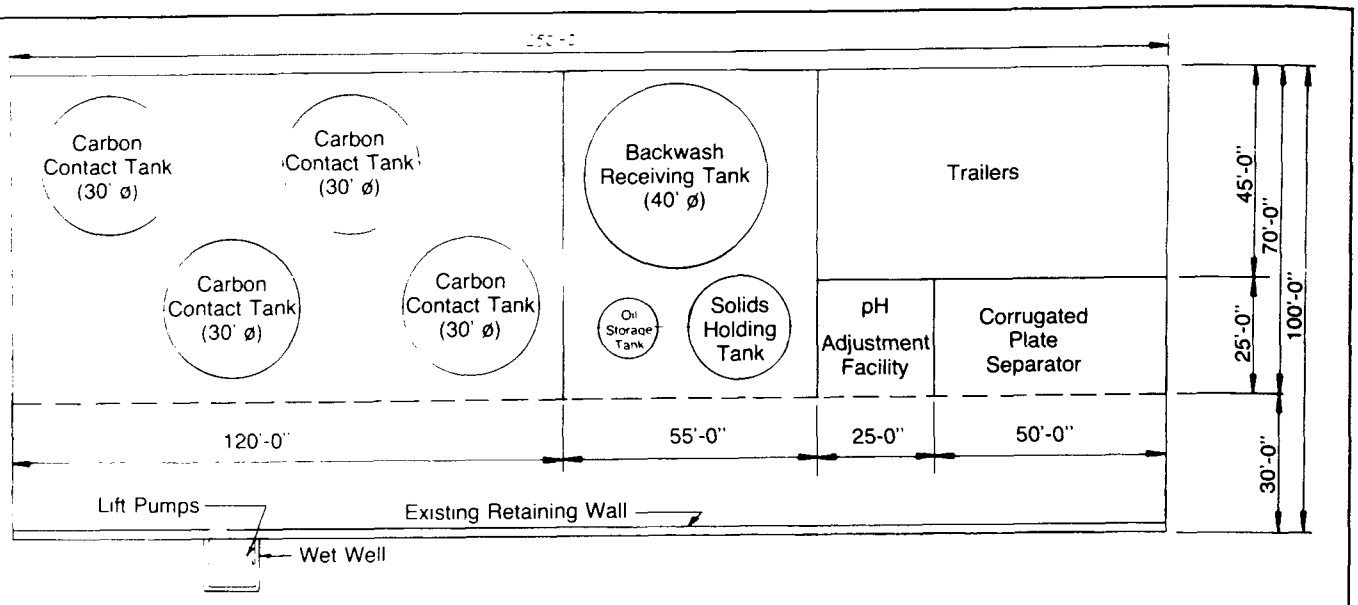


Figure 5.
Pittston Butler Tunnel Process Flow Diagram



Notes and Assumptions

1 Available Area is 250' x 100' with 30' Required Setback, Per Northeastern Engineering Report - Page 2.
2 Corrugated Plate Separator Requires 25' x 50' Plan Area.
3 Trailers are Approximately 12' x 50', and Allow 1/2 Length of Trailer For Mobility and Accessibility.
4 Backwash Receiving Tank Sized to Receive Backwash from Two Contactor Compartments, Each with Surface Area of Approximately 160 ft^2, and a Backwash Rate of 20 gpm/ft^2 for 15 Minutes
5 Oil Tank Sized for 10,000 Gal. to Allow for Intermittent Tank Truck Removal.
6 Solids Holding Tank Sized for 1,000 lb/day of Solids (6 mgd, 20 mg/L TSS), Two Days Storage Capacity at 1% TSS (10,000 mg/L).
7 Carbon Contactors Will Be Installed 10' Apart to Allow for Piping, Etc.

Figure 6.
Pittston, Butler Tunnel
Proposed Equipment Arrangement Site Plan

COST ESTIMATES

Estimates have been made for the installed capital costs for the major equipment included in the treatment system (Table II.) The estimates of the total installed capital cost for the 3.0 mgd and Butler Tunnel Treatment System are $2,279,400, and for the 6.0 mgd System, the estimate is $3,434,700. These estimates are based on an ENR Index of 3160, and do not include certain direct costs associated with construction such as engineering, construction management and startup. These cost estimates are considered to be accurate to $\pm 30\%$.

Estimates of the operating costs (Tables III and IV) for the Butler Tunnel Treatment System were also developed. The estimate of the total operating cost for the 3.0 mgd System is $1,347,000/year, and for the 6.0 mgd System, the estimate is $2,559,000/year.

Review of the data in these tables indicates that the carbon represents the most significant cost. The principal factors which will affect these costs are:

- Raw Wastewater Strength: as the concentrations of contaminants in the raw wastewater decrease, the life of an existing carbon bed increases. The value of raw wastewater concentrations, used in making these estimates of operating costs, was the median of the values for DCB. If the concentration of DCB in the Butler Tunnel discharge decreases, the life of the adsorption bed would correspondingly increase.
- Allowable Effluent Concentration at Carbon Exhaustion: the effluent concentration will directly influence adsorption capacity of the carbon bed. As shown for the carbon isotherm in Figure 4, as the equilibrium concentration of DCB in solution increases, the lb DCB adsorbed/lb carbon increases. Increasing the allowable final effluent concentration of DCB at breakthrough from 20 $\mu g/l$ to 400 $\mu g/l$, reduces the estimated carbon replacement cost by over 70%.
- Unit Cost of Replacement Carbon: while this may be obvious, it is a significant point. Fundamentally, the cost per pound for replacement of a particular carbon must

Table II.
Estimate of Installed Capital Costs for Butler Tunnel Treatment System
(ENR Index = 3160)

Item	Estimated $ 3 mgd	6 mgd
1. Life Pump Station	172,400	217,200
2. Flow Division Box	25,800	25,800
3. Corrugated Plate Oil Separators	115,100	276,100
4. pH Adjustment Facility	63,900	90,900
5. Flow Division Box	25,800	25,800
6. Carbon Adsorption Facility	876,100	1,368,500
7. Sludge Holding Tank	32,400	46,600
8. Oil Holding Tank	22,300	28,700
9. Chlorination Facility	73,000	124,800
10. Centrifuge	178,900	185,000
Subtotal	1,585,700	2,389,400
11. Miscellaneous[1]	396,400	597,300
12. Contingency	297,300	448,000
Total[2]	2,279,400	3,434,700

1. Includes piping, electrical, instrumentation and site work.
2. These estimates do not include certain direct costs associated with construction of the facilities such as engineering, construction management and start-up.

Table III.
Estimate of Operating Costs for Butler Tunnel Treatment System
(3 mgd Design)
Pittston, Pennsylvania
(May 1980)

1. Labor 27 manhours per day $11 per hour (salary and benefits) 52 weeks 7 days per week	$ 108,100/year
2. Maintenance (mechanical, structural, electrical, instrument) 3% of capital costs other than carbon inventory	$ 42,500/year
3. Electrical HP at $0.50/kwh	$ 17,400/year
4. Chemicals Caustic: 350 tons/year at $200/ton Chlorine: 36.5 tons/year at $400/ton Carbon[1]: 833 tons/year at $1,200/ton	$1,084,200/year
5. Sludge and Waste Oil Disposal Sludge Disposal: 600 tons/year at $125/ton Waste Oil: 21,900 gal/year at $0.83/gal	$ 94,400/year
6. Total Estimated Operating Costs	$1,347,000/year

1. Actual quantities and costs for carbon replacement will depend on allowable effluent concentration at breakthrough, and the actual adsorption capacity of the carbon which is finally selected for use. The value indicated reflects the probably order of magnitude of these costs, assuming effluent DCB concentration at breakthrough of less than 50 μg/l.

Table IV.
Estimate of Operating Costs for Butler Tunnel Treatment System
(6 mgd Design)
Pittston, Pennsylvania
(May 1980)

1. Labor 27 manhours per day $11 per hour (salary and benefits) 52 weeks 7 days per week	$ 108,100/year
2. Maintenance (mechanical, structural, electrical, instrument) 3% of capital costs other than carbon inventory	$ 62,300/year
3. Electrical HP at $0.05/kwh	$ 26,300/year
4. Chemicals Caustic: 700 tons/year at $200 ton Chlorine: 75 tons/year at $400/ton Carbon[1]: 1,670 tons/year at $1,200/ton	$2,174,000/year
5. Sludge and Waste Oil Disposal Sludge Disposal: 1,215 tons/year at $125/ton Waste Oil: 43,800 gal/year at $0.83/gal	$ 188,300/year
6. Total Estimated Operating Costs	$2,559,000/year

1. Actual quantities and costs for carbon replacement will depend on allowable effluent concentration at breakthrough, and the actual adsorption capacity of the carbon which is finally selected for use. The value indicated reflects the probable order of magnitude of these costs, assuming effluent DCB concentrations at breakthrough of less than 50 μg/l.

be combined with the adsorption capacity of that carbon to, in effect, establish the cost per pound of contaminant removed. In general, two types of carbon are available. The first type of carbon is virgin carbon; the second type is reactivated carbon. The costs and capacities of virgin carbon are higher than for reactivated carbon. Virgin carbon is available from a greater number of suppliers than is reactivated carbon; therefore, purchases of virgin carbon are done more in a "buyer's market" than are purchases of reactivated carbon. Of course, in either case, unless some form of service contract is established, variations in spent carbon disposal costs/resale value must also be considered.

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COMPUTER-ENHANCED GEOPHYSICAL SURVEY TECHNIQUES FOR EXPLORATION OF HAZARDOUS WASTE SITES

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INTRODUCTION

Collection of chemical and geological data during site assessment activities is an integral and necessary part of hazardous waste site investigations. Among the first investigative methods that might be employed at a site are geophysical surveys. These *ex situ* studies are based on geohydrologic changes induced by waste materials, and can provide a more complete picture of subsurface phenomena prior to *in situ* sampling and well drilling. Included among the potential applications are:

Location and/or Delineation of the Boundaries of Suspected Burial Sites.

Many of the techniques used depend on a change in density, reflectivity, susceptibility, or permittivity of target materials, all of which are characteristic of buried wastes. This type of underground location is readily accomplished by a magnetometer/radar combination that has been successfully employed by Battelle-Northwest in many locations. The ability to accurately locate burial trenches, individual targets such as drums, and concentrations of landfilled trash/wastes has been demonstrated. Other techniques may be used if poor resolution is acceptable.

Location of Waste Containers.

At many sites, the possibility exists that high concentrations of hazardous materials could be encountered when probing underground. This is particularly true at uncontrolled sites and locations where burning/burial has occurred. To minimize the hazard of drilling or coring into such deposits, a survey should be made before drilling commences. Radar, magnetometry and metal detection are applicable tools since the targets do not provide adequately defined acoustic reflection and resistivity measurements are too difficult to interpret unless detailed surveys are conducted.

Location of Underground Pipes and Cables.

Wells or cores must not be drilled through underground utility conduits. This is a problem at any site where industrial operations are concentrated and where insufficient information on underground utility routes exists.

Several techniques are available for locating or tracing utility conduits. Acoustic or radiofrequency generators can be used to drive a metallic line and the route traced by detectors from the surface. Resistivity measurements can provide information on nests or concentrated runs of metallic objects. For the most general case where either metallic or nonmetallic conduits are possible, a combination of magnetometry and radar offers the greatest definition. About the only situation that may not be identified with this combination is plastic gas lines and the location of these are likely to be documented since plastic pipe has not been used until relatively recent times.

Location of Discontinuities in Underground Strata.

Radar or acoustic systems can be employed to detect discontinuities, either natural or manmade, in an underlying stratum or bedrock. Acoustic/seismic methods can be employed if the voids are large (on the order of 100 m^2 or greater), whereas radar can detect much smaller holes (on the order of 1 m^2 or less). However, the radar system is limited in depth of penetration to 3 to 10 m for typical lithology.

In either case, the presence of intervening strata confounds reflection patterns and limits the use of these methods. Other techniques may be used in special instances. For example, magnetometry is an excellent tool for location of voids/faults in magnetic bedrock such as basalt and intervening layers are acceptable if they are spatially congruent. Gavimetry has similar applicability, although resolution is poorer and might be used to detect mine shafts, limestone caverns and sinkholes that are evident on the surface.

Location of Water-Bearing Strata.

Since the dielectric contant of water-bearing materials differs considerably from other geologic structures, it should be possible to use radar systems to map elevation and slope of the water table. On surveys to date, the authors have had only moderate success in delineating such features. The water table in one case, was quite obvious in radar scans, but this represents a favorable case (Depth of 2 to 3 m and salt water). In other cases, the depth to ground water has been too great ($>$10 m) or the aquifers not sharply defined enough to allow meaningful interpretation. In some instances, the presence of intervening strata or discrete objects (rocks) totally masks the effect.

In favorable cases, survey techniques might be used to define the limits of a contamination plume. The ideal case would be highly contaminated sources infiltrating at a high rate. Electrical resistivity would be most applicable in attempting to delineate the plume; very low frequency (VLF) resistivity techniques probably offer the greatest chance for success.

Location of Abandoned Wells and Drill Sites.

Occurrence of old wells, abandoned drill holes, burial pits, sinkholes, and other penetrations of near surface impermeable layers provide potential infiltration points for contaminated surface water. It has been shown that radar works well in locating such areas of disturbed earth, especially considering that backfilling these holes would rarely have been done according to good engineering practices.

Infrared imaging has also been used with less spectacular success in locating old excavations. Acoustic holography is a relatively new technique that is ideal for plotting depth and characteristics of boreholes once they have been located.

Location of Solution Channels, Cracks and Fissures.

Geophysical surveying in this application is less certain, and depends on characteristics of the specific site. Acoustic/seismic reflection probably has the widest application, although interpretation would be extremely difficult in complex matrices.

Radar probably is not generally applicable, although specific instances may be amenable to this treatment. Tracer methods are applicable, but require an extensive experimental program.

Location of Objects of Historical Interest.

Some Army installations contain sites of great archaeological interest. Although exploration is not an objective of site survey programs, geophysical methods provide aid in minimizing disturbance of archaeological sites during conduct of on-site exercises.

Since most discrete objects and structural features of archaeological interest are located within the first few meters of the surface, a radar system that provides underground map views is an excellent tool for these investigations. The potential for this application was demonstrated during a radar survey of Fort Monroe for the U.S. Army.

Geophysical Logging.

Various down-hole analytical techniques may be applicable to site assessment programs. The porosity of media down boreholes can be determined by neutron-epithermal neutron methods, which in some cases can be used to derive permeabilities. Natural gamma radiation logs can be used to determine certain lithologic changes and estimates of geochemistry. Electrical logs provide a more detailed observation of water strata than can be obtained from inspection of cutting returns.

GEOPHYSICAL SURVEY SYSTEM

Researchers at Battelle-Northwest have selected metal detection, magnetometry and ground-penetrating radar for inclusion in an integrated survey unit for burial ground and other subsurface investigations. Radar transceivers are available for operation at frequencies of 100, 300, 500 and 900 mhz.

The vehicle was specially constructed of nonferrous materials to facilitate the use of a magnetometer mounted alongside the radar unit. In addition to transporting the radar and magnetometer, the vehicle contains a microcomputer and a telemetry system which acquires, preprocesses, and transmits radar/magnetic data to a larger computer at the survey site. Recent additions include an all-terrain Trackster transporter and a motor home for transport between sites and to permanently house the computer systems.

A subsurface survey is accomplished in four steps.

1. A grid covering the study area is marked on the ground surface to guide subsequent measurements and to provide location coordinates.
2. Manual survey of the grid using hand-held metal detectors, marking all identified targets and transferring locations to an overlay map.
3. Operation of the survey vehicle over the same grid, accumulating radar and magnetometer data. The data produced by the survey instruments is transmitted to a PDP 11-34 computer where it is processed, formatted, and stored on either a magnetic tape or a disk storage unit. Preliminary data manipulation and processing functions can be performed on site to edit and compress the data for final storage or to facilitate data monitoring or previewing during a survey. This near real-time data handling capability can be of immeasurable value during conduct of a site survey.
4. Data superposition and analysis is done mainly by a unique software package created to filter and enhance output. Graphic display devices are used first to provide vertical profiles of each radar survey run. The profiles are then combined in digital form and sliced horizontally to generate a map view of a selected depth interval in the area surveyed. When specialized enhancement programs are applied, the output appears as color photographs with specific hues depicting buried targets. This system has been applied to surveys conducted in Idaho, Washington, New York, Virginia, Indiana, Pennsylvania, Utah and Nevada.

DATA PROCESSING AND DISPLAY

As received and recorded by the computer in the field, the radar data are not in an optimal form to be displayed and interpreted. Subsequent digital data programs can enhance the quality and usefulness of the data. Several computer programs have been developed at Battelle to enhance and display the radar and magnetometer survey date.

Figure 1 is a flow chart showing the computer programs involved in the data recording/processing/display

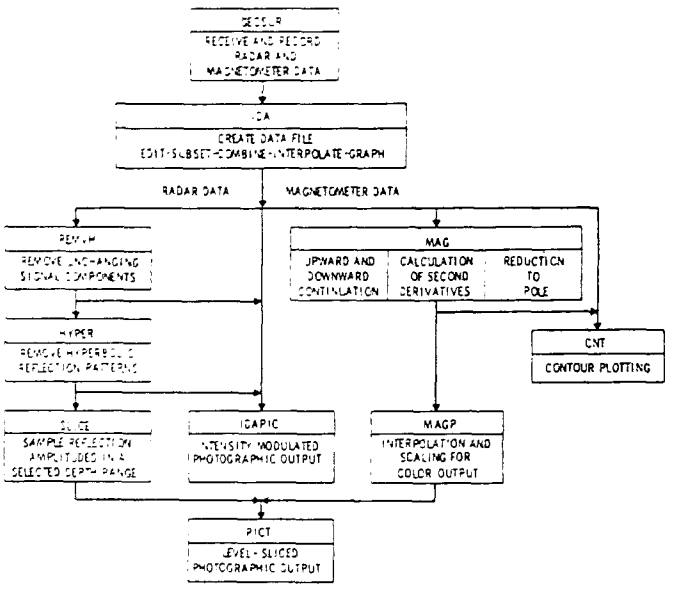

Figure 1.
Computer Program Flow Chart for Radar and Magnetometer Data

sequences for radar and magnetometer data. The GEOSUR and ISA programs are for recording and manipulating the data after it has been transmitted to the computer from the survey vehicle, and are not described further.

The stored digital radar data can be thought of as a three-dimensional array containing 120 bytes/ping, N pings/track, and M tracks. The data processing programs REMVH and HYPER operate on two-dimensional radar data; that is, they operate on each track in sequence. Program SLICE operates on the entire three-dimensional array to construct a two-dimensional array.

Program REMVH

A characteristic of the reflected radar signals is that they contain components that are unchanging from ping to ping and convey no information about subsurface reflectors. These components are due to a combination of factors: the oscillatory shape of the waveform, the presence of a ground surface reflection, random reflections from the survey vehicle and the radar unit itself, and electronic effects in the radar unit. These unwanted signal components appear in a radar image as alternately bright and dark horizontal bands. The left half of Figure 2 illustrates this effect. In each image of Figure 2, the horizontal dimension corresponds to distance along the traverse line, and the vertical dimension is proportional to the travel time of the radar signal (or to depth).

The purpose of program REMVH is to remove the banding due to stationary signal components. Let I ($1 \leq I \leq 120$) be the datum index in a given ping, and let J ($1 \leq J \leq N$) be the ping index in a given track (N is the number of pings in the track). For each fixed value of I, the program computes a running histogram as it scans the array in the J direction. At a given point, (I, J), in the array, the running histogram includes all data with the bounds I1 = I-1 to I2 = I+1 and J1 + J-JA/2 to J2 = J+JA/2, where JA is a specified number. At the edges of the array, the bounds are as follows: if I = 1, I1 = 1; if I = 120, I1 = 120; if J = 1, J1 = 1; and if J = N, J2 = N. The banding is removed by computing an average value from the data within the bounds of the running histogram, then subtracting the average from datum I, J. However, if the row contains values that are substantially higher or lower than the average value, this simple procedure can yield local correction values that are either too high or too low. This has the effect of introducing a spurious horizontal oscillation in the data. The histogram provides a simple means for excluding a range of high and low values. Improved corrections are typically obtained by excluding the highest and lowest 10% of the data from the calculation of the average.

The right half of Figure 2 shows the effect of applying program REMVH to the raw radar data. This approach to radar image enhancement improves the detectability of discrete buried objects or irregular masses of waste material, but it is not effective in cases where it is necessary to detect flat, horizontal interfaces.

Program HYPER

The function of this program is to remove hyperbolic reflection patterns from radar images, or reflection profiles. Hyperbolic patterns occur because a radar output beam has a finite angular width. Reflections are therefore received from a buried object both before and after the sensing transducer passes directly over it. It is sometimes desirable to remove the hyperbolic patterns from the radar profiles because they can increase the difficulty of interpreting the data.

Program SLICE

Ground penetrating radar surveys normally involve cumbersome methods for mapping detected buried objects. The locations of buried objects are usually determined visually from a collection of radar profiles, then manually transcribed to a map. The purpose of program SLICE is to utilize a digital computer to accomplish the same task.

Program SLICE is essentially a routine to construct a selected two-dimensional data array from the original three-dimensional array. A depth range is specified in terms of data indices which range from 1 to 120. Then for each ping in the array, a new array element is derived by averaging the ping over the specified depth range. The dimensions of the new array are N x M, where N is the number of pings per track and M is the number of tracks. Because the original data spacing along a survey track is much less than the track spacing, it is necessary to expand the new array in the across-track direction. This is accomplished by linear interpolation. Interpolation in both directions allows the array size to be completely selectable.

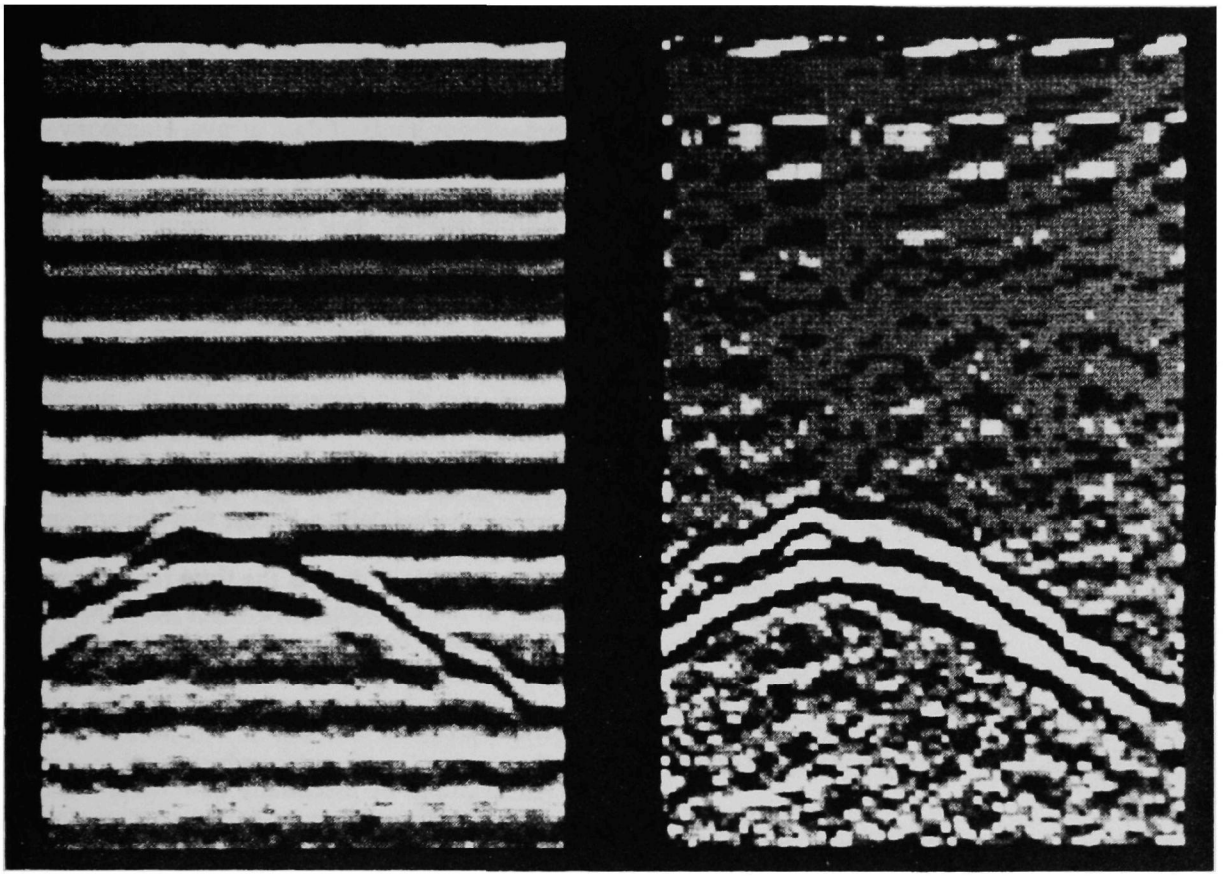

Figure 2.
Two Forms of a Single Radar Profile Illustrating
Computer Processing Operations

In cases where the distribution of buried objects is sufficiently sparse to allow radar reflections from a wide range of depths, a single, thin, horizontal slice will show only those objects contained in the corresponding narrow depth range. Examples of the output of program SLICE are shown in Section 5.

Program IDAPIC

Preliminary video monitor and hardcopy displays of raw and processed radar data can be made almost in real time by means of a data previewing capability included in program IDA. Final output products, however, are made in photographic form by utilizing a DICOMED D48, black and white or color, digital film recorder.

The function of IDAPIC is to transmit IDA formatted radar data to the film recorder. It provides options for file subsetting, image contrast enhancement, and color-coded level slicing.

Program PICT

This is a general purpose program for producing photographic images of raster-scan data from a wide variety of sources. In particular, it accepts the file structure of the output data produced by program SLICE. It is otherwise similar in both form and function to program IDAPIC.

Magnetometer Data

The data acquisition system on the survey vehicle is designed to transmit either one or two magnetic field values along with each transmitted radar ping. Two magnetic field values are allowed to order to provide for the possible future use of two magnetometers. However, only one has been used in past and current programs. The magnetometer data is, therefore, basically a two-dimensional layer in the three-dimensional IDA data array.

Program MAG

Numerous methods for analyzing magnetic data have been described in the literature. Commonly, these methods involve data manipulation operations such as upward and downward continuation of the magnetic field, calculation of vertical derivative and reduction to the pole. Program MAG performs all three of these operations. Its basic function is to systematically alter or enhance the magnetic field patterns in such a way that they can be more easily interpreted.

In a region free of magnetic materials, the total magnetic field anomaly, ΔB, satisfies Laplace's equation; that is:

$$\frac{\partial^2(\Delta B)}{\partial x^2} + \frac{\partial^2(\Delta B)}{\partial y^2} + \frac{\partial^2(\Delta B)}{\partial z^2} = 0 \qquad (1)$$

By the method of separation of variables, the solution of this differential equation can be expressed as:

$$B(x,y,z) = \sum_m \sum_n f\left(\frac{mx}{L_x}, \frac{ny}{L_y}\right) \exp\left[-2\pi\left(\frac{m^2}{L_x^2} + \frac{n^2}{L_y^2}\right)\right]^{1/2} \cdot z \qquad (2)$$

where

$f\left(\frac{mx}{L_x}, \frac{ny}{L_y}\right)$ = a two dimensional Fourier series expansion of the magnetic field in the measurement plane $z = 0$

$$Lx = M\Delta x$$

$$L6 = N\Delta y$$

M and N are the number of data in the x and y directions, respectively, and Δx and Δy are the data spacings in the x and y directions, respectively.

Upward and downward continuations of a magnetic anomaly are calculated by inserting the appropriate values of z into the above summation. Vertical derivatives of ΔB are calculated by differentiating the exponent within the summations.

Program CNT

Program CNT is a system routine on Battelle laboratory computers. Its function is to plot contour maps from various kinds of data arrays. Hardcopy output products are typically drawn on a CalComp plotter.

Program MAGP

It is often useful and desirable to display magnetic data in the form of a color picture. This is conveniently accomplished by means of program PICT. However, the number of magnetic measurements made in a given area is generally small in comparison with the number of picture elements needed to form a pleasing image of the magnetic field pattern in that area. A procedure is needed to effectively increase the number of data. Program MAGP, therefore, is basically a linear, two-dimensional interpolation routine to expand the magnetic data file.

Program PICT divides the total range of magnetic field values in the expanded file into a discrete number of levels, assigns a color to each level, and produces a level-sliced color picture of the magnetic field values.

EXAMPLES OF OUTPUT

An example of essentially raw radar data is given in Figure 3. This scan represents a plot of depth (negative vertical axis) versus track length (horizontal axis), with the ground surface at the top of the raster. Dimensions of the vertical profile correspond to a depth of 6 m and a track length of 30 m. The return from a small spherical object about 0.2 m in diameter is noted to illustrate the

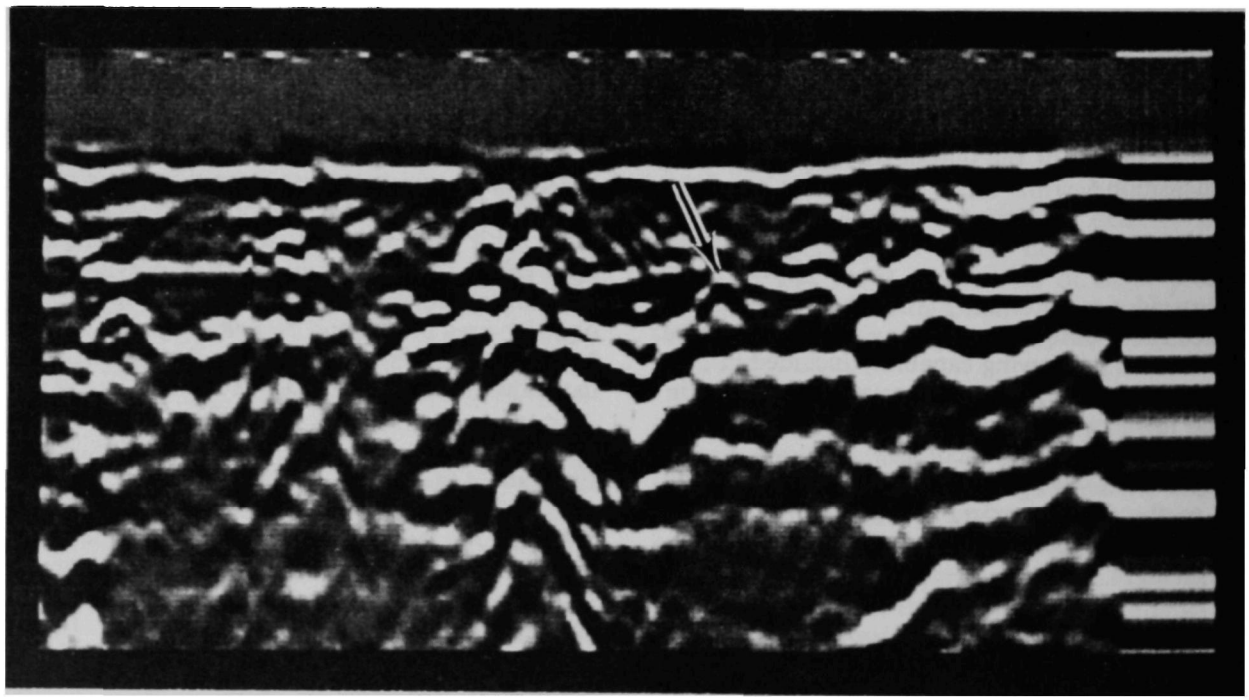

Figure 3.
A Radar Profile Showing the Reflection from a Sphere (arrow)

difficulty in interpreting such records for the location of specific objects.

The results of an actual survey yield a series of vertical profiles. Each record represents an excursion by the survey vehicle along parallel tracks at some spacing. Interpretation of vertical profiles by visual analysis and transfer to a grid map provide information on large underground structures, especially continuous forms such as pipes, sewers, wall foundations, etc.

An example of color-enhanced horizontal slicing illustrating the utility of the processing is given in Figure 4. In this case, slices from 0 to 1.5 m depth have been combined and filtering introduced to enhance the location of discrete, small targets. The number and distribution of such objects are apparent.

The area shown covers about 3 acres. Interpretation of some of the gross artifacts, few of which are apparent from records of prior site activity or surface features, is shown.

DIRECTIONS FOR NEW DEVELOPMENT

Several aspects of Ground Penetrating Radar Technology require further development in order to enhance broad scale application of the method. Presented below are some areas of improvement that Battelle is currently pursuing:

- Transceiver-antenna design; improved waveshape, antenna coupling, increased peak power, tunable-frequency systems
- Antenna arrays and associated electronics to improve resolution and to provide increased areal coverage capabilities
- Collection, transmission and manipulation of data at faster rates and with improved reliability
- Review-refresh memory data systems; comparison of old and new data to detect changes in underground systems
- Portable, handled radar systems for coverage of small, remote, rough terrain areas with surface obstacles such as rocks, trees, fences, etc.
- Target recognition through signature analysis, 3-D data overlay systems, size and shape correlation, deconvolution of wave forms
- Integration of GPR data with acoustic profiling, sonic holographic and/or electrical resistivity techniques to improve detection of nonmetallic objects
- Improved, ruggedized transport system, including automatic locator systems to define xy coordinates and attach angle of the transporter
- Electromagnetic characterization of soils, subsurface geologic strata, and representative targets

Success in expanding the technology will provide an enhanced capability for investigations of Hazardous Waste sites.

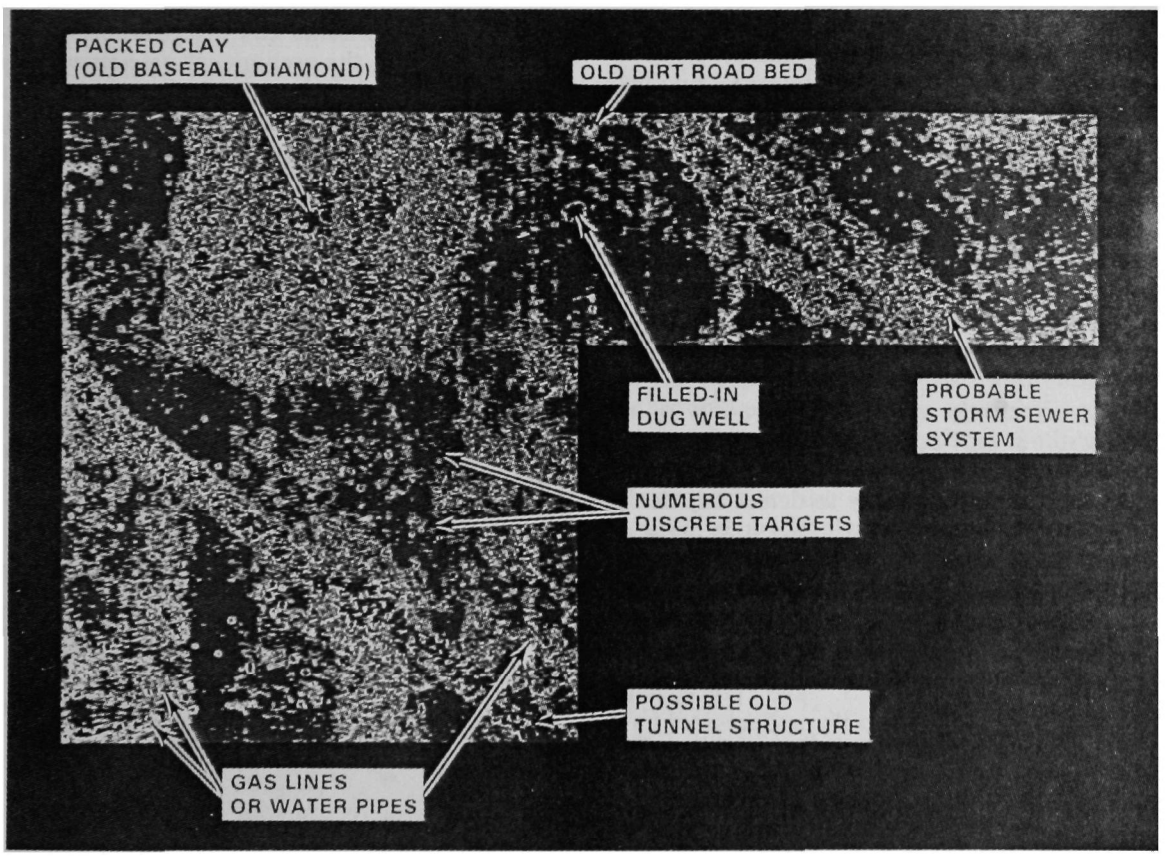

Figure 4.
Computer-Produced Map View of Radar Reflections at a Survey Site with Filtering to Reduce Broad Reflection Patterns

THE USE OF MATHEMATICAL MODELS TO ASSESS AND DESIGN REMEDIAL ACTION FOR CHEMICAL WASTE SITES

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INTRODUCTION

It is estimated that there may be 30,000-50,000 old disposal sites and sites contaminated from spills in the United States, of which 1,000-2,000 are sufficiently contaminated to pose a hazard to the public. Restoration costs are likely to exceed $1,000,000 per site.

Faced with the complexity and high costs of addressing such a large number of sites, it is clear that formalized methods are required to expedite the restoration process and identify the most cost-effective means of site remedial response. This paper describes a methodology which utilizes mathematical models describing fluid flow and contaminant transport. These constructs have been developed over a period of nearly two decades and employed to solve a variety of surface and groundwater contamination problems. They offer the ability to organize, interpret and better understand what is presently occurring, and in addition, provide the ability to predict what will occur in the foreseeable future. These capabilities are of particular value in designing remedial action since, through the use of these tools, one can:

- determine when a specific site is sufficiently characterized and understood such that when implemented the selected remediation program will be effective
- allow one to design a cost effective site characterization and data gathering effort
- rapidly and cost effectively assess a wide variety of remedial options without moving any dirt
- design a cost effective site surveillance and monitoring plan which will maximize the ability to detect any deviation from the remediation plan.

THE SITE RESTORATION PROCESS

While it is the abandoned landfill or superfund problem set has has stimulated the current interest in site restoration, two major programs in the U.S. have preceded it. The U.S. Department of Energy and its predecessors have had an active Decontamination and Decommissioning (D&D) program for many years now. Similarly, the U.S. Army Toxic and Hazardous Materials Agency has conducted its Installation Restoration (IR) Program since the mid-seventies. As a result of these undertakings, a formalized approach to site restoration has emerged. The approach is divided into three phases : (1) site characterization, (2) site assessment and (3) site remediation.

Site Characterization

Work performed during site characterization is directed to the description of the source(s) of contamination and the surrounding environment. The objective is to enumerate and quantify to the extent possible the physical, chemical, and biological factors which will affect fate and migration of contaminants. For maximum efficiency, characterization is performed in an integrated manner with assessment so that only necessary data are collected.

The first element of characterization, the preliminary survey, is focused on gathering all existing data on a site. If data are sufficient, no further characterization efforts are required. If the preliminary assessment reveals data gaps which must be filled before a final assessment can be made, then additional characterization efforts are implemented. Hence, the preliminary assessment is employed to determine the adequacy of existing data and the optimum design for any subsequent data collection activities.

When active characterization is necessary, it is divided among a number of field activities. Geophysical survey techniques can be employed to map deposits. These efforts are complimented by field geohydrologic investigations which determine the nature and extent of geologic and hydrologic features which will affect the movement of water and contaminants. Finally, sampling and analysis is performed to detail the disposition of contaminants in the environment and the physical/chemical properties of geologic media which would attenuate movement. All characterization activities may not be required at every site. As noted previously, the type and extent of activities should be identified during a preliminary assessment.

Post-closure characterization can actually be thought of as two distinct activities: (1) surveillance of remedial action implementation and (2) post construction monitoring. The former is directed toward assuring safe performance of work and conduct of that work in the manner prescribed in the final plan. The second activity tries to confirm the effectiveness of the remedial action on a continuous basis and, in so doing, will provide a warning in the event of failure and provide for the collection of a historical record that can be used to determine the reason for failure.

Site Assessment

Activities conducted for the assessment are designed to determine the implications of the available data. In this

context, they are interpretative in nature. The first level of assessment, preliminary assessment, is conducted using available data to determine if sufficient information is on hand to characterize a site and quantify the risk posed by that site. Two levels of output are possible. The first is a determination that current data are insufficient. In this case, the assessment identifies the minimum necessary data that should be collected to allow conduct of a final assessment. The second possible output is the result of a final assessment itself.

The use of the mathematical modeling tools needs to begin in this initial assessment phase. Even if sufficient data for implementation of a mathematical model are not available at this stage the organization and approach required to implement a mathematical model can greatly aid the initial assessment process and improve ones ability to understand the system. When enough existing data are available to justify the implementation of a mathematical model in this initial assessment phase, the quality of the assessment and the understanding of the system improves even more.

The final assessment is conducted only after sufficient data and system understanding are in hand. Narrowly defined, the product of a final assessment is the description of the time frames, durations and concentrations of contaminants that various segments of the environment will be exposed to. In this context, the assessment product is a prediction of what continuous monitors would record if the situation were allowed to remain in its current state. When coupled with data on the dose-response function for the contaminants of concern, the assessment output is converted to an estimate of the risk posed by the site. Consequently, the assessment product is essential to several key decision points:

1. Which sites pose unacceptable risks and therefore require remedial action?
2. How extensive must clean-up action be to bring a site within the realm of acceptable risk?

When it is determined that remediation is required and conceptual approaches are identified, assessment is again conducted to predict the effectiveness of proposed alternatives and to identify the most cost effective post-closure monitoring plan.

Site Remediation

Remediation activities are the major end-product of site restoration work. They are initiated whenever a final assessment concludes that risks posed by a site are unacceptable. At that time, the preliminary work is begun to identify all feasible alternatives. After a cursory screening, the most promising alternatives are described in a conceptual framework and input to the post-closure assessment where estimates are made of the effectiveness of each alternative. Output from the post-closure assessment is compared to output from the final site assessment to determine the level of risk reduction offered by each alternative. Alternatives not capable of reducing risks to acceptable levels are discarded. Remaining candidates are ranked according to cost. The ratio of risk reduction to cost is then employed to select the most cost-effective approach.

The selected alternative is then taken into final design and construction. Post-closure characterization is conducted to assure that construction is performed in accordance with final designs and to detect any releases or activities which pose a hazard to the public as a result of remediation.

The key element of the above approach to site restoration is the assessment activity. When properly conducted, an integrated assessment continues to focus attention on the most cost-effective configuration for conduct of work. In the early stages, assessment is employed to minimize the extent of expensive field characterization work while insuring that sufficient data are collected for evaluation. In the body of the assessment, the objective is to obtain as accurate a measure of risk posed by a site as possible so that a determination can be made as to whether a site requires remediation, and if so, how much. The post-closure assessment is directed to quickly ascertaining the likely effectiveness of remedial action alternatives and their optimum design before resources are committed as well as to identify a minimum, yet sufficient, configuration for the monitoring network that will provide all the desired information.

The strength of the assessment phase is directly related to the technology employed to accomplish it. Developments over the last decade suggest that, when properly applied, mathematical models for fluid flow and contaminant transport are the best tools currently available for solving environmental problems. They provide the decision maker with the extra insight needed to determine the optimum solutions for a given problem.

MATHEMATICAL MODELING—AN OVERVIEW

It is important to briefly discuss in general terms what a mathematical model is, its value, its limitations and its range of application in order to illustrate its value as a tool in the problem assessment and remedial action design process. Mathematical models, whether analytical or numerical, can only be a limited representation of an actual system or "cartoons of reality.[4] Models allow one to examine an entire system by incorporating expert understanding of a complex system with the generally limited field data in a form which can be tested against field observations of system response to various driving forces. Disagreements between model and observation can be used to guide further field studies or to cause initial interpretations of the system to be modified in plausible ways.

Processes that occur in the actual system are described by appropriate mathematical equations which correlate the system's physical and chemical conditions in a proper manner such that as changes are made to the physical and chemical parameters describing the natural conditions, the appropriate response of the real system may be predicted by solving the mathematical equations.

In order to construct and effectively utilize a model it is important to:

(1) Understand the physical, biological and chemical pro-

cesses which occur within the system of interest
(2) Identify and determine the important physical, biological and chemical parameters and inputs which allow the solution of the mathematical equations which govern the physical and chemical processes that occur
(3) Characterize the current condition of the system and identify its boundaries and boundary conditions
(4) Update model parameters as new system data or a better understanding of the system are attained.

Models, in general, are not static; they must be dynamic unless the system being modeled is very simple. A model acts as a storehouse for all the pertinent information assimilated on the system, and or the understanding of the processes which occur in the system. A model is capable of learning in the sense that as the data density and quality improve, those improvements can be incorporated into the model to improve its predictive capabilities. As the understanding of processes advances, the model equations or parameter relationships can be changed to incorporate this new knowledge and so improve ability of the model to predict. Model maintenance is an integral part of any effort involving the use of models.

Mathematical hydrodynamic and transport models, which can be constructed at various levels of complexity or realism depending on the use to be made of them, attempt to duplicate the real system by a series of complex equations that describe fluid flow and material transport. The advent of high speed digital computers has made the solution of these complex sets of equations practicable and cost effective for:
(1) Developing an understanding of a complex system
(2) Determining sensitivity of the system to uncertainties in data and understanding
(3) Providing insight on the system and making predictions of system response to various perturbations
(4) Prediction of system response to various proposed management alternatives
(5) Testing the adequacy of various engineering designs.

The steps involved in modeling are:
(1) Definition of the study objectives
(2) Collection of data on the system
(3) Formulation of a conceptual model of the system
(4) Translation of the conceptual model and data on the system into the form required for the selected numerical model
(5) Calibration and verification of the numerical model
(6) Check of the sensitivity of the model to variations in input data
(7) Use as a predictive or investigative tool to attain the study objectives.

Model output (or predictions) always needs careful evaluation because the results are generally only as accurate as the data and the knowledge of the system upon which the models are based. Model results should be considered as a guide to the probable system response. In general, when properly applied, models are the best tools available for assistance in understanding and making decisions on complex systems. Modeling alone, however, is no substitute for routine monitoring in problem areas. A successful management program must include both modeling and continued monitoring.

Table I.
Characteristics of a Few of the Ground-Water Flow and Transport Models Being Employed in Safety Assessment of Nuclear Waste Repositories and for Other Ground-Water Studies

HYDROLOGIC	
PATHS(a)[14]	Two-dimensional, analytical/numerical method, homogeneous geology, saturated flow.
VTT[18]	Two-dimensional, finite difference numerical method, heterogeneous geology, saturated flow, multilayer systems with interaquifer transfer.
FE3DGW[8]	Three-dimensional, finite element numerical method, heterogeneous geology, saturated flow.
CFEST(b)	Three-dimensional, finite element numerical method, heterogeneous geology, coupled flow, energy and solute transport.
CONTAMINANT TRANSPORT	
GETOUT[6]	One-dimensional, analytical method, chain decay, single speciation, equilibrium sorption, constant leach rate, dispersion.
MMT[1,21]	One- and two-dimensional, discrete parcel random walk numerical method, chain decay, single speciation, equilibrium sorption, time variant leach rate, dispersion, and arbitrary source distribution.
CFEST	Three-dimensional, finite element numerical method, heterogeneous geology, coupled flow, energy and solute transport.

(a) All the hydrologic models operate in a transient or steady state mode and have streamline or pathline options that can predict travel time.
(b) Code documentation in progress.

Description of a Few of the Many Available Mathematical Models

The effort to site nuclear waste repositories under the sponsorship of the U.S. Department of Energy has been responsible for the identification and development of a suite of ground-water hydrologic and transport models. The modeling technology involves: (1) hydrologic codes to define the ground-water flow field and indicate water flow paths and travel times and (2) transport codes to describe the movement and concentrations of the contaminants in the flow field and the rates of arrival of contaminants at points of biosphere uptake.

The groundwater hydrologic and transport codes identified and developed include several levels of complexity. Code selection and use are determined by the study purpose, the quantity and quality of input data and the processes felt to be driving the system. There are hydrologic codes at four levels and transport codes at three levels as shown in Table I.

In addition to the saturated flow models there are various levels of hydrologic codes for modeling unsaturated hydrologic systems. These codes for unsaturated flow modeling are required when the contaminant source is located in the unsaturated hydrologic system. The codes which Battelle has had experience applying include:

•UNSAT[9]—one dimensional, finite difference numerical method, unsaturated flow, with crop water extraction.
•TRUST*[10,11]—one or two dimensional, integrated finite difference numerical method, unsaturated flow, deformable porous medium.

Numerous mathematical models have been developed and applied to a variety of surface water contamination problems. These models include a variety of surface water hydrodynamic and transport models which have been utilized to understand these complex systems as well as predict future surface water quality. These models include hydrodynamic, contaminant transport and sediment transport models for river, lake and estuarine systems. A few of these models which Battelle has had experience in applying are given in Table II.

APPLICATIONS OF MATHEMATICAL MODELS

Surface water and groundwater hydrodynamic and contaminant transport models are directly applicable to problems related to siting new facilities, assessing existing contaminated ones as well as evaluating remediation options when required. The level of sophistication required for any effort is dictated by data availability, major phenomena of importance (i.e., saturated or unsaturated flow and the level of resolution desired. The usefulness of models as an aid in these assessment and remediation processes is best illustrated by examples of past work with similar purpose. Three such examples are given below.

Table II.
Characteristics of a Few of the Available Surface Water Hydrodynamic and Contaminant Transport Codes

HYDROLOGIC	
EXPLORE[2]	Two-dimensional (x-y), dynamic wave, finite difference code for modeling tidal or river flow in estuary or river systems.
DKWAV[2]	One-dimensional, kinematic wave, finite difference code for modeling river flow and accounting for rainfall and runoff contributions.
DWOPER[7]	One-dimensional, dynamic wave, finite difference code for modeling river flow and accounting for rainfall and runoff contributions.
CONTAMINANT TRANSPORT	
EXPLORE	Same as above but also simulates contaminant transport for dissolved contaminants.
DKWAV	Same as above but also handles contaminated sediment transport both overland and in rivers.
SERATRA[7]	Two-dimensional (x-z), transient, finite element code for sediment and contaminant transport modeling in rivers, lakes and estuaries.
FETRA[7]	Two-dimensional (x-y), transient, finite element code for sediment and contaminant transport modeling in rivers, lakes and estuaries.
TODAM[7]	One-dimensional, transient, finite element code for sediment and contaminant transport modeling in rivers, lakes and estuaries.

*The capability of TRUST has been expanded to allow stream lines and pathlines to be predicted from TRUST input and output streams.

Kepone in the James River

As a part of the Kepone mitigation feasibility study,[5] a mathematical simulation of sediment and Kepone (a highly chlorinated pesticide) transport in the James River estuary was conducted by applying the sediment and contaminant transport model, FETRA, to an 85-km river reach between Bailey and Burwell Bays. The FETRA code consists of three submodels coupled together to take into account sediment-contaminant interaction. The submodels are:
1) sediment transport model, 2) dissolved contaminant transport model, and 3) particulate contaminant (contaminants adsorbed by sediment) transport model. Transport of sediment and particulate contaminants is simulated for each sediment type or size fraction. The modeling procedure of the FETRA code involves simulation of sediment transport. The results are then used to simulate dissolved and particulate contaminants by accounting for interaction with the sediments. Changes in river bed conditions are calculated including: 1) river bed elevation change, 2) distributions of ratio of each bed sediment component in the bed and bed armoring, and 3) distribution of contaminants within the river bed.

The FETRA code was applied to simulate the migration of sediment and Kepone for three river discharges. Tidally influenced depth and velocity distributions in the study area were obtained by the unsteady, one-dimensional code, EXPLORE. These results were used by the two-dimensional code, FETRA, to obtain longitudinal distributions of sediment and Kepone. Hence the results discussed here are cross-sectionally averaged values changing with tidal flow. Comparison of computed results and field data for both sediment and Kepone concentration indicates very good agreement, confirming the validity of the model.

Mathematical simulation of Kepone transport under most probable flow conditions yields an estimate of 89.1 kg/yr of Kepone transported seaward from Burwell Bay. Of this 89.1 kg of total Kepone, 25.3% is carried by sediment, while 74.7% is in a dissolved phase. Since it is estimated that approximately 9600 kg of Kepone is present in the top 0.3m of bottom sediment in the river, with this flushing rate, it may take at least 108 yr for natural water-sediment flushing mechanisms alone to clean the James River.

The effectiveness of ten partial Kepone cleanup activities to reduce Kepone concentrations in the river was studied by simulating ten hypothetical conditions by the FETRA code. Through this cost effective evaluation process, it was quickly determined that none of the partial mitigation options would yield significant reductions in total flushing times. Hence, ineffective expenditures were avoided.

Assessment of Seepage From Buried Uranium Mill Tailings

The advantages of returning uranium mill tailings to the pits excavated during surface mining operations are being more widely recognized and utilized to minimize any un-

desirable environmental effects.[13] Particularly notable among the benefits is the better control of radon gas emission through appropriate mill tailing burial. This advantage alone warrants burial of the tailings.

As plans are made for the burial of the tailings in pits, (as opposed to using conventional tailings ponds above the ground surface), concern arises about the potential for contaminant seepage from the buried tailings. Disposal in the mined out pits places the tailings nearer ground water and may increase the potential for ground water contamination.

The purpose of this study was to examine potential for ground water contamination by seepage from buried tailings under four alternatives of clay liners and tailings placement. To accomplish this comparison of alternatives, laboratory work and numerous measurements were made on materials typical of the site. These measurements provided the data on soil characteristics necessary for input to the hydrologic flow and transport models which were used in this assessment study.

The four alternatives considered to minimize seepage of contaminants from buried mine tailings included:

1. Placement of saturated tailings in a covered pit with a clay liner in the bottom, but no side liners
2. Placement of dewatered tailings in a covered pit with clay bottom liner, but no side liners
3. Placement of saturated tailings in a pit having a clay bottom liner, no side liners, and drains to facilitate pumping of drainage solution from sumps placed above the bottom clay liner
4. Placement of saturated tailings in a pit with both bottom and side clay liners.

The assessment involved combined subsurface fluid flow and contaminant transport modeling of the four alternatives for controlling seepage from buried tailings. The assessment included combined saturated and partially saturated flow and contaminant transport models for two-dimensional vertical, cross sections typical of the tailings burial pits proposed for use at the site.

The results obtained from the models were the contaminant flow paths away from the tailings pits, the advancing contaminant flow fronts for various sorbed and nonsorbed constituents of major environmental concern, and the associated quantities of contaminant flow for each of the alternatives. These results enabled the comparison of the environmental consequences of the four alternatives. It was also possible to gain considerable insight about combining the beneficial alternatives to obtain the best overall method for controlling seepage from the buried pits.

Although four alternatives were considered in this study, only the first three alternatives, which utilize a bottom clay liner but no side liner, provided important results. All of the results obtained in this study demonstrated that a side liner on the upper 70 to 80% of the typical 30.5m side wall height is of very little or no benefit in reducing contaminant seepage; hence, high side wall liners are unnecessary and use of such would moreover be economically wasteful.

The study demonstrated the very real benefits of reducing the volume of fluid available to seep from the tailings. The similarity fo contamination of consequences for systems that use dewatered tailings or underdrains tends to indicate that the means of reducing the volume available for seepage is less important than the actual volume reduction of water that can be realized.

Based upon what was learned from this study, it was felt that the best contaminant seepage control would be provided through combining the desirable features of the four alternatives considered. The recommendations would include the accepted pit covering procedure already planned for the site; specifically, the additional proposed control alternative was:

1. To provide a well constructed bottom clay liner placed at least 3.0 m above the regional water table and not less than 0.9 m thick
2. To provide stub clay side liners continuing part way up the pit side wall that form a continuous saucer-shaped bottom and side liner for the pit
3. To install a network of gravity drains and pumping sumps with the drains in the tailings sufficiently above the bottom clay liner to provide very effective drainage of the tailings
4. To pump tailings drainage effluent from sumps while the pit is being filled with tailings and on an as needed basis for the first 6 to 8 months after the filling has been completed.

Additional studies were proposed to determine the applicability of these side liner recommendations at other sites and to assure acceptable minimum contaminant seepage under other conditions. Specifically, further study is needed for various soil materials and other pit configurations using the combined approach of lining and reducing tailings water. Such studies should also be followed by companion field observation as the recommended management practices are put into use at the Wyoming site or elsewhere to check, verify, and improve upon the recommended disposal control practices. In this way, it will be possible to economically further reduce contaminant seepage and better assure the adequate disposal of uranium tailings in burial pits.

Initial Assessment of Fixed Flue Gas Desulfurization (FDG) Sludge as a Landfill

The first full-scale application of IU Conversion Systems, Inc. (IUCS) fixation process (Poz-O-Tec® process) for treating flue gas desulfurization (FGD) sludge is in operation at the Conesville Power Station of the Columbus and Southern Ohio Electric Company.[3] The Poz-O-Tec® process blends fly ash, bottom ash (if desired), lime, scrubber sludge and other additives. The Poz-O-Tec® sludge is landfilled in a surface disposal area where it hardens to a material with relatively low permeability.

In this two phase project the movement of contaminants in the groundwater is being studied in order to provide a basis on which utilities can make decisions regarding the Poz-O-Tec® method, in particular and the dis-

® Registered Trade Mark.

posal of FGD sludge, in general. The Phase I efforts dealt with initial site characterization and preliminary assessment, whereas Phase II will include extensive field monitoring, model application, and a final assessment.

In Phase I, which will be discussed here, a model data base was formulated and laboratory studies were conducted to determine saturated and partially-saturated permeabilities of sludge and ash materials, and to describe the composition and distribution of the sludge and ash leachate. The data base and laboratory results were used to implement, calibrate, and verify a two-dimensional, finite difference, hydrologic flow model for the study area. The model output was coupled with a technique of graphing contaminant arrival distribution to predict the distribution in time and space of contaminants traveling with the groundwater within the study area.

The flow model was calibrated against a potential surface representative of a high Muskingum River stage. As a check on the accuracy of the model prediction, the model was verified against a low river stage potential surface. In both cases, the model prediction was in good agreement with the field-measured potential surface.

A sensitivity analysis was conducted to determine the sensitivity of the model predictions to changes in transmissivity (T) and recharge rate (Q). The findings indicated that the model is fairly sensitive to changes in these parameters; therefore, the T and Q distributions arrived at in the calibration process cannot be changed appreciably without significantly altering the model prediction. It should be noted, however, that once calibrated and verified, the final modified transmissivity distribution was within plus or minus 10% of the initial transmissivity distribution.

Hypothetical examples were used to demonstrate the methodology for studying arrival distributions of contaminants at the Muskingum River. Attention was focused on contaminant migration from two surface water ponds (Poz-O-Tec® and emergency sludge pond) within the Poz-O-Tec® disposal area and not on seepage to the groundwater over the entire disposal area. This emphasis was chosen because:

- Laboratory studies and field investigation have shown the Poz-O-Tec® material to be highly impermeable (10^5 to 10^7 cm/sec), implying little, if any, water percolates through this material
- Man-made and natural channelization has been developed in the disposal area which encourages immediate runoff of precipitation into the Poz-O-Tec® pond (i.e., water does not remain ponded on the Poz-O-Tec® material)
- The Poz-O-Tec® pond is hydraulically connected to the water table, thereby providing a direct path for Poz-O-Tec® runoff to move into the groundwater
- Leakage from the emergency sludge pond (used to intermittently store thickened unfixed FGD sludge) to the groundwater could easily have occurred between January 1977 when the Poz-O-Tec® operation began and September 1978, at which time the pond was lined.

The results of the Phase I modeling, characterization and data gathering efforts were used to provide input to the monitoring system design of Phase II. At the conclusion of these Phase I efforts it was not possible to thoroughly assess the groundwater contamination resulting from the Poz-O-Tec® process for three reasons:

- Chemical analysis of groundwater obtained from below the Poz-O-Tec® and ash pond found sulfate to be the only water quality parameter above drinking water standards (secondary drinking water standard)
- The source of the sulfate (Poz-O-Tec® , or fly ash, or both) has not been identified
- If it can be assumed that contaminants enter the groundwater in pulses in direct response to rainfall, arrival distribution techniques have shown that their concentrations will be greatly reduced in the process of reaching the Muskingum River.

Additional monitoring and water quality analysis of the Phase II efforts will be necessary before the degree of groundwater protection provided by Poz-O-Tec® can be determined.

SUMMATION

The authors have briefly outlined the need and role of mathematical models in the site characterization, site assessment and remedial action design phases of a site restoration process for a hazardous chemical waste disposal site. In order to dispell some of the misunderstanding and distrust regarding mathematical models and their useage, a brief overview was presented along with summary descriptions of typical model application efforts. Some of the basic concepts of mathematical modeling and how the various kinds of currently available codes can be effectively applied to problems of a type similar to those of site restoration at a chemical waste site have been shown.

The key points regarding mathematical models are:

(1) Mathematical models are simply tools and like many other tools come in a variety of forms from simple to complex and must be utilized by craftsmen skilled in their appropriate use
(2) Models provide a systematic approach for organization and interpretation of data on complex systems as well as a means for achieving a better understanding of these systems and lastly provide a means for comparing alternatives or making predictions
(3) Models can not be used in lieu of data for assessment or as a substitute for monitoring

Mathematical models need to be utilized throughout the site restoration process from the initial characterization phase and continuing through the remedial action design, construction and final surveillance monitoring phases. The capabilities of mathematical models can be utilized in the site restoration process to:

(1) Help determine when a site is sufficiently characterized and understood for remediation to be implemented when it is required
(2) Aid in the design of cost and time effective data gathering efforts associated with site characterization
(3) Aid in the rapid and cost effective assessment of:
    - whether remediation is required

•a wide variety of remediation options when it is required

(4) Aid in the design of a cost effective site surveillance and monitoring plan.

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PARAMETRIC ANALYSIS OF GEOLOGICAL HAZARDOUS WASTE DISPOSAL

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INTRODUCTION

The uncontrolled discharge of hazardous material has steadily increased not only because of increases in population, agriculture and industry, but also because law and regulations, such as the Clean Air Act (as amended) and the Marine Protection, Research and Sanctuary Act (as amended) curtail the discharge of hazardous pollutants in the air and water, leaving the alternative of land disposal as the last or final disposal practice. And, as can be seen from past experiences, the best available technology has not always resulted in secure landfills. There is growing evidence of the vulnerability of clay and plastic liners to the effects of certain chemicals, there is also the difficulty of installation and susceptibility of plastic liners to puncture. Moreover there are little data to show that the lifetime of the plastic liners, even if they stay intact, will exceed the lifetime of the hazardous wastes they contain.

Consequently, the authors have done a parametric analysis to see how the waste disposal repository acts as a total system and to determine what features need to be improved to guarantee the safety of the disposal facility.

To study the problem, one has to look at the system as a whole, where the various parameters interact, and allowing variation in values of the parameters according to the uncertainty of these values. To do this, the authors adopted a simple conceptual model in which the repository is located close to the ground surface (less than 10 meters), the waste is packaged, is leached by groundwater, is sorbed during its travel underground and finally reaches the biosphere. Dilution in the biosphere has not been considered. Concentrations in the biosphere have been compared to recommended limits.

In this initial screening of geological hazardous waste disposal sites, one can afford to use simpler models, so that with a minimum of information they can be satisfactorily used to predict the behavior of contaminants under normal or extreme conditions. A simple one-dimensional analytical solution to the diffusion-dispersion equation in porous media was used to show that, in a multiparameter system characterized by the packaging, the waste disposal technique, the geology and hydrology of the site, there are a number of combinations (multidimension response surface) that will result in concentrations released to the biosphere that are less than permissible values, but more important that there are many parameter combinations that will not meet release criteria.

ANALYTICAL MODEL

The one-dimensional transport equation for horizontal, single-phase flow in saturated, unconsolidated and homogeneous media can be expressed as:

$$\frac{\partial c}{\partial t} = -u\frac{\partial c}{\partial x} + D\frac{\partial^2 c}{\partial x^2} - \frac{\rho}{\epsilon}\frac{\partial s}{\partial t} + kc^n \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Ogata and Banks[2] presented a general solution of the form:

$$\frac{c}{c_o} = \tfrac{1}{2}\left[\operatorname{erfc}\left[\frac{1-\theta}{2(\theta/Pe)^{1/2}}\right] + \exp(Pe)\operatorname{erfc}\left[\frac{1+\theta}{2(\theta/Pe)^{1/2}}\right]\right] \quad \ldots\ldots (2)$$

where

$\theta = (u * t)/X$

$Pe = (u * X)/D$

Sorption is implicitly considered as "u" was used as the velocity of the pollutant, under the assumption that the mass transfer of solute to sorption sites is rapid and that the sorption equilibrium is linear, $ds/dc = Kd$, where Kd is the distribution coefficient and the term $[1 + (Kd/\epsilon)]$ is known as the retardation factor and gives the relative velocity of movement of a sorbing solute to the movement of water.

Input Data

The study considered the solubility limit as the initial concentration of the pollutant in the aquifer and the longitudinal dispersion coefficient with a fixed value of 0.9 m/day. The parameters that were varied were: groundwater velocity 0.1, 0.01, 0.001, and 0.0001 m/day, partitioning coefficients of 1, 10, 100, 1000, and 10,000 l/g and distance to the biosphere of 100, 1000, and 10,000 meters. The data are summarized in Table I. Biological or chemical degradation were not considered, since the pollutants under study are "conservative" substances.

Table I.
Chemical Characteristics of Pollutants

Pollutant	Partition coefficient (1/g)	Permissible ambient conc. µg/l	Solubility limit (mg/1)
AROCLOR 1254	10^4-10^6	0.001	0.012
ENDRIN	100-250	0.004	0.26
TOXAPHENE	1-100	0.005	1.75

RESULTS

Three different pollutants were studies: PCB, toxaphene, and Endrin. Each has different sorption characteristics, different solubility limits and different permissible water concentrations.

Aroclor 1254 (PCB), has high partitioning coefficients from 10^4 to 10^6 l/g, low solubility limit of 0.012 mg/l and permissible ambient concentration of 0.001 µg/l. Endrin has partitioning coefficients of 100 to 250 l/g, solubility limit of 0.26 mg/l, and permissible ambient concentrations of 0.004 µg/l. Toxaphene has partitioning coefficients of 1 to 100 l/g, solubility limit of 1.75 mg/l, and permissible ambient concentration of 0.005 µg/l. The ambient concentration values were those recommended by EPA in Quality Criteria for Water [3] and the solubility values are those in the treatability manual.[4] Partitioning coefficients have been obtained from different publications and from a Vanderbilt University study.[5]

The results of the analyses are presented in Table II and in normalized form in Figures 1, 2, and 3, so the analysis will be valid for any pollutant if we know the initial concentration, the release criteria concentration, and the partitioning coefficient.

At 1000 meters from the source, which is considered as a realistic distance in humid climates for the pollutant to be released to the biosphere in the case of near surface geological repositories, Aroclor 1254 will reach the release criteria limit with groundwater velocities of 0.1, 0.01, 0.001, and 0.0001 m/day, at 6.25 x 10^3, 23.0 x 10^3, 35.0 x 10^3 and 37.0 x 10^3 days, respectively. For the same groundwater flow rates, Endrin will reach the biosphere in 8.7 x 10^3, 22 x 10^3, 29 x 10^3, and 31 x 10^3 days, and toxaphene at 22.5 x 10^3, 24 x 10^3, 25 x 10^3, and 25.5 x 10^3 days.

As one can see, pollutants can be expected to appear in concentrations higher than recommended values in about

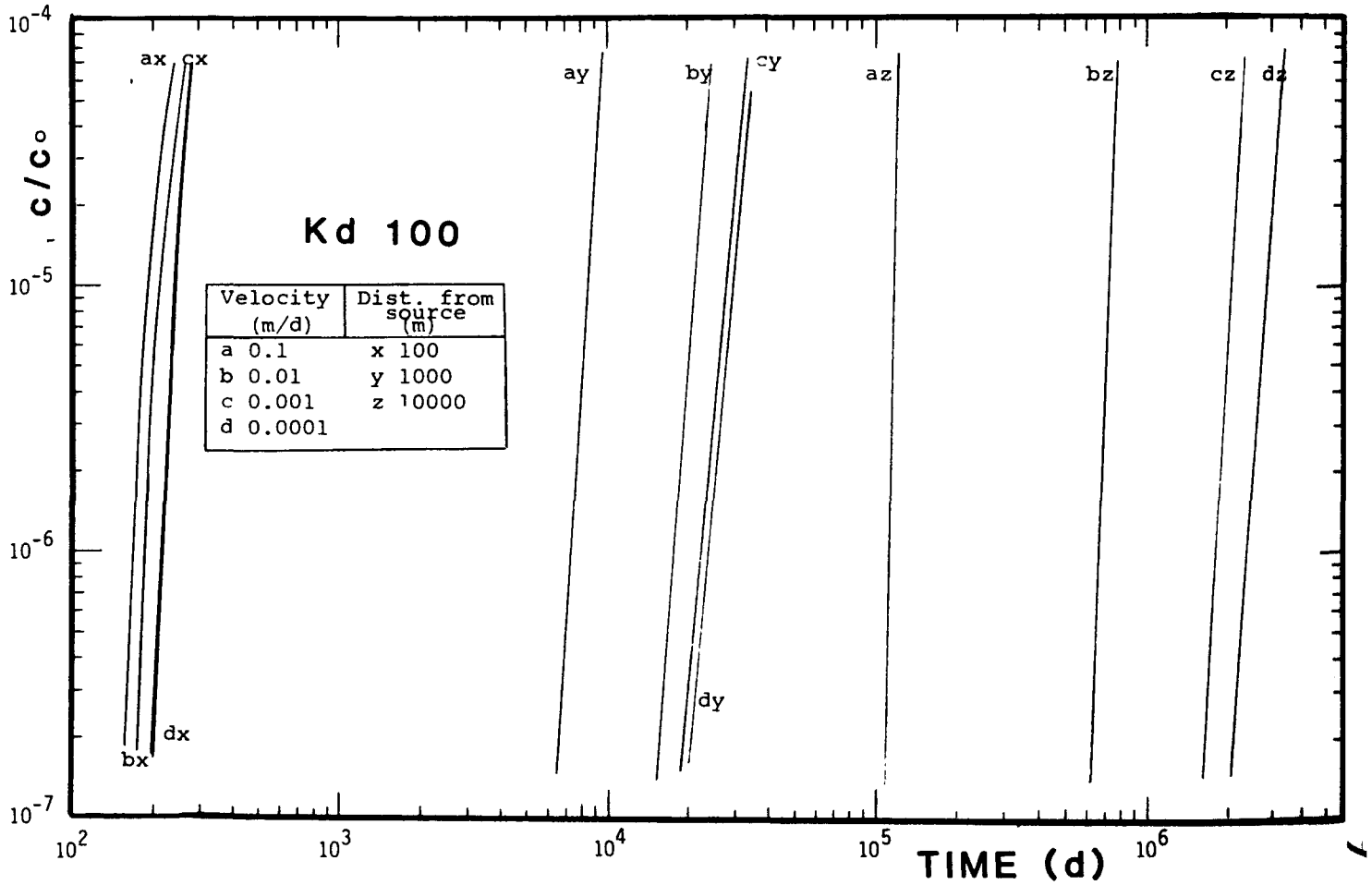

Figure 1.
Time to Reach Ambient Criteria Concentrations

Table II.
Time to Reach Ambient Criteria Concentration (d)

Velocity (m/d)	0.1			0.01		
Distance (m)	100	1000	10000	100	1000	10000
AROCLOR 1254	240	6250	88000	350	23000	600000
ENDRIN	200	8700	110000	225	22000	740000
TOXAPHENE	230	22500	1650000	250	24000	2400000

Velocity(m/d)	0.001			0.0001		
Distance (d)	100	1000	10000	100	1000	10000
AROCLOR 1254	370	35000	2300000	390	37000	3500000
ENDRIN	240	29000	2100000	245	31000	2900000
TOXAPHENE	255	25000	2600000	260	25500	2700000

20 years, with high groundwater velocities and in 100 years, with low velocities. These times are not sufficiently long to prevent contamination of the biosphere from these contaminants.

Even if one considers the best possible conditions, high retardation factors, low groundwater velocities and high ratios of release concentration over solubility ($10-^{4}$), the time involved is only 120 years. If one considers low retardation factors, high groundwater velocities and moderately low ratios of release concentration to solubility ($10-^{7}$), at 1000 meters from the source, the release criterion will be reached in a decade.

CONCLUSIONS

This simple model shows how recommended maximum release concentrations to the biosphere can be reached in short periods of time if the leachate is permitted to reach solubility limit values in the aquifers underlying hazardous waste sites. Natural existing conditions will not secure the pollutants for extensive periods of time. Only in very limited situations, with low concentrations of hazardous materials located in extremely favorable hydrogeological conditions, (low precipitation and thick clay formations), will the pollutants be secure in near surface geological repositories. If these calculations are correct, for near surface storage one can assume that one can only substantially decrease the groundwater velocity with great effort and the distance to the biosphere with equally great effort.

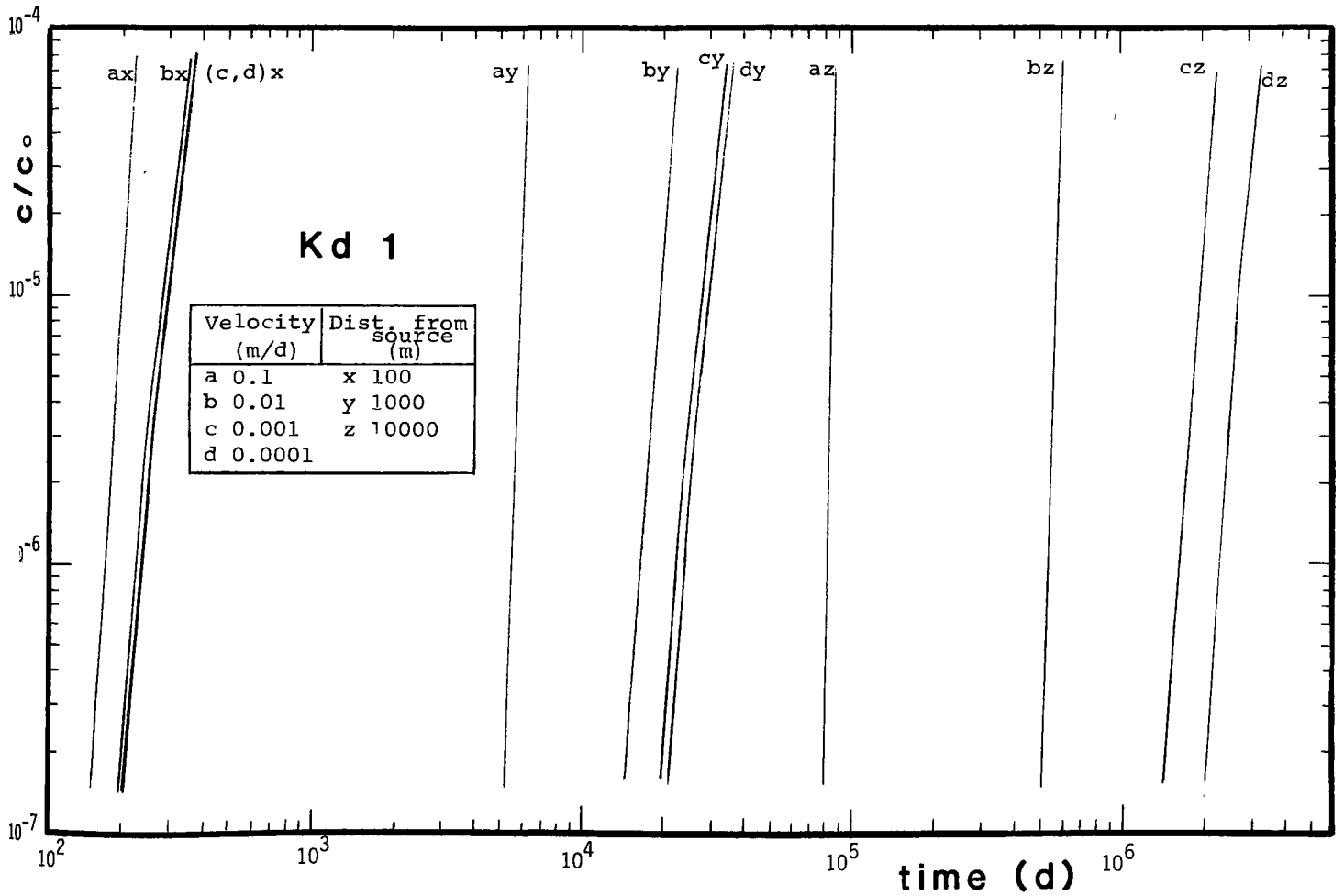

Figure 2.
Time to Reach Ambient Criteria Concentrations

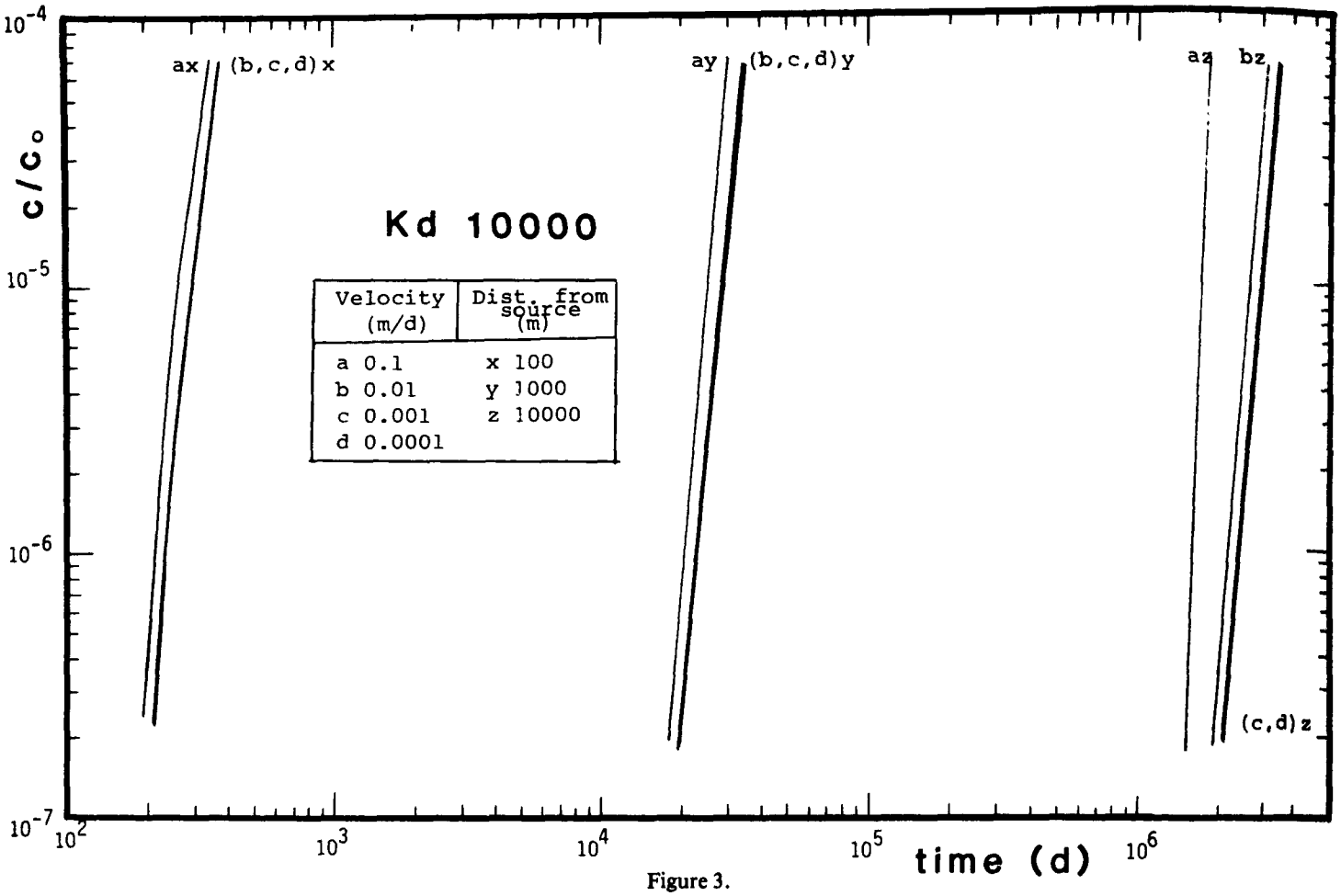

Figure 3.
Time to Reach Ambient Criteria Concentrations

Consequently, the major parameters that are susceptible to revision are the solubility limit and the partition coefficient. To decrease the solubility limit requires an alternation in the form of the waste. This, of course, would differ for specific waste types. One may conclude that, for certain wastes, only total destruction, by incineration, for example, is acceptable. Whereas for the others, it is possible that encapsulation methods may be sufficient. It may also be possible to change by altering the natural chemistry of the site. However, this can only be a temporary solution.

Therefore, it may be necessary to examine alternatives to near surface disposal. Disposal at intermediate depths (>50 m) would in general, decrease the groundwater flow and increase the distance to the biosphere.

NOMENCLATURE

c_o —initial concentration mg l^{-1}
c —final concentration mg l^{-1}
D —dispersion coefficient $m^2 d^{-1}$
ε —soil void fraction %
k —reaction constant
n —order of reaction
s —mass of solute sorbed per unit dry mass of solid
t —time
u —average velocity m d^{-1}
x —distance in flow direction m
ρ —bulk density of soil g m^{-3}

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LOCATING OF GROUNDWATER POLLUTION SOURCES FROM LIMITED FIELD DATA

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INTRODUCTION

Conventional methods of locating an unknown groundwater pollution source require an extensive number of observation wells from which sufficient data can hopefully be obtained to plot concentration contours for the identification of the pollution source.[1] Such an operation usually is quite expensive and furthermore, with limited field data, results are approximate, at best. However, by assuming constant dispersivity of the contaminant and the steady state groundwater flow field, the mass transport equation for the contaminant becomes linear. Thus, to locate the pollution source is now equivalent to solving an identification problem of a linear dynamic system.

The aquifer parameter identification problems or so called inverse problems, have been investigated for the past 10-15 years. Faust and Mercer[2] gave a brief account of its recent development. In general, the calculation procedure for groundwater flow consists of finding a parameter set (transmissivity, storage coefficient, sources, etc.) that minimizes deviations between observed and calculated values of hydraulic head. Thus, for steady state flow problems, the criterion adopted to define the optimal set of parameters is to minimize:

$$\sum_{i=1}^{m} (h_i - \hat{h}_j)^2 \qquad (1)$$

where H_i and $\hat{h}_i$ are the observed and calculated heads at node i for a total of m observations. For the unsteady state flow problems the criterion function is the minimization of:

$$\sum_{j=1}^{T} (h_{m,j} - \hat{h}_{m,j})^2 \qquad (2)$$

where $\hat{h}_{m,j}$ and $h_{m,m}$ are the calculated and the observed heads made from O to T at mth discretized point corresponding to time t_j, where j = 1,2, ...T.

Several methods are available in order to achieve the minimization. Cooley[3] derived the modified Gauss-Newton procedures after linearizing the steady state equation using a similar technique to that used by Yeh and Tauxe.[4] Frind and Pinder[4] solved the inverse problem for transmissivity by the Galerkin finite element approach using steady state hydraulic heads as input data. For the dynamic system, Yeh[6] presents a good review on the methods of aquifer parameter estimation for unsteady state flow in an unconfined aquifer. Methods such as quasi-linearization, maximum principle and gradient method, influence coefficient method and the minimax-linear programing approach are presented in detail for achieving the minimization.

The application of the system's approach, however, for the identification of a groundwater pollution source similar to those for aquifer parameter identification seems to have been overlooked by previous researchers. In fact, if a steady-state flow field is assumed, the system control equation is linear. The criterion is then the minimization of the following expression:

$$J_t = \sum_{i=1}^{m} (y_{i,t} - \hat{y}_{i,t})^2 \qquad (3)$$

in which $\hat{y}_{,,t}$ and $y_{i,t}$ are the calculated and observed heads of concentration made at ith well corresponding to time t. The matrix equation resulting from the finite element discretization for the mass transport equation can be written:

$$\dot{c} = B_c + g \qquad (4)$$

where the location and the strength of the pollution source are contained in the vector g. The estimate, $\hat{g}$, approaches the true value of g as J_t approaches a minimum value. The method adopted in this study for achieving the minimization is based on system sensitivity theory which will be described in the following sections. As written, the paper presents the theoretical foundations for the study which will be presented at a subsequent time.

ANALYTIC FORMULATION

The governing equation of two-dimensional mass transport of a contaminant in groundwater flow can be written as follows:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = q + \frac{\partial}{\partial x}\left(D_x \frac{\partial c}{\partial x}\right) + \left(D_y \frac{\partial c}{\partial y}\right) \qquad (5)$$

where

c = concentration of the contaminant
u,v = velocity components of groundwater
D_x, D_y = components of dispersivity
q = source term

The source term q can be formulated according to the physical behavior of the pollution sources. Adey and Connor[7] outlined some expressions of the source term including sources with time decay, rate, etc. In order not to obscure the trend of thought in a jungle of equations, a simplified, but typical, formulation will be described.

The pollution source considered here is of a point source (or sources) with constant strength. Thus, the source term is as follows:

$$q = \Sigma q_i \vartheta (x - x^*_i)(y - y^*_i) \tag{6}$$

where

ϑ = Dirac Delta function
q_i = strength of the ith source
(x^*_i, y^*_i) = coordinates of the ith source

The major axes of the dispersivity tensor coincide with the global axes of the aquifer and, furthermore, the velocity field of the groundwater is steady but may vary spatially.

With proper initial and boundary conditions prescribed, the governing equation can be solved numerically to determine the concentration distribution of the pollutant over a period of time. Using the finite element method, it can be shown[8] that the Galerkin's expression for an aquifer element of depth b and fluid density p is:

$$c^T \{(K + A)\, c - M\dot{c} - Q\} = 0 \tag{7}$$

in which the superscript T indicates transpose and,

c = concentration vector of nodal unknown
$\dot{c}$ = time derivative of c
ϕ = interpolation function

$$K = \iint \rho b \left[D_x \left(\frac{\partial \phi}{\partial x}\right)\left(\frac{\partial \phi}{\partial x}\right)^T + D_y \left(\frac{\partial \phi}{\partial y}\right)\left(\frac{\partial \phi}{\partial y}\right)^T\right] dx\, dy$$

$$A = \iint \rho b \left[u\phi \left(\frac{\partial \phi}{\partial x}\right)^T + v\phi \left(\frac{\partial \phi}{\partial y}\right)^T\right] dx\, dy$$

$$M = \iint \rho b\, \phi\phi^T\, dx\, dy$$

$$Q = \int_{s_2} \bar{q}\phi\, ds + \Sigma q_i\, \delta (x - x^*_i)(y - y^*_i)$$

$\bar{q}$ = normal derivative of c prescribed on segment s_2 of the boundary

By assembling the element matrices into global matrices for the whole solution domain and applying the boundary conditions, one arrives at the final form of finite element formulation of the problem as follows:

$$\bar{M}\dot{\bar{c}} + (\bar{K} + \bar{A})\, \bar{c} = \bar{q} \tag{8}$$

where $\bar{M}$, $\bar{K}$ and $\bar{A}$ are the assembled matrices of M, K and A, respectively, and $\bar{c}$ and $\bar{q}$ are assembled vectors of c and q, respectively.

For convenience, we can drop the notation "–" and (8) to obtain the following:

$$\dot{c} = Bc + g \tag{9}$$

where

$$B = -M^{-1}\,(K + A) \tag{10}$$

$$g = M^{-1} q \tag{11}$$

If one assumes a zero normal gradient of concentration across the whole boundary, the entries in the vector q all vanish except those corresponding to source locations. For example, for a source of strength r located at the j node of the descretized finite element domain then the entry of the j th row of vector q is r.

The problem of locating a pollution source is an inverse problem of that just being described. The concentration is considered known, in fact, they are given from the concentration measurements taken at equal time intervals at observation wells. The problem is to identify the unknown vector g which contains the information of where the source (or sources) is located and what is its strength (or strengths).

METHOD OF SYSTEM SENSITIVITY

Let y_t be a measurement vector at time t then:

$$y_t = F_{ct} \tag{12}$$

where F is the location matrix of the observation wells. F is an m x n matrix with zero entries except at well nodes:

$$F = \underbrace{\begin{bmatrix} 0 \cdots 1 \cdots 0 \\ 0 \cdots 1 \cdots 0 \\ \vdots \\ 0 \cdots \cdots 1 0 \end{bmatrix}}_{n} \Bigg\}_{m} \tag{13}$$

If $\hat{y}_t$ is an estimate of y_t and

$$J_t = (y_t - \hat{y}_t)^T R\, (y_t - \hat{y}_t) \tag{14}$$

then J_t represents the magnitude of error between the estimated and observed concentration at time t. (R is a weight matrix of the observation wells.) In particular, for R = I (identity matrix) then

$$J_t = \sum_{i=1}^{m} (y_{i,t} - \hat{y}_{i,t})^2 \tag{15}$$

The system sensitivity theory provides a recurrence formula for $\hat{g}$ (estimate of g) for the next time step in a manner so as to minimize J_t. When J_t approaches a minimum value, $\hat{g}$ approaches the real g.

$$\hat{g}_{t+\Delta t} = \hat{g}_t - \frac{\partial J}{\partial g}\bigg|_t \Delta \tag{16}$$

in which Δ is the step size, ranging between 0 and 1 for normalized elements. $\frac{\partial J}{\partial g}$ will be evaluated through the governing equation of the physical system and the measurement matrices.

For convenience,

let

$$e_t = y_t - \hat{y}_t \tag{17}$$

thus

$$J_t = e_t^T R\, e_t \tag{18}$$

and

$$\frac{\partial J}{\partial g_i}\bigg|_t = \frac{\partial J}{\partial e_t} \cdot \frac{\partial e_t}{\partial g_i} \quad i = 1.2, \ldots. n \tag{19}$$

now

$$\frac{\partial J}{\partial e_t} = \frac{\partial}{\partial e_t}(e_t^T R\, e_t) = 2R\, e_t \tag{20}$$

and

$$\frac{\partial e_t}{\partial g_i} = \frac{\partial}{\partial g_i}(y_t - \hat{y}_t) = \tag{21}$$

$$F \frac{\partial c_t}{\partial g_i} \quad i = 1.2, \ldots. n$$

thus

$$\frac{\partial J}{\partial g_i}\bigg|_t = 2e_t^T RF \frac{\partial c}{\partial g_i}\bigg|_t \quad i = \tag{22}$$

$1.2, \ldots. n$

$\frac{\partial c}{\partial g_i}$ is the so called trajectory sensitivity vector which should be obtained from the governing equation of the system. From equation (9) it can easily be shown that

$$\frac{\partial \dot{c}}{\partial g} = B \frac{\partial c}{\partial g} + I \tag{23}$$

Furthermore, if the time derivative of the concentration is approximated by a finite difference formulation, i.e.,

$$\dot{c} = \frac{c_{t+\Delta t} - c_t}{\Delta t} \tag{24}$$

the combination of equations (23) and (24) gives the desired expression of the trajectory sensitivity vector in iterative form:

$$\frac{\partial c}{\partial g_i}\bigg|_{t+\Delta t} = (B \frac{\partial c}{\partial g_i}\bigg|_t + \alpha_i) + \frac{\partial c}{\partial g_i}\bigg|_t \quad i = 1.2, \ldots. n \tag{25}$$

in which

$$\alpha_i = \begin{Bmatrix} 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{Bmatrix} \leftarrow i \text{ th row}$$

In short, equations (16), (22) and (25) compose the iterative numerical system for obtaining the converged value of g.

OVERVIEW OF COMPUTATIONAL PROCEDURE

For illustration, a generalized example will be discussed. Consider a given suspect site that is arbitrarily subdivided into a finite element pattern of quadrilateral elements. The groundwater flow pattern can be in any direction with respect to this pattern but must be known or, at least, assumed. The observation wells are located on the grid and are numerically generated through equation (8). With data from these wells, the problem becomes one of locating the pollution source which is arbitrarily shown in Figure 1. (Note that multi-source problems can also be handled by this method.)

The computer programs are written in such a way that the assembled matrices, M, K, A can be called out for matrix operation. Arbitrarily select 1/3 of the total nodes

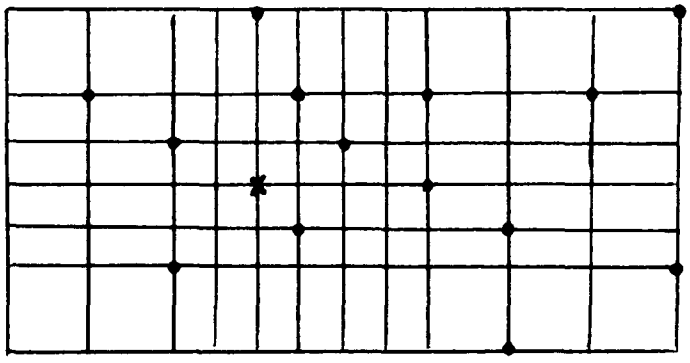

Figure 1.
Example Problem Showing Typical FEM Grid and Source and Observation Wells

and regard them as observation wells. The generated time series of concentrations at these nodes then serve as measurements at observation wells.

The flow chart of a sample computer program is given in Figure 2. The convergence criterion currently being used is:

$$\left| (\hat{g}_{I+1} - \hat{g}_I)/\hat{g}_I \right| \leq 10^{-3} \tag{26}$$

i.e., when the relative error in each entry of the g vector is less or equal to 10^{-3}, it is considered to be a convergent system.

During the initial iterations, adjustments are needed for selection of proper step size (Δ). To big a step size may cause the process to diverge. It, in general, reflects on

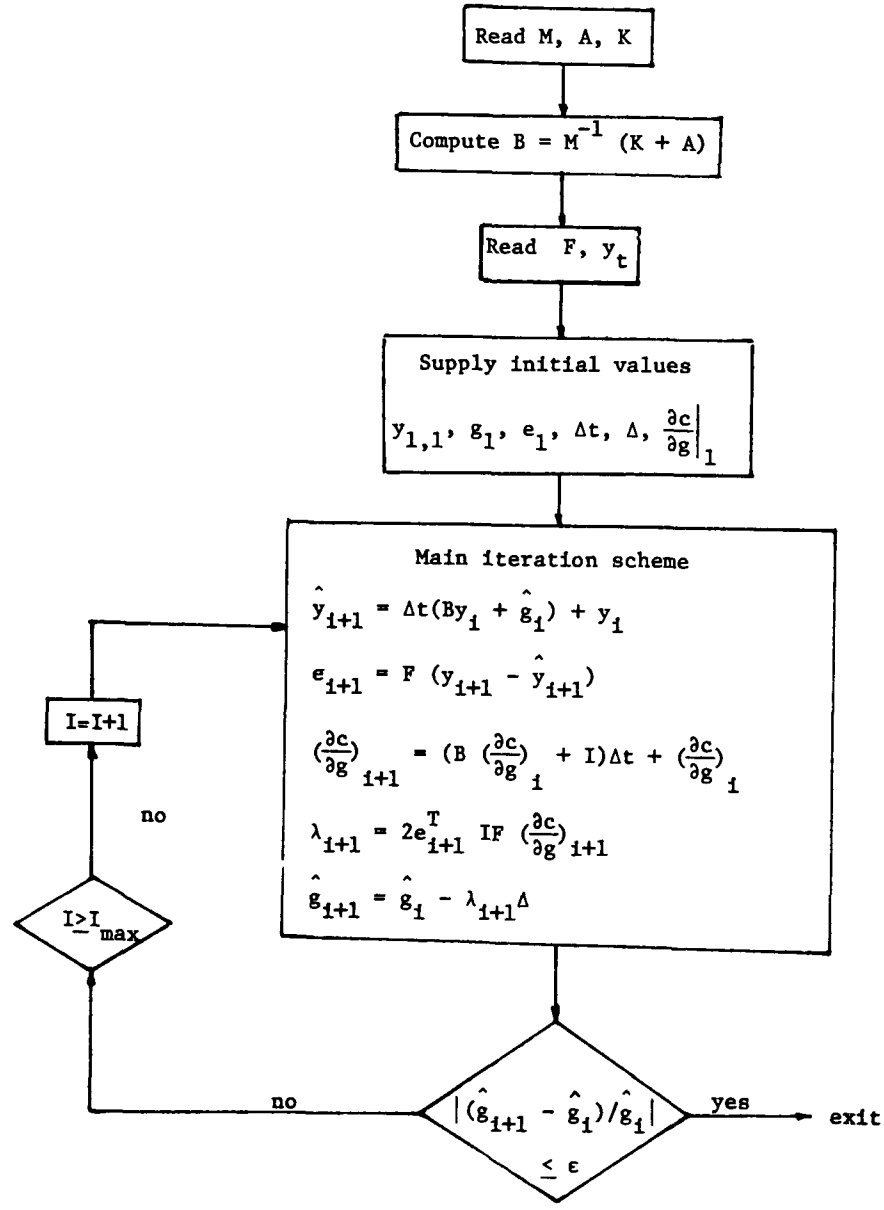

Figure 2.
Computer Flow Chart for Program Currently in Use

the growing residue. The step size should be cut in half if such a situation occurs. As noted in the introduction, programs are currently being run using the method in a wide variety of situations. Results will be forthcoming shortly. They are in the form of pollution contours, the focus on which clearly identifies the pollution source (or sources).

SUMMARY AND CONCLUSIONS

The general problem of locating a pollution source by having data from a limited number of observation wells is quite challenging, yet worthwhile, since its environmental impact is extremely important. One potentially useful analytic technique for this purpose is the use of the finite element method (FEM). While a good deal of information exists on this subject as far as taking a known source and mapping out its migration, the inverse problem of finding the source from a limited number of observation points is more difficult.

Still more important is that of the available methodologies, the application of a systems approach (as described herein) is a new solution technique. With a steady-state flow field assumed, the system control equation is linear and the criterion function can be minimized to an arbitrarily selected value.

The method of system sensitivity was described in the paper along with related theoretical considerations. This analytic formulation was the basic objective in this study. While work is still ongoing, the basic programs are developed (see flow chart of Figure 2) and various problems are currently being evaluated.

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DIOXIN INVESTIGATIONS IN SOUTHWEST MISSOURI

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INTRODUCTION

During 1971, in a well-known incident of waste mismanagement, three horse arenas in Missouri were sprayed for dust control with a mixture of used oil and chemical waste still bottoms. In the ensuing three years, 64 horses died and ten adults and children became ill as a result of contact with the contaminated soil.

It was not until 1974, and after excavation and removal of the arena soils, that tetrachlorodibenzo-p-dioxin (TCDD) was identified as the causative agent. Investigation by the Missouri Division of Health and the Center for Disease Control (CDC) traced the source of this substance to the defunct Northeastern Pharmaceutical and Chemical Company (NEPACCO), which had leased manufacturing facilities at a chemical plant in Verona, a small community in southwest Missouri.

As a result of an anonymous phone call from a former NEPACCO employee, the Environmental Protection Agency (EPA) became interested in the past activities of this company in 1979. The caller made allegations concerning other sites where NEPACCO wastes were disposed of and provided names of prospective interviewees. The historical record of the company and the specter of additional TCDD sites, coupled with the Agency's burgeoning interest in hazardous wastes, prompted an immediate investigation. This paper summarizes the results of that ongoing effort.

HISTORY AND BACKGROUND

In November of 1969, NEPACCO leased a specific manufacturing area of the Hoffman-Taff, Incorporated chemical plant in Verona for the purpose of making hexachlorophene. Hoffman-Taff had previously used this area in the manufacture of "Herbicide Orange" for the military. As a result of curtailed usage in Viet Nam, Hoffman-Taft lost its contract and the facilities sat idle for a number of months. Shortly after NEPACCO leased the manufacturing line, the entire plant was acquired by Syntex Agribusiness, Inc.

The beginning processes of the herbicide and hexachlorophene operations were similar, and apparently the idle facilities represented an opportunity for NEPACCO to begin manufacturing with minimum capital expenditure. Both processes involved the intermediate production of 2, 4, 5-trichlorophenol (2, 4, 5-TCP). A major difference in the two operations, and of central interest to this investigation, was the subsequent treatment of the 2, 4, 5-TCP. Hoffman-Taff produced a technical grade herbicide which permitted impurities, including TCDD, to go forward into the final product. The pharmaceutical grade hexachlorophene necessitated distillation of the 2, 4, 5-TCP, which resulted in a still bottom waste stream with TCDD concentrations in the range of 350 mg/l.

Between approximately April 1970 and January of 1972, NEPACCO is reported to have produced 328 batches of 2, 4, 5-TCP. Shortly thereafter, the company lost its market and ceased operations as a result of the limited use restriction imposed on hexachlorophene by the Food and Drug Administration (FDA).

EPA INVESTIGATION

Agency investigation of the past activities of NEPACCO began in October of 1979 and resulted from an anonymous phone call from a disgruntled employee who had been terminated by Syntex; he had worked in the NEPACCO area. This individual identified other former employees who allegedly had knowledge of NEPACCO operations, waste management practices, and disposal sites in the area.

In response to this information, a field team spent two weeks in southwest Missouri conducting interviews with former NEPACCO and Hoffman-Taff employees, independent trash haulers and landowners and in reconnaissance of reputed disposal sites. A parallel effort of the investigation included retrieval and review of all available historical information on the company which encompassed FDA files, Missouri Department of Natural Resource and Division of Health files, court depositions from the horse arena incident, as well as in-house documents.

This initial investigation resulted in the identification of three potential sites which included Baldwin Park in Aurora, the Syntex trenches west of the Verona plant, and the Denney Farm Site, which was sampled by the Agency in April of 1980. As a result of the publicity surrounding the Denney site investigation and the numerous contacts between EPA employees and area residents, other rumors came to the Agency's attention. These leads were pursued in August of 1980 and resulted in the identification of additional sites.

To date, the Agency has interviewed approximately 75 individuals and has identified seven proven or potential NEPACCO waste disposal sites which are in various stages of investigation or cleanup. In significance, these sites vary from major undertakings such as the Denney Farm Site, where remedial work is underway, to farms having small volumes of NEPACCO wastes with TCDD concentrations in the parts per trillion (ppt) range.

SITE STATUS

Baldwin Park

Located in Aurora in Karst topography, this 170-acre site was at one time a lead and zinc mining area with shafts, reportedly, up to 380 ft. deep. Following exhaustion of mineral resources, the tract, or at least a 30-acre portion of it, was used as a municipal dump by Aurora, as well as surrounding communities.

According to interviewees, large quantities of expended filter cake material, used by NEPACCO for product purification, was disposed of in the dump along with municipal trash. In 1973, the site was closed and reclaimed and given its present name. Although a sample of the NEPACCO filter cake discovered at another location was found to contain TCDD at a level of 8 ppb, samples of runoff and municipal and private wells surrounding Baldwin Park have not revealed detectable levels of NEPACCO contaminants. No final disposition of the site has been made.

Denny Farm Site

Identified during the October 1979 reconnaissance, the Denney farm is the largest proven site discovered to date. The site is in a rural wooded area of Karst topography on a ridge top approximately one third mile from the nearest surface water which is a losing stream. Visual evidence of the existence of the site included a depression in the ground about 10 ft. wide and 50 ft. long, with a mound of soil at the west end. Interviewees indicated that between 30 and 150 drums of waste were buried there in 1971. The drums were dumped from the back of a truck, lay as they fell, and were in marginal condition at the time of burial. Although eyewitnesses were unanimous in their belief that the trench contained NEPACCO waste, specific information as to drum contents was completely lacking.

In the winter of 1980, the Agency decided to mount a field sampling investigation with the objective of documenting site contents and any lateral migration of these contents. Although there was no direct evidence to indicate the presence of TCDD, the knowledge that the drums came from NEPACCO and the company's history of waste mismanagement, dictated that the study plan be designed to provide the highest levels of personnel protection. Consequently, a draft plan was developed and widely circulated for comment within the Agency as well as without. Many excellent suggestions were received and incorporated into the final plan.

Preparatory activities undertaken in support of the investigation included removal of site vegetation, the erection of an eight-foot security fence, personnel baseline physical examinations, a town meeting in Verona to explain EPA activities and, finally, a field trip to the site for the news media immediately prior to imposing access restrictions.

Sampling, which included collection of perimeter soil samples as well as exposure and sampling of drums, took place in April of 1980 with the highly capable assistance and support of the EPA National Emergency Response Team. Initial on-site activities included setting up a decontamination station for men and equipment, putting up a wind speed and direction indicator, and the surveying in of perimeter sample locations.

Protective clothing and safety gear, depending upon the particular work task, ranged from disposable splash suits with rubber boots, gloves and hard hats, to the encapsulating "moon suits" for those individuals working in the trench and sampling drum contents. During the time that the trench was open, the rural fire department was on site, and aircraft were restricted from the area.

Working from one side of the trench, a back hoe was used to excavate down to a depth of 1.5 to 2.0 ft. Manual shoveling completed the removal of soil from around the drums in preparation for sampling. Thirteen drums, some of them crushed and empty, were exposed. Eight drums with visually varying contents were selected for sampling. Following completion of sampling, the trench was immediately closed and samples packed for shipment.

Analytical results received in June 1980 ranged from 1.4 ppb TCDD in some drums up to 319 ppm in others. A single composite soil sample taken in the trench from around the exposed drums had a TCDD concentration of 72 ppb.

Following confirmation of TCDD and based upon expert testimony that migration would occur, and that the location was neither suitable for hazardous waste nor could be made suitable, a temporary cap was put over the trench to eliminate percolation of precipitation. Concurrently, EPA initiated a weekly monitoring program of private wells and surface waters in the area, and directed Ecology and Environment, Inc. to prepare an engineering report evaluating appropriate remedial measures. The Agency also entered into discussions with Syntex Agribusiness.

Effective September 12, 1980, Syntex, while denying knowledge or responsibility for any acts of NEPACCO or others in placing wastes in the trench, entered into a consent decree to undertake remedial measures at the site. The company's site restoration plan, comprehensive in scope and sophisticated in design, was approved by the Agency on February 25, 1981. Following construction and stationing of numerous on-site structures and ancillary equipment, Syntex began removal of trench contents on June 15, 1981. As of the writing of this paper, remedial work is still underway.

Syntex Trenches

Located on Syntex property west of the company's plant in Verona are a number of trenches, now inac-

tive and covered, which were ostensibly used by Hoffman-Tate for the disposal of uncontaminated trash. Two of these trenches were reportedly open during the time NEPACCO was active. Some interviewees have alleged that NEPACCO waste, both drummed and in bulk, was put in these trenches, apparently without the knowledge of company management. Syntex and the Agency have opened discussions on this potential site and exploratory sampling is anticipated in the near future.

Farm Site A

A former NEPACCO employee rented a house on this farm located a few miles south of Verona. Six 30-gallon open top drums, originating from the Verona plant and containing minor volumes of a dark residue, had been left in a barn on the farm by the employee. The drums came to the attention of the Agency in late 1979 and were sampled in the winter of 1980. Analysis indicated 7 ppb TCDD. Syntex subsequently agreed to take the drums along with limited quantities of hay, corn and potatoes which were also stored in the barn. A barn dust sample was collected following removal of these materials and final disposition of this site is awaiting the analytical result.

Water and Wastewater Technical School

The hexachlorophene operation in Verona also resulted in the production of a high-strength refractory wastewater which was initially discharged to evaporative lagoons owned and operated by Hoffman-Taft. In September of 1971, Hoffman-Taff refused to accept anymore of this wastewater and NEPACCO subsequently entered into a contractual arrangement with the Water and Wastewater School in Neosho, Missouri for acceptance of this wastewater and for the conduct of treatability studies. For convenience, a portion of this wastewater was put in a small open top steel tank on the school grounds for analysis and the treatability studies.

As a result of the publicity surrounding the Agency's ongoing investigation in the area, school officials became suspicious of the asphaltic-like residue remaining in this tank and collected a sample in the fall of 1980. Analysis by a commercial laboratory indicated a TCDD concentration of approximately 2 ppm.

In response to this finding, EPA personnel assisted in a cleanup of this solid material on school grounds which had accumulated as a result of students operating a valve on the tank. Following confirmation of TCDD by the EPA Regional Laboratory, which also reported a residual of 62 ppb in the spill area soil after cleanup, the tank and 15 drums of residue mixed with attached soil were removed to a remote bunker on school property for temporary secure storage.

In addition, Syntex Agribusiness assisted by putting up an eight-foot security fence around the spill area while EPA personnel assisted the school in putting a temporary cap over the area to eliminate the possibility of migration of contaminated soil particles. Although a final solution for the spill area and the drummed wastes has not been determined, the public health and environment is being protected in the meantime.

Neosho Digester

Between October of 1971 and February 1972, 225,000 gallons of NEPACCO wastewater was trucked to Neosho, about 30 miles west of Verona. The waste was placed in an open top abandoned wastewater treatment plant digester for storage, apparently with the expectation that the Technical School, which operated the plant at the time, would find some means for treating it.

After NEPACCO went out of business, the waste remained in the digester. Starting in 1977, after the city of Neosho resumed operational control of the wastewater treatment plant, the digester was filled in with rock, soil, and various other fill materials. In March of 1981, an EPA team, using a drilling rig, collected a core sample from the bottom (20 foot depth) of the digester. Analysis of the sample revealed 2,500 ppm of 2, 4, 5-TCP and 60 ppb TCDD. Following this finding, down gradient stream and private well water samples were collected. The analytical results are not available as of the writing of this paper and disposition of the site is pending.

Farm Site B

In addition to Baldwin Park, two farms are known to the Agency as having received the NEPACCO filter cake. Although the source of the rumor is not known, there was a belief among some local farmers that the filter cake, presumably because of residual hexachlorophene, was good for controlling hoof rot in cattle. In an imaginative approach to waste disposal, NEPACCO permitted farmers to take this material, which was subsequently spread in feedlots and gate areas in such a manner that the cattle would walk through it. One feedlot sampled in August of 1980 was found to have 0.4 ppb. In addition, 8 ppb was found in a sample of the filter cake itself, which because of a leaking drum, was dumped on the ground and never spread or mixed. Although the landowner has been cautioned to stay away from the two areas, final disposition of the site is pending.

DISCUSSION

At this point in time, all NEPACCO sites are suspect. The objective of the investigation in southwest Missouri is to determine where all NEPACCO wastes, of whatever description, were disposed of, and to take appropriate remedial measures at those sites judged to pose some hazard to public health or environment. This objective is being accomplished by a number of parallel paths which include interviews of former NEPACCO employees and area residents, sampling and technical evaluation of available documents and information, with the aim of reconstructing the NEPACCO process and developing estimates of wastes quantities.

Approximately 35,400 gal. of NEPACCO still bottoms have been accounted for to date. This figure does not in-

clude the bottoms recovered from the Denney site which have not been entirely quantified as of the writing of this paper. Even less quantification is possible with other NEPACCO waste streams, and there is no assurance that other sites will not surface. Indeed, at this time, the Agency is aware of rumors and hints of other sites too vague to be addressed in this paper.

Some ten years after the event, this investigation has proven to be extremely resource intensive. Time has dulled the memory, some individuals have moved away, others have died, and still others have expressed concern about publicity and are reluctant to talk with EPA investigators. The investigation has been further hampered by unavoidable delays in obtaining NEPACCO records, by limited access to low analytical detection capabilities for TCDD and finally, by the absence of guidance criteria in determining environmentally acceptable levels for TCDD.

The activities of NEPACCO in the handling and disposal of their various waste streams are classic examples of hazardous waste mismanagement. These practices have adversely affected the health and welfare of some individuals and have produced a sense of fear and uncertainty in the minds of others.

In bright contrast, the residents of southwest Missouri, and the Agency, are fortunate in having the problem solving capabilities of Syntex Agribusiness brought to bear upon the legacy left by NEPACCO. The commitment of Syntex to the Denney Farm Site has resulted in a model project which is testimony to the company's positive environmental philosophy.

THE DENNEY FARM SITE REMEDIAL PROJECT: A MODEL FOR THE SAFE EXCAVATION, STORAGE, AND ELIMINATION OF DIOXIN

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INTRODUCTION

Syntex' project to clean up and permanently dispose of hazardous wastes, abandoned some 10 years ago by another company, may be considered a model of industrial governmental cooperation. Its success is due to the efforts of Syntex' sophisticated multi-disciplinary team and to the commitment, cooperation, and sense of mutual respect that developed among Syntex Agribusiness, the United States Environmental Protection Agency (USEPA) and the Missouri Department of Natural Resources (MDNR).

This joint effort was particularly important because Syntex did not generate the problem but inherited it. Syntex neither created nor disposed of the wastes in the disposal trench, and the disposal site is not on Syntex property. Syntex found itself involved in this matter only because it purchased a chemical plant at Verona, Missouri, from another company which had earlier leased part of its facility to the North Eastern Pharmaceutical & Chemical Co., Inc. ("NEPACCO") for the manufacture of hexachlorophene. In the summer of 1971 NEPACCO, in violation of its lease and unknown to Syntex, arranged with the owner of the Denney farm, located in Southwest Missouri, to have barrels of its waste transported to the farm and disposed of in a trench located on the property. It is this trench and its contents that Syntex, the USEPA and the MDNR have been concerned with since.

In 1979-80 the disposal trench was found by an EPA investigation team and determined to contain highly toxic wastes, including 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin, commonly known as dioxin. Syntex, the EPA and the MDNR joined together to develop a plan designed to clean up safely the toxic wastes found in the disposal trench.

Unfortunately, the task was seriously complicated by the absence of crucial facts such as the size of the trench, the number of barrels in it and the identity of the wastes in those barrels. Testing was undertaken to ascertain this information using ground penetrating radar, metal detectors, electromagnetic conductivity and resistivity. However, the results, while providing an estimate, were not as helpful as one might have wished. For example, after various tests over a number of months, estimates of the size of the trench ranged from a rectangular depression 53 feet long, 10 feet wide and 10 feet deep, to a left shoe print shaped trench some 65 feet long, 20 feet wide and 10 to 12 feet deep. In fact, the trench was found to be approximately 60 feet long, 8 or so feet wide and only 6 feet deep. Estimates of the number of barrels in the trench ranged from 30 to 150; approximately 90 were found. Perhaps most difficult was that while there was some information on the range of wastes generated by NEPACCO, which included innocuous materials as well as flammable solvents and dioxin, no one knew their concentrations or quantities.

TEAM APPROACH

To develop a plan to solve this problem safely, Syntex realized early in the project that the expertise of a number of disciplines was necessary. Needed was expert toxicological advice to assess what risks existed at each stage of the operation and a determination of when protective clothing was necessary and what types were advisable to wear. Needed also was a determination how best to assure that no materials would escape into the environment if some untoward event occurred during excavation. State of the art analytical capability was crucial for quick, accurate assessments of the materials found in the trench. Particularly important was a construction crew that could perform under conditions made difficult by the presence of extensive safety equipment and could operate their machinery with such delicacy that drums which had thin sides due to corrosion would not rupture.

Finally needed were sophisticated legal and public relations input to help develop the plan and maintain the firm's good relations with the EPA, MDNR and the local community.

Therefore, Syntex gathered together a multi-disciplinary team composed of an engineer, equipment operators, skilled laborers, a toxicologist, specialists in environmental health and safety, analytical chemists, lawyers, public relations experts and executives in order to devise a plan that could safely tackle the Denney farm site disposal trench.

PLAN DEVELOPMENT

After months of hard work, lthis team developed a plan whose goal was to minimize and protect against possible dangers to on-site workers, the nearby community and the environment while simultaneously maintaining the mutual

objectives of the parties involved: to remove and dispose of hazardous wastes located at the Denney farm site.

The Denney farm site Final Plan did exactly that. It established a series of procedures to remove all materials: liquids, flowable sludges, chemical solids, containers, visibly contaminated soils and other soil from the Denney farm site disposal trench to provide immediate protective containment of the hazardous wastes excavated and to detoxify those wastes with higher concentrations of dioxin and to provide an environmentally safe way simultaneously to contain and detoxify any low level contaminated soil from the trench.

Safety Program

However, prior to beginning actual work the Final Plan required every individual who would work at the Denney farm site trench to undergo special medical examinations and to complete a specially designed training program. A detailed health and safety review was conducted by occupational physicians, toxicologists and hygienists; it focused on determining if any worker had a particular sensitivity or susceptibility to dioxin or other toxic chemicals believed to be in the disposal trench. Particular attention was paid to routes of exposure via the respiratory tract, skin and mucous membranes. Any worker with such a sensitivity or susceptibility was not permitted to work on the project. All workers passing the medical exams then underwent extensive training at the Verona plant prior to actually beginning work at the disposal trench. During this training they were instructed on the tasks they were to perform at the trench and practiced safety and emergency procedures.

The prospective workers also learned how to use the various types of required protective clothing. The most stringent protective clothing was Category I equipment consisting of complete respiratory, skin and mucous membrane protection.

Category I protection was used by employees working in the disposal trench while the waste from the trench was being removed. These workers used a supplied air continuous flow system for maximum working efficiency consistent with the primary objective of full assurance of respiratory safety. They were also protected by a full body guardian chemical suit (akin to a "moonsuit"), a white cap safety helmet completely covering the head and neck, and neoprene safety boots. This equipment afforded complete body protection and allowed the mobility necessary to remove safely the drums and contaminated soil.

Category II equipment, used only outside of the disposal trench, had less stringent protective requirements. It consisted of a chemical protection suit, safety hat, gloves, boots and an air purifying respirator.

Category III equipment was required for the relatively minor operations. Category III standard safety equipment and clothing included a safety hat, disposable Tyvek suit, coveralls and safety boots.

After those workers who would be participating in the excavation and monitoring activities at the Denney farm site underwent medical examinations, were specially trained for the safe handling of dioxin, learned how to use their safety equipment, and were schooled in emergency procedures, construction at the disposal trench was ready to begin.

SITE CLEANUP

The first order of business was to expand the 8-foot-tall chain link fence already surrounding the disposal trench to accommodate the additional structures necessary to implement the Final Plan. This fence served to prevent any individuals or animals from accidentally wandering onto the site. A guard was also stationed on the site to dissuade the curious and add an additional measure of safety and security to the area.

Next, a Temporary Work Site Protection Structure (the TWSPS) 100-feet-long and 48-feet-wide was erected over the entire disposal trench. The purpose of this structure was to provide a cover that would prevent rainfall from entering the trench site, reduce the effect of wind on the handling of contaminated soil and provide a safe storage area for containment drums.

Once the TWSPS was erected over the disposal trench a Temporary On-Site Drum Storage Area (TOSDSA) was constructed to provide a diked, weather protected and secure storage location for all drummed materials and overpacks. The TOSDSA was constructed with reinforced concrete with an emphasis on structural integrity and leak proofing.

Two Microbiological Degradation Basins (MDBs) were then constructed in order to safeguard and treat contaminated soil excavated from the Disposal Trench.

Finally, before excavation began, ancillary but important additional equipment was placed at the Denney farm site: an air compressor to supply air to the workers who would actually be in the trench, electrical wires, pipe lines for water, fuel, nitrogen, a forklift, a generator and a back hoe.

An anemometer was installed to determine wind speed. If the wind velocity exceeded a certain level, the project would be shut down to avoid the possibility of escaping particles. Further, air sampling devices were placed about the site and their filters were assayed regularly for dioxin; none was ever found in any of these samples.

Excavation

The excavation began by removing the cap and the first layer of earth. Then, workers carefully began digging around the barrels in the trench with shovels. Both opened and unopened barrels were uncovered. Once a barrel was found, its contents and any material that had leaked out were extracted by a special vacuum system and transferred into clean barrels. The contaminated barrels, once emptied, were then carefully lifted from the disposal trench and placed in overpacks. Once the new barrels and overpacks reached their capacity, they were sealed, labeled and taken to the TOSDSA.

After the barrels were removed, all the visibly contaminated soil was removed and placed in 55 gallon drums and

moved to the TOSDSA. The remaining soil was then placed in the MDBs. This soil will be tested and, if found contaminated, subjected to treatment.

Using this method of excavation, removal, and storage the disposal trench has been emptied—90 barrels were found in it although some of the barrels were broken or disintegrated so an exact count is impossible. The disposal trench has been sampled and the samples are being assayed to determine if the soil is still contaminated.

DIOXIN DEGRADATION

It is expected that the most contaminated materials will be amenable to photolysis, which involves breaking down the nuclear structure of dioxin using light energy, usually in a specific wavelength range. Photolysis studies have shown that dioxins may be photolytically degraded by natural sunlight. A photolysis treatment plant provides the photochemical reaction necessary to destroy the dioxin compound by using an ultraviolet source of light in an enclosed and controlled setting.

A photolysis treatment system was developed to treat approximately 4300 gallons of an oily dioxin-contaminated waste NEPACCO had abandoned in a tank at the Verona plant. The first step was to make certain nothing leaked from the storage tank. Six years of work preceded a decision to go forward with development and use of the photolysis process primarily because of its potential for success and the degree of safety it offered. It is a low pressure, low temperature, and fully closed system providing almost no opportunity of human exposure to the material to be detoxified as well as virtually no chance of toxic release to the surrounding environment.

The system was successful. During the summer of 1980 Syntex extracted virtually all of the NEPACCO waste from the tank and destroyed 99% of the dioxin. This system will be used to detoxify a portion of the materials at the Denney farm site.

Some materials found at the Denney farm site can also be disposed of through landfills and other EPA approved methods. Other material cannot be so easily discarded. Syntex has explored a variety of different technologies to dispose of these substances such as microbiological degradation which is the molecular degradation of an organic substance resulting from the complex actions of living organisms. To assist this biological process, various organic nutrients are to be added to treat the contaminated soil in the MDBs. Syntex and the EPA will be closely monitoring the dioxin levels in the MDBs to determine the success of microbiological degradation.

CONCLUSION

While the project is not fully complete, the hazardous wastes from the Denney farm site trench are excavated and secured, with progress being made toward their ultimate disposal. The success of this project is the product of a team composed of a solid core of individuals with highly developed expertise. It is also the result of the close cooperation and mutual respect among Syntex, the EPA, the MDNR and the local communities, without which this project would have not been possible.

A HAZARDOUS WASTE DISPOSAL PROBLEM VS A SYSTEMATIC APPROACH FOR IMPOSING ORDER ONTO CHAOS

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INTRODUCTION

Occidental Chemical Company, a subsidiary of Hooker Chemical Corporation and its parent, Occidental Petroleum Corporation, owns and operates an agricultural fertilizers and pesticides plant in the San Joaquin Valley at Lathrop, California. This plant came into national prominence in 1977 following discovery that a substantial proportion of the pesticide workers were sterile. Presumably, the cause of this sterility was from exposure to a nematocide, Dibromochloropropane (DBCP) which was both formulated (1957 to July 1977) and manufactured (1963 to 1971 and 1974 to 1976) at the plant. Subsequent to this discovery, the State of California banned the sale and use of DBCP on August 12, 1977. This initial action was expanded into a nationwide mandatory suspension of the production and use of DBCP except in certain limited areas.

The combination of the sterility issue and certain Company documents indicating potential adverse environmental effects caused the U.S. Environmental Protection Agency (EPA) and State of California to investigate the Company's operations. On December 18, 1979, the U.S. and State of California filed suit in U.S. District Court against Occidental. On February 6, 1981, following over a year of technical studies and protracted legal maneuvering, a consent decree was lodged with the Court which established the framework for additional necessary studies and implementation of remedies.

The activities which led ultimately to the successful settlement of the case were characterized by a series of investigations which first sought to understand the potential problems, then defined the actual problems, and finally designed necessary remedies. The first of these was a multimedia environmental audit of the Company's operations.

AUDIT OF OPERATIONS

From September 18 to 28, 1979, investigators from the U.S. Government and State of California reviewed Company records and conducted interviews of employees at the Lathrop facility. The subjects of these inquiries were: past and present waste-generating processes and the disposal practices employed; in additional environmental data were collected (air, water, soil, groundwater). Attempts were made to gain information from the beginning of operations (1953) to present. Information on this time span was imperative because past disposal practices could still be causing adverse effects in the soil and groundwater systems.

The audit of Company operations in Lathrop, California determined that past production and disposal practices relating to liquid and solid wastes were inadequate, resulting in contamination of the groundwater and soil in the vicinity of the plant. Major findings of the audit included:

- Wet phosphoric acid operations, commencing in 1953, resulted in the generation of considerable amounts of gypsum ($CaSo_6$) and losses of fluoride. The gypsum was stored onsite during drying on permeable soil presumably resulting in percolation of sulfate ions to the local groundwater which was known to be between 2 and 7.6 m of ground surface.
- Ammonia, ammonium sulfate and ammonium phosphate/sulfate operations resulted in discharge of ammonium ions to unlined ponds, presumably resulting in percolation to groundwater.
- Sulfuric acid plant operations resulted in onsite burial of vanadium pentoxide catalyst causing, at a minimum, soil contamination.
- Pesticide formulating and manufacturing operations, some commencing as early as 1957, were characterized by use of over 100 active ingredients. Liquid waste disposal practices until at least 1976 included use of unlined ditches and ponds in permeable soil areas. Furthermore, until at least 1970 some pesticide waste solids and concentrated liquids were disposed of onsite in shallow trenches. Presumably these trenches were either exposed directly to the groundwater table or very close to it. A review of Company records for selected years indicated small percentage losses of pesticides. However, although these were small in terms of percentages, they represented large quantities when considering millions of kilograms of pesticides were formulated and/or manufactured.
- A review of past environmental data available through Company records and State of California files provided strong indications of environmental contamination attributable to the facility. Sulfate concentrations in one of the Company wells increased from 28 mg/φ in 1960 to over 2,000 mg/φ in 1979. At least 27 organic compounds

had been detected near the facility in soil, shallow groundwater and process, irrigation and potable wells. All these compounds were known to have been handled at the facility. Of these, 12 are known animal carcinogens.

- An aerial overflight of the facility conducted as part of the audit, using false color infrared imagery, indicated dark and discolored areas to the west of previous disposal areas. Vegetation appeared to be stressed; this pattern could have been caused by leachate migrating from the disposal site.

PLAN OF STUDY

Based on the audit findings and State of California records indicating probably significant, albeit not fully defined, environmental contamination, a plan of study was formulated to address the problem. This plan of study, developed jointly by the Company, the State of California, and the USEPA National Enforcement Investigations Center, presented a comprehensive approach for systematically determining whether certain inorganic, organic and radiological substances were present in the groundwater and soils in the vicinity of the Company facility and whether or not these substances were attributable to the Company's operations. The study would determine whether, and if so, which mitigation and remedial measures were necessary to prevent an imminent and substantial endangerment to public health and environment. Programs for groundwater analysis, soil analysis, private and public well monitoring and groundwater modeling were designed. The plan of study was divided into three phases:

Phase I—That phase of the groundwater and soil analysis program necessary to determine whether any organic, inorganic or radiological constituents were present in groundwater or soils in the vicinity of the Company's plant. This was to include, but not be limited to, the following:

- Define the vertical and horizontal zone of the aforementioned constituents within the groundwater and soils
- Establish the direction of movement of the subsurface plumes and their rates of movement
- Develop proposed mitigation measures if any are determined to be necessary to protect public health and the environment against imminent and substantial endangerment from contamination of groundwaters and soil resulting from the Company's operations

Phase II—That phase of the groundwater and soil analysis program necessary to:

- Evaluate the overall effectiveness of any mitigation measures, if any were determined to be necessary
- Define any additional remedial measures needed to be in compliance with waste discharge requirements and protection of public health and the environment from an imminent and substantial endangerment

Phase III—That phase of the groundwater and soil analysis program conducted after the implementation of mitigation measures, if any were determined to be necessary, that would evaluate ongoing compliance with the waste discharge requirements and protection of public health and the environment.

Groundwater Analysis Program

A total of 14 monitoring sites were selected surrounding the facility (Figure 1). Eight of these locations were selected to reflect presumed upgradient and downgradient groundwater conditions, the areal confines of the facility and locations of past disposal sites. Six additional sites were selected to reflect conditions radiating out several hundred meters from the plant boundary locations. Sampling at these sites would enable determination of whether and to what degree contaminants would attenuate in the directions of assumed groundwater movement. Three permanent wells were to be constructed at each site. The intent was to locate wells at depths of greatest contamination, background conditions below the leachate plume and approximately midway in the plume. It was recognized that additional wells may become necessary if the geohydrology of the area created several plumes rather than one. In fact, there are now 55 monitoring wells installed at the site (Figure 2).

One of the principal dilemmas faced by the formulators of the plan of study was what parameter(s) would be used to define the depths of the desired wells. As noted previously, numerous compounds, both inorganic and organic, had been handled at the facility, presumably with varying attenuation and migration rates. Of prime concern were many of the organics with known adverse health effects. After considerable discussion, it was determined that existing state of the art information could not afford an exact determination of the best parameter(s). Intentions were to initially examine groundwater conditions down to approximately 46 m or background conditions, whichever was greatest. Because this would mean numerous samples, the issues of expense and time to analyze indicator parameter(s) had to be addressed. Sulfate was finally chosen as the primary indicator because (1) considerable quantities had been introduced to the groundwater by the facility from the gypsum ponds, (2) sulfate was believed to be as mobile as any of the organics and (3) it could be monitored rapidly and inexpensively. To augment this indicator, additional indicator analyses were performed onsite for pH, conductivity, Redox potential and ammonia nitrogen.

In order to delineate areal stratigraphy, particularly at the well sites, samples were to be collected at representative depths during drilling. Once all stratigraphy data were collected from the 14 sites, three representative bore holes to 61 m were to be drilled in the study area to collect undisturbed samples for representative permeability and porosity measurements.

Drilling techniques employed to accomplish desired goals included both a dual tube reverse air rotary rig and a conventional rotary rig. With the dual tube rig, air flows down the outer annulus of the drill rod and carries cuttings and groundwater up the inner tube to ground surface and exits via a cyclone. Since air flows are on the order of 30 m/sec, an observer at ground surface sees es-

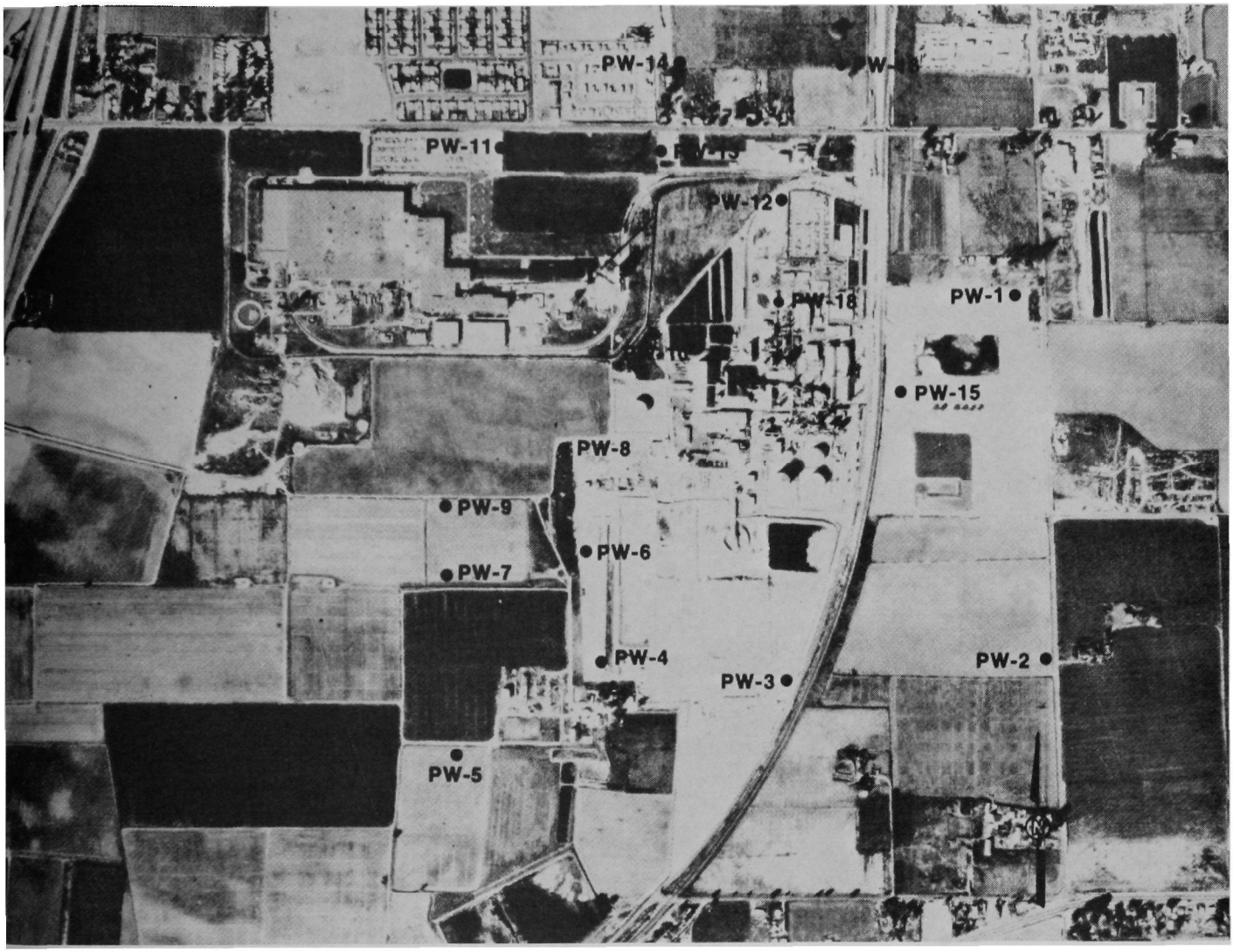

Figure 1.
Study Area Showing Permanent Wells Sampled During
Phase I and Interim Phase II Study.
(Scale: 1'' = 1,100')

sentially an instantaneous representation of cuttings and groundwater. This procedure enabled a continuous logging of stratigraphy by an experienced geologist and also afforded indicator groundwater sampling at approximately 3 m intervals. Once a depth of desired sampling was reached, advancement of the drill rod was halted but the air was left on. This afforded a representative water sample since the rapid air flow purged the drill rod of any contents. At certain times, when in clay formations and some sandy material, plugging occurred and it was necessary to add a "water mist" to the airstream to lubricate the drill bit. Representative groundwater samples were then obtained by stopping the mist approximately 1 m before the desired depth, advancing the drill rod and allowing ample time for air purging of any mist water.

Once desired groundwater and stratigraphy samples were collected at a site, conductivity, sulfate, ammonia nitrogen and stratigraphy data were plotted against depth. Three depths were then selected for permanent wells. Although the depths were ostensibly to represent the previously mentioned criteria of highest sulfate concentration, background sulfate and mid-concentration, reality often dictated a more detailed determination. For example, in some instances, there were no sharply defined curves; consequently, a combination of the data plots, the existing stratigraphy and considerations of adjacent site data had to be used to select depths of permanent wells.

Once depths were selected, 30 cm bore holes were drilled using a conventional rotary rig for installation of permanent wells of 15 cm diameter steel casing. Because a major concern was precluding the introduction of any contaminants into the wells, the rotary drill contractor was instructed to only use water as a drilling fluid, if possible, rather than drilling mud. This proved successful at all 42 wells installed at the 14 sites (three per site). At the bottom of each casing was a concrete plug followed by a 1.5 m stainless steel screen to afford adequate withdrawal from the water-bearing formation. All wells were gravel

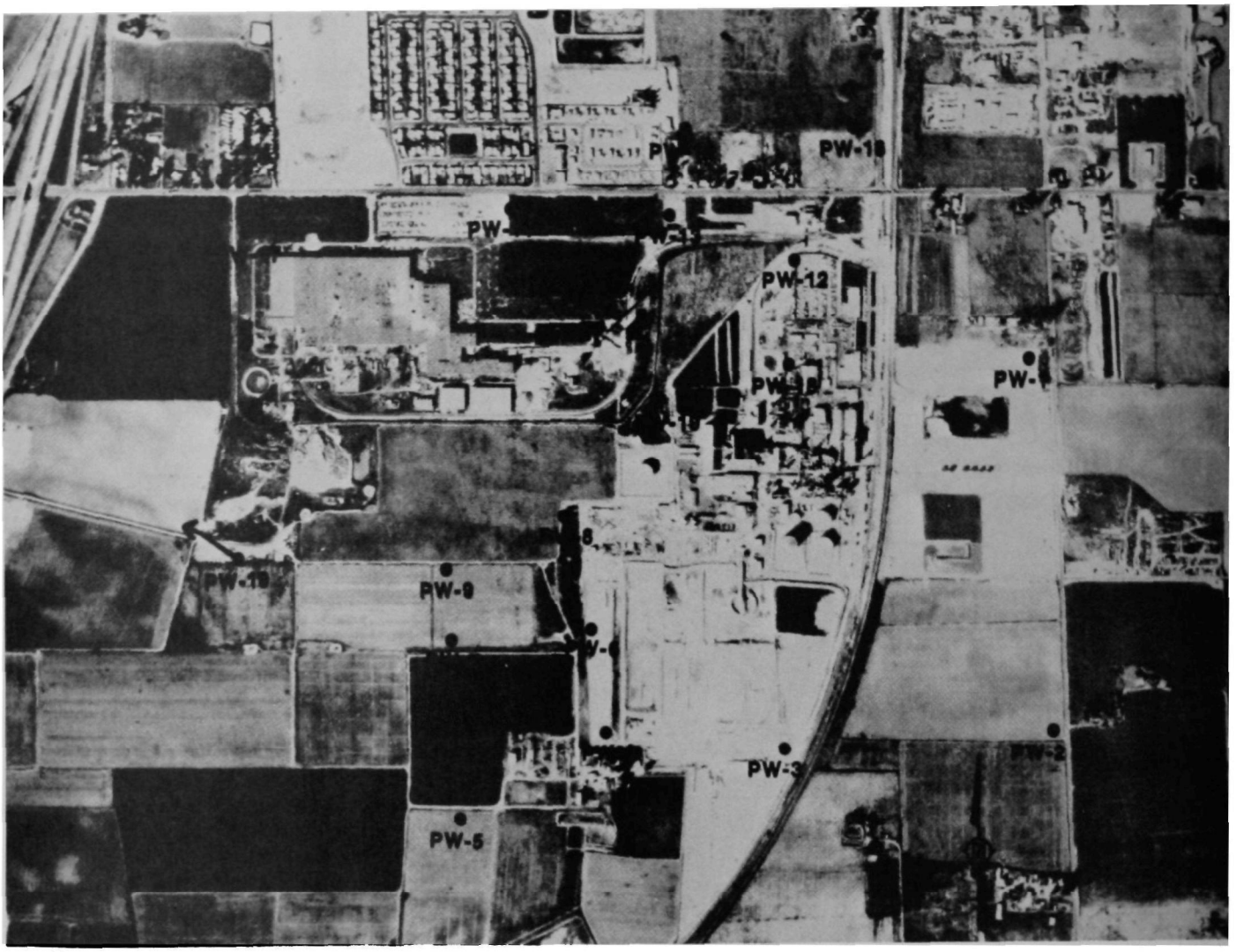

Figure 2.
Phase II. Permanent Well Sampling Locations
(Scale: 1" = 1,100')

packed to above the screen and then cement grouted to the surface to isolate the screened section. To assure no contaminants would be introduced at the surface, the casing extended to 0.6 m above ground surface and was fitted with a metal cap which could be locked. Wells were developed/cleaned by pumping at least 7,600 φ with an airlift and/or a submersible pump. Purged water was collected in tanks and returned to the Company's onsite hazardous waste tanks for subsequent disposal.

Groundwater characterization sampling was conducted with a submersible pump and an air-inflatable packer. The pump/packer assembly was lowered to a point where the packer was just above the top of the well screen. The packer was then inflated via an air line to the surface to isolate the well casing from the screen down. The pump was activated and a volume of water equal to at least 5 volumes of casing below this screen was purged to the surface via a Teflon* tube and discharged to hazardous waste tanks. Representative samples could then be collected for desired analyses (Table I). The selection of these parameters was based on compounds handled at the facility in greatest quantities, based on audit findings and compounds previously found in groundwater and soil samples in the area. The analyses selected included 29 pesticides, 12 metals and other inorganics and a radiological assay.

Once sampling was completed at a given well, the pump/packer/Teflon-tube assembly was moved to the next well and used again. It was assumed that the purging volumes would be sufficient to carry away any contaminants left on the Teflon from the previous well. To verify this, quality assurance sampling was periodically conducted by purging the Teflon with deionized distilled water. Samples were collected of the deionized distilled water as well as the water discharged from the Teflon at the end of purging.

*Registered Trade name.

Table I.
Parameters Chosen for Groundwater Characterization

Organics

DBCP	Malathion
ETDB (EDB)	Diazinon
α-BHC	Disyston (Disulfoton)
Lindane (γ-BHC)	DEF
β-BHC	Dimethoate
Δ-BHC	Trithion
Aldrin	Dibrom
Toxaphene	Methyl Trithion
Thiodan I (Endosulfan)	Dioxathion
Chlordane	Fenthion
DDT	Phosdrin (Mevinphos)
Perthane	Ethion
Methoxychlor	Sevin
Ethyl Parathion	DNBP
Methyl Parathion	

Inorganics and Metals

Nitrate	Fluoride
Sulfate	Copper
pH	Zinc
Conductivity and Temperature	Chromium
Vanadium	Arsenic
Nickel	

Other

Oxidation Reduction (Redox) Potential

Radiological Assay (gross alpha scan, radium scan, uranium scan, thorium scan and gross beta scan)

Soil Analysis Program

The audit of the Company's past practices revealed the existence of a number of past disposal areas, including unlined ponds, conveyance ditches and burial sites. Although the locations of some of the sites were obvious since they were above ground and clearly visible, others such as alleged pesticide burial trenches in the so-called "Boneyard" area were not. No Company person interviewed could identify the number or exact location of the burial areas. In approximately 1970, use of the Boneyard area had been discontinued and subsequent filling and grading had rendered visible identification impossible. The only document available which appeared to show the locations of some of the trenches was a blueprint submitted to the State of California in 1970. Its accuracy was presumed by the Company to be questionable.

In order to determine whether previously disposed materials needed to be escavated and transported to State of California approved hazardous waste disposal sites, a sampling program had to be designed for the known areas such as past disposal ponds and ditches. This included core sampling to approximately 3 to 5 m below grade. Sampling locations were selected representing the geographical bounds of the disposal sites, the discharge points and the lowest points (in ponds) (Figures 3 and 4). The procedure used was to collect discrete samples at the surface, 0.6 m, 1.5 m and 3 m. The surface sample (0-10 cm) was collected by shovel and placed into a solvent-rinsed glass or other appropriately prepared jars for subsequent analysis (Table II). The remaining samples were collected using a hollow stem auger drill rig and split-spoon samplers. The sampling procedure included drilling down to the desired depth and then advancing a split-spoon sampler with the rig to collect the desired soil sample. Samplers were opened and contents transferred onto a sheet of Teflon to preclude cross contamination. Samples, once split by quartering or mixing and aliquoting, were tranferred to appropriately prepared glass jars for transport to labs for analysis. The Teflon sheet was rinsed with deionized and distilled water and a 1:1 solution of hexane and acetone between samples. The split-spoon sampler was cleaned in a similar manner between samples to preclude cross contamination.

Table II.
Parameters Chosen for Soil Sample Characterization

Organics

EDB	Malathion
DBCP	Diazinon
α-BHC	Disyston (Disulfoton)
Lindane (γ-BHC)	DEF
β-BHC	Dimethoate
Δ-BHC	Trithion
Aldrin	Dibrom
Toxaphene	Methyl Trithion
Thiodan I (Endosulfan)	Dioxathion
Chlordane	Fenthion
DDT	Phosdrin (Mevinphos)
Perthane	Ethion
Methoxychlor	Sevin
Ethyl Parathion	DNBP
Methyl Parathion	

Metals

Vanadium	Zinc
Nickel	Chromium
Copper	Arsenic

Other

Radiological Assay (gross alpha scan, radium scan, uranium scan, thorium scan and gross beta scan)

pH

Relocating past disposal trenches/pits presented a most interesting technical problem. As noted previously, the only written evidence of possible locations was a 1970 site map. A reconnaissance of the area indicated that some of the map reference points could still be located. After considerable thought and discussion the following approach was adopted:

- Assume the site map was at least generally accurate
- Locate and physically stake out the disposal sites from site map locations
- Attempt to locate disposal sites by cutting exploratory trenches at right angles to the assumed directional lie of the trenches. This included using a backhoe and cutting

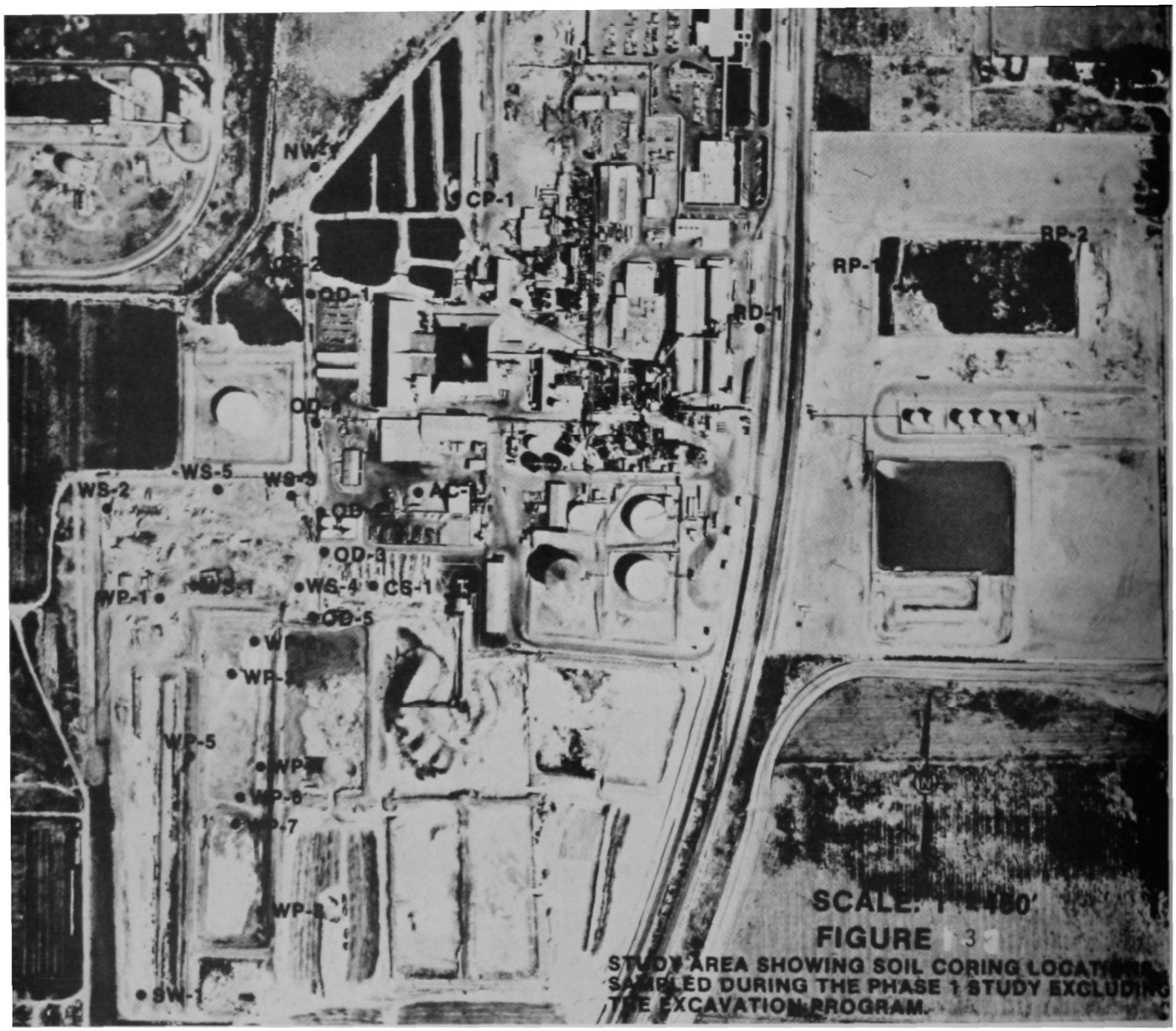

Figure 3.
Study Area Showing Soil Coring Locations Sampled During the Phase I Study Excluding the Excavation Program.
(Scale: 1" = 460')

to the water table which was generally 1.8 to 2.4 m below the ground surface (Figure 5)

- Once disposal trenches are intersected, rotate the exploratory trenches 90° and commence in directions of the disposal trench. This procedure was employed to determine the length of the trench as well as to assess, by visual observation of trench contents, the need for immediate total trench excavation versus sampling followed by possible excavation
- Once initial excavation and sampling activities are completed, collect soil core samples with depth adjacent to the trenches for parameters previously referenced (Table II) to ascertain whether migration of contaminants requiring further excavation has occurred.

The approach detailed above led to the discovery of four major disposal trenches and a number of pockets of disposal pits. The discovery of one trench and how it was subsequently addressed is particularly noteworthy. The exploratory trench intersected the disposal trench and efforts began to continue exploratory trenches in the direction of the disposal trench (north-south). Visual observation of the contents (e.g., remnants of drums, bags and acid tank liners), however, led the investigators to believe they had located the major chemical trench referenced in internal

Company records and interviews during the audit. This led to a decision to mine out the entire trench with the backhoe rather than proceed with exploratory trenches.

The approach taken was to first remove the approximately 0.6 to 0.9 m of overburden to one side of the trench and then excavate from that point down to the water table. Any metal drum remnants, pesticide produce containers or other probable hazardous waste containers, were removed by hand to hazardous waste bins or overpack drums and hauled away to California-approved Class I hazardous waste disposal sites. Soil and other trench contents were excavated by backhoe and placed on sheets of black plastic for subsequent sampling and decisions regarding disposal. The location of where the material came from in the original trench was catalogued for future reference.

While proceeding in this manner, thousands of ½ and 1 pint glass pesticide bottles, some broken and empty of contents, some partly full, or full were discovered. The labels of these bottles indicated such products as 40% DDT, 50% Chlordane, 2,4-D, 2,4,5-T and Dieldrin. Ominously apparent was the fact that many containers were still below the water table.

Because of the inherently hazardous nature of the disposed material, a decision was made to excavate below the water table and remove the material with sealed trucks to Class I disposal sites. Considering the characteristics of the disposal area and discussions concerning past recollections of the trench operation, it was decided that excavation 0.9 m below the water table should remove any containers etc. originally deposited. The approach for accomplishing this included use of a "mud wave." This

Figure 4.
Study Area Showing Soil Coring Locations During Excavation Program.
(Scale: 1" = 135')

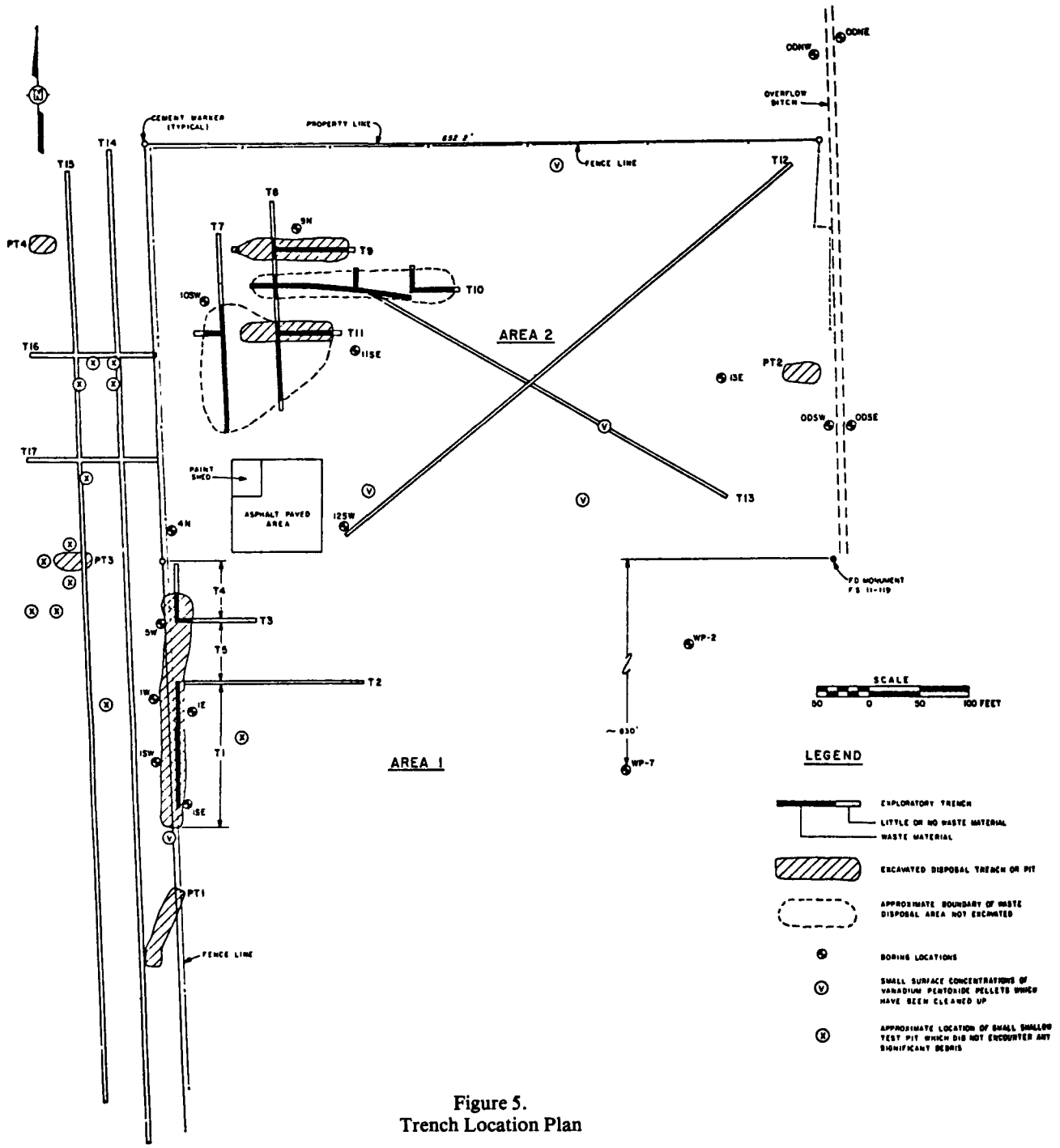

Figure 5.
Trench Location Plan

included starting from one end of the trench with a bulldozer, cutting down 0.9 m and moving the excavated material a short distance forward in a wave. Clean fill was immediately brought in to replace the excavated material and the process was repeated. Water, pushed forward by the wave, was pumped to a truck from a crude sump carved out of the downstream end of the trench and taken to the Company's onsite hazardous waste disposal tanks. This procedure was continued until the trench was entirely excavated and filled with clean fill. Soil exposed at the bottom of the cut by the bulldozer blade while advancing the wave had a clean appearance, supporting the belief that the procedure selected would escavate all previously deposited containers and solid materials. Evaluation of potential migration of contaminants through the soil was accomplished by the previously described core sampling program and the groundwater monitoring wells.

Worker safety during excavation was of primary importance to the investigators. Extensive physical examinations were performed on the workers before and after the project. While working at or near the trenches, workers

were required to wear hard hats, safety glasses, fresh respirators with multiple purpose cartridges (including organic vapors), rubber boots with steel toes, rubber gloves and cloth coveralls which were changed at least daily. Cloth coveralls were selected over a more impermeable suit since actual physical contact, other than with the rubber gloves, with excavated materials was minimal. Since summertime temperatures in the Lathrop area often exceed 38 °C, the cloth coveralls also posed less risk to the worker from the standpoint of heat exhaustion. For those workers who were collecting samples or otherwise having greatest contact with materials, impermeable aprons were provided.

Private/Public Well Monitoring Program

As part of the effort to ascertain the extent of groundwater contamination as well as to assure protection of the public health, both private and public wells in the plant vicinity were sampled (Figure 6). Parameter coverage included the Table I list, excluding pH, Redox potential, conductivity and temperature.

Wells sampled included all known drinking water wells within approximately 1.6 km of the facility. In addition, the Company offered a one-time sampling to any of its employees who were using private wells, however remote from the facility. Procedures employed included first conducting a well inventory survey followed by gaining consent to sample. Sampling of approximately 28 wells was conducted twice monthly for the first 3 months and then monthly for 2 months. By that time at least four complete sets of data were available for each well sampled. This number of complete samplings was judges necessary by the State of California to support decisions regarding possible closures of wells. Sampling methods included collecting the samples in prescribed containers as close to the well head as possible. Water lines were flushed for a period of time judged sufficient to gather a representative sample.

Groundwater Modeling

Although the previously described monitoring of groundwater wells and examination of soil samples was essential to document the extent of contamination, it was also recognized that a groundwater modeling effort was necessary, particularly in designing and assessing long term remedies. The purposes of the Phase I modeling efforts were to:

- Develop a preliminary two-dimensional model of the study area
- Gain an understanding of the relative importance of the factors that influence groundwater movement in the area
- Make a preliminary assessment of any existing and future pollutant transport paths
- Define future groundwater modeling efforts for subsequent phases

Inputs to the first phase modeling effort included using data gathered during the groundwater, soil and private well monitoring activities as well as independent data-gathering efforts. From the ongoing activities data was gathered relating to stratigraphy, piezometric head measurements from the permanent wells, and soil characteristics (i.e. porosity, permeability, grain size, analyses). In addition, data were gathered or estimated for existing land use, well pumpage and construction characteristics in the area, return flows from major users in the area, precipitation recharge, boundary conditions and anticipated soil-chemical-water relationships. Pump tests were also performed using a combination of existing production wells, permanent groundwater monitoring wells and additional piezometers as needed.

Once the data were synthesized into the preliminary model, several sensitivity studies were conducted to determine the importance of:

- Vertical depths of the flow field
- Boundary conditions
- Recharge sources
- Pumping patterns (extent and seasonal patterns)
- Aquifer characteristics

Since an integral objective of the plan of study was to determine necessary remedial measures, several model simulations were conducted to forecast future pollutant transport pathways resulting from various remedial alternatives.

RESULTS

Implementation of the Plan of Study substantiated initial concerns regarding the seriousness of the problem. Considerable pesticide-contaminated soils were found in a former disposal area, the pesticide pond bottom and the ditch which conveyed pesticides to the pond. Based on soil core sampling data, decisions were made regarding the degree of need for offsite disposal at California Class I or II-1 sites. In all, approximately 1100 m^3 of material were excavated and hauled to Class I sites and 2400 m^3 to II-1 sites. Excavated areas were backfilled with clean soil to within 1 m of grade. A 0.3 m layer of clay (10^6 cm/sec permeability) was deposited above this, and then 0.6 m of clean soil was deposited. The final grade was sloped to accelerate runoff from the areas.

Groundwater sampling demonstrated the presence of numerous pesticides in wells adjacent to past disposal sites. DBCP was detected in numerous onsite wells, reaching concentrations as high as 1.2 mg/ℓ in one well 61 m deep. Sampling of domestic wells confirmed the presence of DBPC in wells to the north by the Oxy facilities. Concentrations were considerably less than those found in the test wells, (approximately 4 mg/ℓ). Occidental, upon review of these data, agreed to provide a new permanent source of water to the affected and potentially affected residents.

The data collected from the test and domestic wells were also used to select an ongoing monitoring program for February, June and October of subsequent years, as well as locations for additional wells to further refine definition of the areal and vertical extent of the groundwater contamination. Two of the wells completed to over 91 m yielded no detectable DBCP. Another well nest constructed west of the Libby Owens Ford (LOF) plant also showed no detectable concentrations of DBCP. Ground-

water modeling efforts confirmed the migration of groundwater to the west, consistent with assumed regional travel, but also indicated a strong vector toward the northeast, a result of heavy groundwater pumpage.

These physical studies and modeling results were used by Occidental to design a proposed groundwater purge system to cease further migration of contaminants offsite. Purged groundwater from five extraction wells will be treated onsite in an activated carbon treatment system. Pilot plant studies have indicated removals of pesticides to below detection limits. The Company has proposed injecting treated wastewaters into a deep aquifer (more than 100 m) which already contains high dissolved solids. The governmental agencies are currently reviewing this proposal and once a remedial system is finally approved, it must be installed within 180 days.

The extensive work referenced in this report was accomplished over an approximately two year period. In excess of 50,000 analyses of groundwater and soil were conducted. It would be misleading to say that the work is finished or that it progressed without any differences of opinion as to necessary studies and interpretation of results. However, considering the state of the art nature of the work and the extreme difficulty in working in the shadow of an ongoing court case, the cooperation was remarkable. The author believes this project served as an excellent example of how industry and government can put their collective expertise to good use in solving complex technical problems.

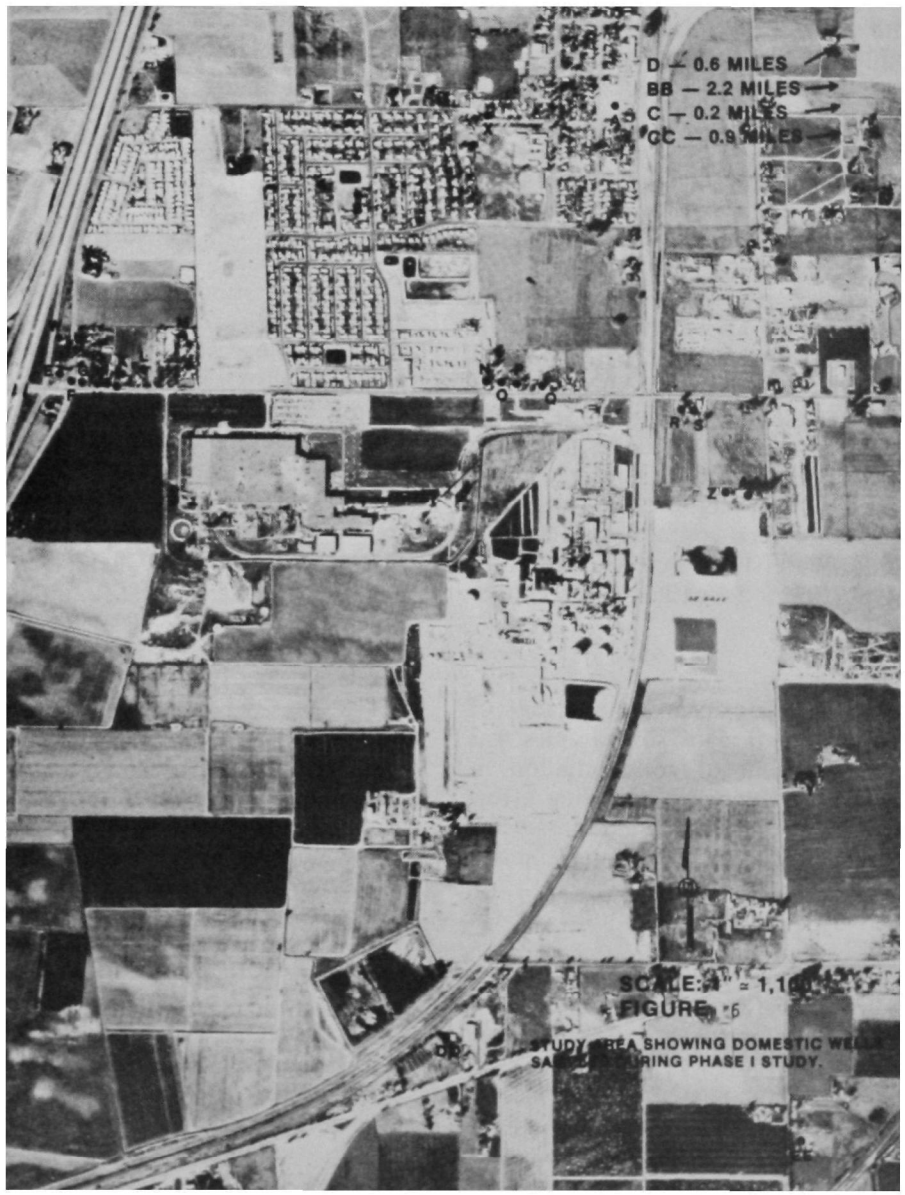

Figure 6.
Study Area Showing Domestic Wells Sampled
During Phase I Study.
(Scale: 1'' = 1,100')

IMPLICATIONS OF THE CHEMICAL CONTROL CORP. INCIDENT

ADAM M. FINKEL
RICHARD S. GOLOB
Hazardous Materials Intelligence Report
World Information Systems
Cambridge, Massachusetts

INTRODUCTION

On April 21, 1980, a massive hazardous waste explosion and fire took place at the Chemical Control Corp. aboveground storage site in Elizabeth, New Jersey, consuming at least 20,000 of the more than 45,000 drums of hazardous waste present at the site. An unusual combination of wind and temperature conditions and the results of a 12-month pre-fire cleanup, prevented the occurrence of an unprecedented public health disaster.

As of September 1981, the post-fire cleanup had cost more than $27 million, and the final site mitigation had not yet been completed. At least four major civil and criminal suits have been filed as a result of this incident, and private damage claims total over $500 million.

The Chemical Control incident provides an important case study of the problems surrounding hazardous waste management and uncontrolled waste sites. No acute incident in the U.S. involving hazardous wastes has incurred a greater response cost and no single acute incident in the U.S. has involved a larger quantity of hazardous waste or a more varied collection of waste.

In this paper the authors will focus on the events surrounding this incident, and their implications for future waste-site responses and for federal and state policies regulating these responses. The paper divides the incident into five distinct phases:

(1) the operations of Chemical Control before the New Jersey Department of Environmental Protection (DEP) took any organized action at the site
(2) The cleanup that occurred during the 12 months before the fire
(3) The fire itself
(4) The intensive response actions during the year after the fire
(5) The work remaining at the site and the ongoing costs and litigation associated with it.

PRE-RECEIVERSHIP

This phase began in the mid-1970s, when Chemical Control began accepting hazardous waste from area generators; it ended in January 1979, when DEP obtained a court restraining order and, for the first time in history, took control of a private company. According to the Oversight and Investigations Subcommittee of the House of Representatives Interstate and Foreign Commerce Committee, DEP solid waste officials knew about the potential problems at the Chemical Control storage facility at least by the spring of 1978, at which time the site contained about 25,000 drums.

DEP and the New Jersey Division of Criminal Justice (DCJ) both agree that their respective agencies did not communicate adequately during the pre-receivership phase because of understaffing. In addition, a DCJ memorandum in 1978 claims that DEP investigators were not adequately trained and, although aware of the problems at Chemical Control, did not have the expertise to assess their severity. Consequently, according to the memorandum, the investigators treated the site as a landfill and applied landfill guidelines to its regulation. Other state officials have said that, if DEP regulators had made adequate checks of the state-required manifest forms, they would have recognized that Chemical Control, licensed as an incinerator facility only, was accepting large quantities of physically non-incinerable wastes.

Since this occurred, New Jersey has developed the 11-state Interagency Hazardous Waste Strike Force, a model program for other enforcement and regulatory personnel around the country. In addition, New Jersey's status as the leading hazardous waste generating state has made its regulatory agencies the leaders among the 50 states in dealing with these problems.

The unregulated existence of Chemical Control during its early history does not appear to be solely a function of the times, though. Testimony given at an Oversight and Investigations Subcommittee hearing on December 16, 1980 claimed that, even now with the implementation of a national manifest system under the Resource Conservation and Recovery Act (RCRA), operators can still maintain sites that pose similar threats as the Chemical Control facility. The principal witness at the hearing was Harold Kauffman, a former official of Duane Marine Corp. in Perth Amboy, New Jersey, who had turned state's witness after being charged with complicity in illegal hazardous waste management.

During his testimony, Kauffman recommended that the U.S. EPA and state regulatory agencies change the focus of their oversight of the hazardous waste industry. According to Kauffman, the state and federal governments emphasize the routine filings of applications, and at present, nearly anyone can pay a fee and become a licensed

hazardous waste hauler or begin the siting process for a landfill. John Albert, who allegedly assumed ownership of Chemical Control in 1977 at gunpoint, claims that he received a DEP hazardous waste hauler's license without asking for one. Albert's other company, Jersey Sanitation, recently received a renewal of its license, even though its principals had been convicted of felonies. Kauffman said that, because no agency currently monitors the background and safety history of applicants for hauling and disposing operations, incidents such as Chemical Control will continue to take place.

Kauffman testified that he did not believe that a company with holdings in the garbage and sanitation industries should be allowed to enter the hazardous waste industry, for several reasons:

(1) operators of garbage trucks can easily mix quantities of toxic wastes with the municipal garbage and
(2) garbage haulers usually have established relationships with municipal dumps, which are less stringently regulated than RCRA hazardous waste landfills.

Consequently, these haulers can pass on significant quantities of hazardous wastes to the municipal dumps. A subcommittee spokesman noted that Kauffman's comments were based on the activities of a limited number of small companies operating in metropolitan New York, and do not necessarily apply to the major firms that deal with both solid and hazardous waste.

Leonard Tinnan, corporate development director for the nation's largest waste management firm, Chemical Waste Management Inc. of Long Beach, California, commented that the large national companies with both solid and hazardous waste operations had largely succeeded in maintaining separate corporate structures for their different functions. Tinnan said that companies such as Chemical Waste Management and Browning-Ferris Industries have gradually separated the organization of solid and hazardous waste operations due to the different backgrounds needed to manage each operation, as well as due to the public fears about the practices that occur among smaller companies.

In addition, at the subcommittee hearing, Congressman Albert Gore (Democrat-Tennessee) said that, when a hauler has a tacit agreement with a disposal facility, the hauler and facility owner could potentially collude to falsify the national RCRA manifests so that, instead of transporting the wastes out of state to another authorized facility, the hauler could mix the waste with household garbage and dispose of it at a municipal landfill. Allegedly, through such practices, hazardous wastes which were supposed to have been incinerated at the Chemical Control facility ended up at the Kin-Buc municipal landfill in Edison, N.J., currently one of the nation's largest uncontrolled hazardous waste sites at 220 acres.

Although one U.S. regulatory agency—the Interstate Commerce Commission (ICC)—is currently attempting to assert its authority to make background checks on hazardous waste haulers, the ICC is receiving considerable opposition from the regulated community. Trade associations, including the Spill Control Association of America and the Hazardous Waste Services Association, agree that a federal agency should take steps to curtail midnight dumping, but believe that ICC regulation of hazardous waste haulers would duplicate existing EPA and U.S. Department of Transportation regulations and would too closely control the entry of legitimate firms into the hazardous waste industry on a geographical or a market-share basis.

PRE-FIRE CLEANUP

This phase extended from April 1979, when DEP hired Coastal Services Inc. to perform preliminary cleanup work, until April 1980, when the Chemical Control storage facility caught fire. When Coastal Services began work, the facility contained a maximum of 60,000 drums and laboratory packs of chemicals, including polychlorinated biphenyls (PCBs), pesticides, cyanides, compressed gases, organic peroxides, high explosives including TNT, picric acid and nitroglycerin, bottled hospital and laboratory specimens and radioactive wastes.

During the one-year pre-fire period, Coastal Services spent approximately $1.5 million and supervised the removal of about 10,000 drums and laboratory packs containing some of the most dangerous wastes. These wastes were disposed of at the CECOS International, Inc., chemical landfill near Niagara Falls, New York. The majority of the high explosives and compressed gases were detonated under controlled conditions at a nearby ordnance works.

Although the preliminary cleanup probably helped to avert a major public health disaster, the fire did take place and caused major damage. As a result, the question remains as to whether the pre-fire cleanup was conducted in an expedient manner and with the proper removal priorities.

Before discussing the contributions of Coastal Services to the pre-fire effort, it must be noted that several observers have said that, at the same time as Coastal was removing wastes, DEP was allowing more wastes to accumulate at the site. A Congressional staff member said that a computer analysis of aerial photographs indicated an influx of several thousand drums after September 1977. According to a former Coastal employee, DEP realized at the early stages of the pre-fire cleanup that, as a result of the increasing national attention given to the site, Chemical Control was virtually guaranteed federal and state cleanup funds. According to this argument, DEP decided to consolidate the wastes present at several smaller waste sites in northern New Jersey and store them at one central location—Chemical Control—where they would be cleaned up along with other wastes at the site.

In contrast, Tom Dalton, former vice-president of Coastal Services, said that the drums which were transported to the Chemical Control site during the pre-fire cleanup represented the contents of 14 trailers abandoned by the former Chemical Control operators at various places throughout the city of Elizabeth. Dalton said that the contents of these trailers contained a maximum of 1000 drums, and that reports of massive drum accumulation resulted from a misreading of the aerial

photographs, which actually showed not an increase in the total number of drums but rather an increase in the surface area covered by the drums due to the transfer of drums stacked six and seven high to piles of drums stacked two and three high. Nevertheless, the Chemical Control operators used the allegations of drum accumulation from outside sources in their trial defense in an attempt to lessen their proportionate liability for the waste consumed in the fire.

The success of the pre-fire cleanup depended largely on the success of the DEP effort to identify the original generators of the Chemical Control waste and encourage them to reclaim their drums. In practice, th is effort took the form of threatening those generators who could be identified from the drum labels with legal action in the massive liability surrounding the Chemical Control site if they did not come forward and reclaim their wastes. During the pre-fire phase, DEP identified several major generators who voluntarily removed almost 7900 drums from the site.

Gregory Heath, technical representative for Peabody Clean Industry, formerly Coastal Services, said that, during the pre-fire cleanup, DEP had refused Coastal's suggestion that it transport the overpacks and drums designated for generator reclamation to an off-site warehouse for temporary storage. Heath also said that, as a result, some of the drums which had been bulked and overpacked for reclamation were consumed in the fire.

While DEP was operating under severe financial constraints, as evidenced by the depletion of the $20 million New Jersey Spill Compensation Fund and the subsequent decision to temporarily raise the chemical and petroleum feedstock taxes that supply this fund, several observers commented that speed rather than economy should have been the primary objective during the pre-fire phase.

Superfund

The same observers expressed concern that the current EPA administration is encouraging slow, deliberate and economical action at waste sites. The Superfund Interim Removal Guidance, which was sent in early August to the federal on-scene coordinators (OSCs), mandates that the OSCs not initiate any long-term remedial action at a site, unless it is among the 400 waste sites on the national priority list and unless a significant effort has failed to locate a responsible party capable of providing the necessary cleanup funds.

Under the guidance document, OSCs have authority to begin so-called "immediate removal actions," or "planned removal actions," in order to stabilize the site and prepare it for long-term remedial work. OSCs must, however, receive approval from EPA headquarters before authorizing a removal action, and EPA has indicated that it intends to "establish a high threshold for undertaking such actions."

In addition, the interim Superfund guidance, which will remain in effect until the final National Contingency Plan is promulgated sometime in late 1982, contains six case histories designed to provide the OSCs with models of typical response actions. At least two of these cases criticize earlier EPA actions at specific waste sites as overly ambitious and expensive. According to the interim guidance, the case history of the Kin-Buc landfill demonstrates EPA's new policy that removal actions should not be initiated at waste sites with continuous chronic releases of hazardous wastes, unless those releases directly threaten human populations.

In practice, EPA policy now prohibits the EPA-funded use of groundwater or leachate treatment systems unless alternative approaches, including the "no-response option," have been considered; in effect, the interim guidance discourages the massive contaminant removal and groundwater treatment actions that EPA and DEP used at the Chemical Control site. Furthermore, in the case history of the PCB storage site at Sharpstown, Maryland, the new EPA interim guidance suggests that drums should be removed to an off-site location only when the drums are actually leaking, and that deteriorating storage containers should only be staged or overpacked. A senior official at O.H. Materials Co. of Findlay, Ohio, the major post-fire contractor, said that this "reduction in the formerly aggressive posture of EPA" may result in greatly increased costs when cleanup is finally initiated and possibly in an increased incidence of catastrophic events at waste sites where the federal government has adopted the "wait and see" approach.

Many observers believe that the "wait and see" policy is inappropriate when evaluating the need for security at an uncontrolled site. The Elizabeth Fire Department, the New Jersey DCJ and the Federal Bureau of Investigation have not yet completed their official arson investigation into the Chemical Control incident, but since the fire occurred during the cool springtime, it seems unlikely that its origins were totally spontaneous. Following the Chemical Control incident, at least one other significant hazardous waste site fire has occurred; on July 10, 1981, the fire at the General Disposal Co. waste site in Santa Fe Springs, California, consumed over 10,000 drums of waste and resulted in cleanup expenditures of up to $2.7 million. The probable cause of that fire was arson; a local resident allegedly tossed a Molotov cocktail onto the site with the intention of starting a small fire to dramatize the need for security and eventual cleanup at the site.

Fire

The actual emergency and subsequent response were characterized by a combination of luck and effective action. Two physical factors decreased the severity of the fire itself. First, the large number of drums and their high packing density created an intensely hot fire, over 2000 °F at its center. As a result, the fire itself acted as a natural incinerator to degrade the hazardous wastes. DEP analyses during the fire showed high concentration of benzene, up to 10,000 ppm in the smoke plume, substantiating the theory that many of the substituted aromatic compounds were degraded into simpler molecules during the fire. Second, repeated wind shifts and a high ceiling kept the smoke plume from settling over a densely populated area near the site.

The firefighters, under the supervision of Elizabeth Fire Director Joseph Sullivan, were particularly effective at combatting the acute chemical emergency. More than a year before the fire, Sullivan had instituted a special site-specific training program in anticipation of problems at the Chemical Control site. Firefighters learned about the location of access routes, the topographic conditions at the site, and the availability of water supplies and utility outlets.

Sullivan said that the training program was instrumental in increasing the speed of the initial response to the blaze. He said that more than 250 firefighters worked on the response, which began at 2254 LT on April 21, and that they successfully contained the fire by 0914 LT the following morning. The land-based firefighting crews uses more than 7.2 million gallons of water to control the fire and two fire boats stationed in the nearby Elizabeth River used several million gallons more.

Heath of Peabody Clean Industry said, however, that DEP should have ordered the firefighters to let the fire burn and to apply water only to control the spread of the fire to adjoining properties. He said that this approach would have created less contaminated water and degraded more material, resulting in a cheaper and less dangerous post-fire cleanup. Alden McLellan, DEP assistant commissioner, agreed that the "free burn" was a viable option, but cautioned that temperatures at the outer edges of the fire might not have been high enough to degrade the most persistent toxic compounds.

Acting Elizabeth Fire Chief Charles Swody said in September 1981 that his department had learned several lessons as a result of the fire. Swody emphasized the need for fire companies to maintain an adequate supply of extra breathing masks because, during the Chemical Control fire, many off-duty personnel and firefighters from neighboring communities provided services and needed protective clothing. Swody also said that, to reduce the amount of worker exposure, his department might have placed greater reliance on remotely-operated equipment and relieved its workers on a more frequent basis. He claimed, however, that no fire department in the country has the budget to afford state-of-the-art protective clothing for each responder at a site incident such as Chemical Control. One firefighter is suing the Elizabeth fire department for pulmonary disabilities allegedly contracted during the response.

POST-FIRE CLEANUP

Introduction

This phase began on April 24, 1980, when DEP contracted with O.H. Materials Co. to secure the site against the immediate threat of contaminated surface water entering the Elizabeth River. Also involved was the removal of hazardous waste drums and contaminated soil from the site, as well as the treatment of contaminated groundwater.

The post-fire cleanup phase lasted until April 1981, when the New Jersey Spill Compensation Fund and the Federal Water Pollution Control Act Section 311 (k) funds were withdrawn and O.H. Materials removed its groundwater treatment system. During this one-year period, more than 350 million pounds of contaminated debris and soil were removed to the CECOS landfill in Niagara Falls for disposal, more than 252,000 gallons of incinerable liquid wastes were taken to the Rollins Environmental Services incinerator in Logan Township, New Jersey, for destruction, and about 36,450 crushed empty drums and 3770 intact drums were removed to secure landfill disposal.

Three basic questions regarding this phase of the response deserve attention: 1) Was the approximately $25 million spent during the year justifiable in terms of the results obtained? 2) Was the level of personnel safety during the post-fire response efficient for an action involving such a large amount and complex mixture of waste? and 3) What new techniques and instrumentation used at Chemical Control could prove valuable at future responses?

Cost

During the post-fire cleanup, O.H. Materials used a team of 71 workers to remove 25,000 barrels, at a total cost of more than $17 million. In contrast, in a similar one-year period, Coastal Services used a team of 14 to remove 10,000 of the most dangerous drums from the site, at a total cost of $1.5 million.

A DEP official commented that, in the days following the fire, DEP did not have time to negotiate the costs of the response because of intense public pressure to initiate an immediate and complete cleanup action. DEP selected O.H. Materials as the cleanup contractor not only because it had the requisite capabilities but also because it offered the most immediate initial response. The DEP official also commented that, in developing its response program, O.H. did not give adequate attention to cost considerations, encouraged by the relatively limitless federal funding for this project.

The DEP official further said that, in the future, state agencies should consider establishing standing contract relationships with cleanup firms and that such contracts should have clearly delineated cost parameters. He cautioned, however, that such relationships tend to form exclusive ties with one company and generate charges of favoritism when incidents with a high potential for profit and recognition occur.

In response, Robert Graziano, vice president of O.H. Materials, said that O.H. Materials took a meticulous, technology-intensive approach in securing and cleaning up the Chemical Control site. He said that O.H. completed more than 90% of the tasks outlined in the original post-fire contract, even though problems with on-site PCBs and deeply buried wastes were encountered during the work. In addition, Graziano said that, prior to the fire, Coastal Services did not have to deal with the problems that O.H. Materials faced with debris, damaged drums and unlabeled piles of drums.

As an example of the legitimate cost differences in various incident responses, Graziano contrasted the Chemical Control incident and response with that at the Seymour,

Indiana waste site. Although Seymour response crews were faced with a similar number of drums as that at the Chemical Control site, they were able to finance the response to date at approximately 20% of the cost, primarily, according to Graziano, because: 1) the drums were segregated before the state of the cleanup, 2) there was no fire to cause a deterioration in site and drum conditions and 3) the remote nature of the Seymour site did not require as extensive community safety precautions.

Worker Safety

The National Institute of Occupational Safety and Health (NIOSH) has not yet completed its investigation into the various cases of worker exposure to hazardous substances during the post-fire cleanup at Chemical Control. James Melius, chief of the NIOSH Hazard Evaluation Section, reported that, in July 1981, NIOSH completed a follow-up medical survey among the approximately 390 firefighters and other response workers at the initial incident. Of the 224 workers who had reported no adverse pulmonary symptoms, such as wheezing, excessive phlegm, and shortness of breath, immediately after the fire, 110 reported the onset of one or more of these symptoms in the following year. Melius said this incidence of delayed effects was serious enough that NIOSH decided to conduct a detailed medical study of the 390 workers to determine the extent of incident-related pulmonary problems.

During the summer months, NIOSH had difficulty determining whether certain transient worker illnesses were due to cyanide poisoning, as suggested by the odors at the site, or due to heat stress. Three cases of worker incapacitation occurred during the early morning hours, however, when heat-stress would not be expected to be a problem. Although NIOSH photoionization tests were negative, NIOSH noted that the vapors could have been acute for transient periods only and may not have been present during the test period.

NIOSH did make several recommendations about work periods at the Chemical Control response and at future actions, including: 1) each thirty-minute work period in full breathing apparatus should be followed by a thirty-minute rest period, 2) workers should be acclimatized to possible heat-stress problems upon entering the site and 3) the dispensing of diuretic drinks, including coffee, colas and alcohol, should be discouraged because of the potential for dehydration.

Melius also reported that, as a result of the cases of heat stress among the workers, NIOSH developed a system for continuously monitoring both the environmental conditions and the worker's heat stress in the field. During August 1981, NIOSH tested the system at a non-chemical site cleanup in Arizona, monitoring the axillary temperature and heart rate of each worker.

A Coastal official said that Coastal Services walked off the Chemical Control site because of the insistence of a DEP official that Coastal workers wear full self-contained breathing apparatus at the early stages of cleanup. This observer disagreed because, at that point in the cleanup, there was a 15-knot wind and a light rain falling, conditions he said created little danger of acute concentrations of fumes. He said that the SCBA gear severely impaired the ability of Coastal workers to navigate through the rubble and wet drums during the early stages, and that such limited mobility actually made conditions less safe than if the workers had been wearing respirators alone.

New Technology

Several new protocols and technologies, with potential usefulness at other responses, have emerged from the Chemical Control incident. These new techniques, which were developed by O.H. Materials, include the following:

(1) A special barrel grappler that remotely handles drums and moves them to a staging area, thereby replacing the standard method of overpacking each drum individually. The grappler consists of a Caterpillar backhoe with a specially-designed arm that can rotate through 360°. IT Corp. used this device at the Santa Fe Springs post-fire cleanup.

(2) A proprietary compatibility sampling protocol, which uses a mobile field laboratory to test both for the toxicity and chemical compatibility of the liquids contained in the drums. This sampling protocol allowed O.H. to identify those drums which could be bulked to reduce the transportation volume of the wastes.

(3) A specially-designed compatibility chamber for liquid wastes, consisting of a 12,000 gal open-top vessel fitted with a series of thermocouples. After adding new materials to the chamber, O.H. personnel could precisely monitor the heat of reaction from a safe distance to determine if the addition of the materials should be slowed due to incompatibility.

(4) A health and safety protocol for moving personnel on and off the site, consisting of several clearly delineated "hot," "warm," and "cold" zones.

(5) A proprietary scheme for identifying and repackaging the contents of the "lab packs." O.H. constructed a portable building on-site for this purpose and retained a professional chemist to perform the testing and repackaging of the laboratory chemicals.

(6) The first field use of the O.H. Underground Recovery and Treatment System (URTS) at a hazardous waste site. The URTS uses a pneumatic recovery system to create a zone of depression, thereby accelerating the movement of contaminated leachate toward the recovery wells. O.H. was able to use a variety of techniques in conjunction with the URTS, including: 1) the high-temperature steam-stripping of solvents in the contaminated leachate, 2) a clarifier unit to precipitate out certain insoluble constituents from the groundwater and 3) an activated carbon treatment unit for final "polishing" of the leachate in preparation for discharing it back onto the site.

In addition, the consultants at Roy F. Weston, Inc. in West Chester, Pennsylvania, took advantage of the Chem-

ical Control incident to make the first successful use of ground penetrating radar (GPR) technology to locate hazardous waste targets in saltwater. The U.S. Coast Guard had expressed concern that the force of the initial Chemical Control explosion had thrown chemical drums into the Elizabeth River and that the water spray during the subsequent firefighting operation had caused sections of the river bank containing the drums to slump into the river. Although previous GPR surveys in saltwater had failed because the uneven salinity of the water attenuated the return signal to an indeterminate degree, the Elizabeth River had a relatively constant salinity and the Weston researchers were able to use a combination of GPR and fathometry readings to determine the exact degree of attenuation at each point and calibrate the results accordingly.

Ongoing Action

After a cleanup program lasting two years and the expenditure of more than $27 million, the Chemical Control site still remains a candidate for Superfund remedial action. According to the former DEP on-scene coordinator, the site has received 56 "points" on the Mitre ranking model, placing it about 20th among the nation's problem sites. DEP has ranked Chemical Control 13th among the 300 New Jersey sites that it wants EPA to consider for Superfund remedial actions. In early September 1981, the EPA Office of Emergency and Remedial Response received a detailed request from DEP outlining the remaining work necessary to clean up the Chemical Control site, which DEP said still presented an uncontrolled leachate threat.

The DEP estimates that an additional $700,000 will be needed to perform the following remedial actions:

(1) Removal and disposal of 1500 cubic yards of contaminated debris, including contaminated soil, plywood and concrete
(2) Removal of sludge from the groundwater clarifier, contaminated spent carbon from the URTS and 75 crushed drums
(3) Removal and detonation of 200 pressurized gas cylinders of "uncertain" integrity
(4) Dismantling of a 10,000-gallon underground steel tank found during the cleanup
(5) Removal and disposal of 60 drums containing PCB wastes concentrated from settling tanks installed during the cleanup. Some of these drums contain up to 977,000 ppm PCBs, although the majority of them contain less than 1000 ppm
(6) Removal and disposal of small quantities of miscellaneous material, including one drum of contaminated clothing, two drums of arsenic pentoxide, one can of potassium cyanide and a 2000-gallon tank truck left on-site by the former Chemical Control operators.
(7) Additionally, the final URTS treatment of the contaminated groundwater had not been completed when the funds were withdrawn.

At least four civil and criminal cases were filed as a result of the Chemical Control incident. In one recent action, a federal grand jury in Newark, New Jersey, sentenced John Albert and Eugene Conlon, the two men who allegedly took over operation of Chemical Control in 1977, to five and three year jail terms respectively for committing two counts each of mail fraud in connection with the Chemical Control operation. These sentences represent the first successful federal felony prosecutions against operators of hazardous waste storage facilities. Since the illegal storage took place before the November 19, 1980 effective date of RCRA, the U.S. attorneys decided to invoke the federal fraud laws.

The prosecutors based their indictment on evidence gathered from the investigation of the acceptance by Chemical Control of a single cylinder of highly unstable perchloroisobutylene from a nearby generator, since the unusual nature of this small shipment made the tracing of bank checks and acceptance letters easy and verifiable. Albert and Conlon were charged with defrauding DEP by promising to treat various wastes at the Chemical Control incinerator, when in fact the wastes were transported to another unlicensed dump site. They were also charged with defrauding various generators by promising to properly dispose of their wastes. The following three suits are still pending:

(1) A criminal trial to bring nuisance charges against Albert and Conlon for maintaining a hazardous situation at Chemical Control. Since New Jersey recently amended its criminal code in 1980 to include hazardous waste violations as felonies, the two Chemical Control operators will only be charged with misdemeanors.
(2) A civil suit filed by DEP to recover nearly $24 million in cleanup costs from the Chemical Control operators. This suit also seeks penalties under the New Jersey Solid Waste Act amounting to more than $25,000 per day; DCJ was pessimistic about the ability of the insolvent Chemical Control operators to provide even a small fraction of the sum needed for significant reimbursement. The federal government may also sue to recover its Section 311 (k) fund expenditures.
(3) A suit against DEP filed by the Loizeaux Builders Supply Co., owners of the property adjacent to the Chemical Control facility. Loizeaux alleges that DEP forced him out of business by taking over his property for use as a drum staging area shortly after the fire.

Perhaps most importantly, the Chemical Control incident contributed to public awareness of the need for environmentally sound disposal facilities. It also had a major effect on the passage of New Jersey's new "Major Hazardous Waste Facilities Siting Act," signed on September 10, 1981 by Governor Brendan Byrne. The Act contains the following provisions encouraged by the Chemical Control incident:

(1) Siting approval shall not be granted to an applicant if any party to the application has been convicted of a crime relating to improper hazardous waste management during the previous ten years

(2) All new major facilities shall be totally or partially constructed above ground and be designed to allow the extraction of 99.9% of all stored or disposed waste
(3) Local inspectors who supply information on improper facility management shall be given one-half of any penalty collected in the ensuing litigation
(4) A facility must undergo a formal siting review process if a capacity expansion of more than 50% is planned.

Conclusion

Despite the controversies surrounding the regulation of Chemical Control, the response to the chronic site problem and the costs and approaches involved in the post-fire response, the final cleanup of the uncontrolled site will represent the successful conclusion of a hazardous waste project whose difficulty may remain unsurpassed in future years. The cooperation between the cleanup contractors and the federal and state regulators proves that, given sufficient time, money and good fortune, the mistakes of the unregulated past can be efficiently and safely corrected.

In the future, researchers, engineers and government officials need to work closely to develop protocols, as well as checks and balances, that can ensure positive results at site actions where these factors are not so favorable. As the Superfund cleanup program begins, the private sector and government participants in uncontrolled site actions should have ample opportunity to perfect the knowledge gained from the Chemical Control incident.

REFERENCES

The authors have relied extensively on information that appeared in the *Hazardous Materials Intelligence Report*, an international weekly newsletter focusing on the safe management of hazardous wastes and hazardous materials and published by World Information Systems, Harvard Square Station, P.O. Box 535, Cambridge, Massachusetts 02238. The *Hazardous Materials Intelligence Report* began reporting on the Chemical Control incident in its Vol. I, No. 5 issue on 13 June 1980 and, since then, has provided regular coverage of the cleanup operation, legal proceedings and other issues related to the event.

A FAST TRACK APPROACH TO MANAGEMENT AND IMPACT ASSESSMENT (PART I)

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INTRODUCTION

The approach discussed here was developed during a Federally funded emergency cleanup action under authority of Section 311 of the Clean Water Act. The subject of the effort and cause for action, the Seymour Recycling facility, is quintessential of the many abandoned, hazardous waste sites found throughout the country. It is a large site covering an area of 13 acres with a diverse collection of hazardous compounds stored in a variety of containers.

BACKGROUND

Located in the Indiana community of Seymour, approximately ninety miles south of Indianapolis, the Seymour Recycling Center was established in 1971 solely to recover methylene chloride used for industrial operations at the Seymour Manufacturing Company. The recycling center soon expanded its operation to include the reclamation of other industrial chemicals.

In 1975, the Seymour Recycling Center incorporated separately from the Seymour Manufacturing Company. In 1978, when the Recycling Center was sold, owner estimates of on-site waste storage included approximately 42,000 55-gallon drums, 100 bulk storage vessels containing approximately 676,000 gallons of waste and seven 20,000 gallon rail cars.

Shortly after the change in owners, serious environmental problems began to develop. The incinerator was operating poorly and without an emission control system. Micrometeorological conditions often resulted in fumigation events affecting nearby residents. These occurrences prompted the affected people to complain to local and State pollution control officials, demanding that they intervene in the operation and force a cleanup to attain compliance with the appropriate regulations.

Representatives of the recycling facility signed a consent decree in June, 1978, with the State of Indiana requiring them to shut down and dismantle the incinerator and to reduce their drum inventory on a scheduled basis. Fourteen months after the consent decree was signed, however, the recycling center's drum inventory actually increased by approximately 3,400. This was confirmed through aerial photographs evaluated by U.S. EPA's Environmental Photographic Interpretation Center in Warrenton, Virginia. According to recycling center officials, the terms of the consent decree were not being met for several reasons including labor problems, lack of availability of secure landfills and lack of State approval to place drums containing solids in non-secure landfills.

Several near catastrophic events developed at the recycling center after agreement and implementation of the consent decree. A major fire occurred in October, 1978, when a vehicle struck a drum containing lithium aluminum hydroxide in hexane, igniting it and several adjacent drums. Also, several major releases occurred on-site including an alkanol amine spill, a chromic/nitric acid spill and an alleged hexachlorocyclopentadiene spill. Finally, in the fall, 1979, after repeated failures on the part of ownership to meet the consent decree schedule, the State of Indiana brought the site to our attention for enforcement action.

AGENCY EFFORTS

The National Enforcement Investigation Center completed a field investigation[1] designed primarily to identify the materials on site and to establish the potential for any toxic materials to adversely affect the local population. Liquids and soils were sampled at locations within the recycling center, the drainage ditch north of the site, nearby residential and industrial wells and the city sanitary sewer downstream from the recycling center. Analyses of the samples discovered the presence of a number of compounds in the area soils with documented adverse human health effects (Table I.).

Table I.
Carcinogenic Compounds Found in Area Soils

Compound	Concentration ($\mu g/l$)
Benzene	5
Chloroform	20
Methylene chloride	200
Toluene	2000

The soil in the area was found to be very porous, potentially allowing infiltration of contaminants into the local groundwater system. Although there were no data documenting groundwater pollution, EPA believed the

presence of such large quantities of hazardous substances on the site and the nature of the soils in the area virtually guaranteed shallow aquifer contamination.

While this initial field investigation was intended to develop information on which to base litigation proceedings under the Resource Conservation and Recovery Act of 1976, its findings made clear the need to seek other more immediate alternatives to achieve a site cleanup. By the time this investigation was completed in late 1979, the recycling center's management was operating in total disregard of the consent decree and had allowed the drum inventory to approach 60,000.

As litigation proceedings went further and cases were filed, the recycling center owners officially declared bankruptcy in early 1980. Without a responsible party to finance cleanup, government action was now the only means by which the site could be stabilized.

In March, 1980, an explosion occurred at the site as a result of waste materials reacting after escaping from their decaying containers. The State of Indiana requested assistance from EPA Region V. A Federal On-Scene Coordinator (OSC) from the Environmental Emergency Section traveled to the site to determine if the explosion and leaking containers constituted a discharge or threat of discharge to navigable waters. It was necessary to make this determination to establish Federal authority and gain access to emergency cleanup funds under Section 311 of the Clean Water Act.

EPA Responds

Shortly after arrival at the recycling center, the OSC made an official determination that the abandoned site represented a threat to public health due to potential surface water contamination from site run-off and probably ground water contamination from infiltration. The OSC convened a Regional Response Team (RRT) meeting. All members for the team agreed that a substantial threat of run off to waters of the U.S. existed as long as the conditions of the site were left unchanged. The U.S. Coast Guard representative made it clear to the response team membership that, as the 311 fund administrator, removal of materials from the site or any activities not directly associated with containment would be considered inappropriate and not eligible for funding.

The OSC hired a contractor under Coast Guard emergency procurement authority. Contractor activities for the next thirty days involved drum segregation and staging, site grading and paving, earth work designed to direct surface water runoff around the site and placement of a runoff lagoon and treatment system to collect runoff from the site itself and treat it through a carbon adsorption system.

311 Action

At the conclusion of this effort which cost $866,000 and after evaluation of the work completed, EPA realized that an alternative approach to contractor procurement was needed to insure a more cost effective use of Federal funds. Placed in the perspective of implementing a site cleanup, the funds expended did not produce significant results. It was evident that extension of traditional 311 procurement practices to address uncontrolled waste site cleanup would mean large expenditures with little cost control capability. After a thorough review of the 311 effort, EPA felt it would be possible to achieve a greater level of effort at less cost by:

(1) removing the constraints on use of the 311 fund for removal of materials from the site and
(2) employing an emergency procurement approach incorporating limited competition.

At this time, EPA's policy was to use Section 311 authority wherever possible at hazardous waste sites threatening surface waters and to undertake whatever was necessary in effecting cleanup to mitigate the threat or discharge. Coast Guard's 311 policy differed. Their main concern was to conserve the 311 fund. They believed the best way to do that was to limit emergency activities at hazardous sites to containment only. The EPA and Coast Guard collective experience at Seymour Recycling indicated that the two policies on use of the 311 fund were not only inconsistent but often in diametrical opposition.

Major Cleanup Needed

In July 1981, approximately three months after conclusion of the initial response, a special congressional appropriation for Section 311 was enacted. An On-Scene Coordinator made a site visit to assess the current conditions and define the activity phases necessary to provide greater site stabilization.

The OSC convened a RRT meeting and put forward a phased plan for complete site cleanup beginning with the bulk tanks, progressing through removal of drums, investigations for buried materials, removal of the contaminated soil mass and ground water recovery and treatment. The members of the RRT believed that the relationship between the site, groundwater and nearby surface water could only be established by completing a groundwater study. The Regional Response Team recommended that while the groundwater study was underway, a permanent dike and security fence should be constructed.

Groundwater Monitoring

The OSC felt that the rapidly deteriorating conditions at the site would not allow time for implementation of a standard piezometric and analytic effort and that the relationship would need to be established in a two to four week period. A quick turnaround approach for identifying the presence of organically contaminated groundwater plumes entering nearby surface waters did exist and had been applied successfully in determining rural waste water treatment needs.[2] The OSC felt this approach could be applied at the Seymour site, yielding results of sufficient quality and clearly defining the relationship between the site itself and nearby surface water (Table II). Details of the groundwater study, the instrumentation used and results are discussed in detail in Part II of this paper.

The results of the groundwater effort were available within ten days. They confirmed that the shallow groundwater aquifer was contaminated and contaminants were entering the nearby surface water system. The bulk storage vessels and drums, all in a general state of disrepair and decay, were in fact a source of an on-going discharge to the East Fork of the White River.

Table II.
Information Derived from Groundwater Study

Rate and direction of groundwater flow
Relative level of groundwater contamination
Source of groundwater contamination
Positions of groundwater inflow into nearby stream

The instruments utilized during the study included groundwater flowmeters and ultraviolet flourescence.

CONTRACTOR SELECTION

Having established the site as a source of contamination, the OSC requested funds for the removal of materials stored in the bulk vessels. Both the OSC and the USCG Contracting Officer agreed that negotiated procurement would provide the best insurance for obtaining the "cost effective" approach. They also realized, however, that the normal procurement process covers a period of time far beyond that considered responsive to this situation.

A "fast track" procurement process needed to be employed in order to begin removal activities as soon as possible. The system ultimately developed was based on a brief scope of work and evaluation criteria ranked in order of priority (Table III).

Table III.
Fast Track Negotiated Procurement

Distribution of solicitations
Review and ranking
Cost negotiations
Selection

The evaluation criteria were distributed as part of USCG's solicitation package. All contractor proposals received were reviewed by a Technical Evaluation Team consisting of representatives from EPA, the Indiana State Board of Health and USGC. The proposals were ranked based on point totals generated through review of the information provided by the contractors in response to the Coast Guard solicitation (Table IV).

Table IV.
Solicitation Requested Information.

Overall company approach
Disposal techniques
Safety precautions
Transportation specifics
Equipment to accomplish task
Pricing

After ranking, the proposals were grouped into three divisions:

(1) acceptable,
(2) unacceptable but could be made acceptable with slight change and
(3) unacceptable.

Negotiations were begun with those contractors grouped in the second division. Technical and pricing modifications to their proposals were requested. These contractors were extremely responsive and modified their proposals for resubmission in approximately one week. These proposals were evaluated again (Table V) and a selection was made.

Table V.
Major Criteria Contractor Selection

Most Environmentally Sound Approach
Most Reasonable Site Safety Program
Most Cost Effective Solution

This entire procurement process required only four and one-half weeks to complete (Table VI) and realized a significant savings of Federal resources. Final cost estimates for acceptable proposals ranged from $350,000 to $4,000,000. After being evaluated on technical and safety terms, cost effectiveness became the pivotal factor. Removal of the materials in the bulk storage vessels has been completed. Costs for that effort went far beyond the contractors estimate but remained less than the next most cost effective alternative.

CONCLUSION

This procurement approach has also been used for two other efforts at the Seymour Recycling Center. These activities involved a detailed hydrogeological investigation and the other involved removal of all liquids in 55-gallon drums on the site. Cost estimates before negotiations were $64,000 to $400,000 and $800,000 to $13,000,000 respectively. The groundwater effort has been authorized but drum cleanup has not because of the limited 311 fund situation.

Table VI.
Time Frame for Negotiated Procurement

Element	Time Span (weeks)
Solicitation Preparation	1
Contractor Proposal	2
Proposal Evaluation	0.5
Proposed Revisions	1
Negotiations and Final Evaluation	1
Total Time to Contract Award	4.5

CONCLUSION

EPA Region V believes that the approaches used during the 311 action at the Seymour recycling center provided valuable information on which to base key decisions in a time frame consistent with the true meaning of emergency response. Defining the role of groundwater at an uncontrolled waste site can provide the OSC with invaluable information on which to base an immediate or planned removal decision. The benefits of the negotiated procurement process far outweighed the necessary resource commitment to effect them in terms of potential gross savings versus the staff time needed to complete intensive review and quick turnaround.

After experiencing the success of using these approaches, EPA Region V was particularly pleased to see the development of a planned removal scenario as part of the Superfund effort and are convinced that this approach, if managed in a timely manner, can achieve significant public health protection quickly and cost effectively.

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2. "Alternative Rural Wastewater Treatment Systems—Case Study Number Two" U.S. EPA, Region 5, draft Environmental Impact Statement, June, 1979.

A FAST TRACK APPROACH TO MANAGEMENT AND IMPACT ASSESSMENT (PART II)

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INTRODUCTION

On August 15, 1980, K-V Associates, Inc. was contracted by the U.S. Environmental Protection Agency Region V under a Section 311 action for emergency service to determine the direction of groundwater flow and location of any subsurface plumes of material associated with chemical waste materials improperly disposed of at the Seymour Recycling Center. The analytical services included the following tasks:

- Determine the direction of groundwater flow from the Seymour Recycling site by obtaining flow data with a Model 10 Dowser groundwater flow meter from roughly 20 locations of shallow augered excavations
- With the aid of existing PVC monitoring wells, determine the vertical profile of flow, if possible
- Clean, develop, and pump monitoring wells surrounding the site
- Obtain at least 20 samples of groundwater in the direction of prevailing flow and along the stream shoreline with a well-point sampler
- Analyze water samples in the field for conductance and fluorescent aromatic hydrocarbon content
- Map the direction of groundwater flow and positions of leachate from the site, indicating locations of inflow into stream, if observed.

The Seymour Recycling Center is located on the periphery of the Freeman Field Industrial Park southwest of Seymour, Indiana. To the north of the Site a stable stream flows directly east-west, then bends northward to enter Heddy Run which discharges into the east fork of the White River.

GROUNDWATER FLOW METER MEASUREMENT

Although several areas of ponded water were observed at the surface near the site, subsurface profiling showed the water to be perched on compacted clay-loam deposits. Augering through the soil would frequently encounter water at 8 to 9 foot depths below the surface. The inflows occurred through limited veins of sand penetrating the sandy-clay deposits. The water was under some pressure and would enter rapidly, fluidizing the sandy loam deposits until eventually stabilizing at a depth of 6 to 7 ft below grade, depending upon grade elevation.

Initially, a 3.5 in. diameter probe with the groundwater flow meter (Model 10 Dowser, K-V Associates, Inc.) was inserted into the sandy deposit at the base of the hole. Attempts at measurement indicated no apparent flow. Samples of the soil mixture were removed from the hole and placed in a 4 in. diameter soil flume to measure the capacity of the soil for flow. No measurable flow could be detected through the mixture with a two-inch water head even though the soil was a sandy consistency. A sufficient content of clay or silt existed to effectively seal off flow through the material.

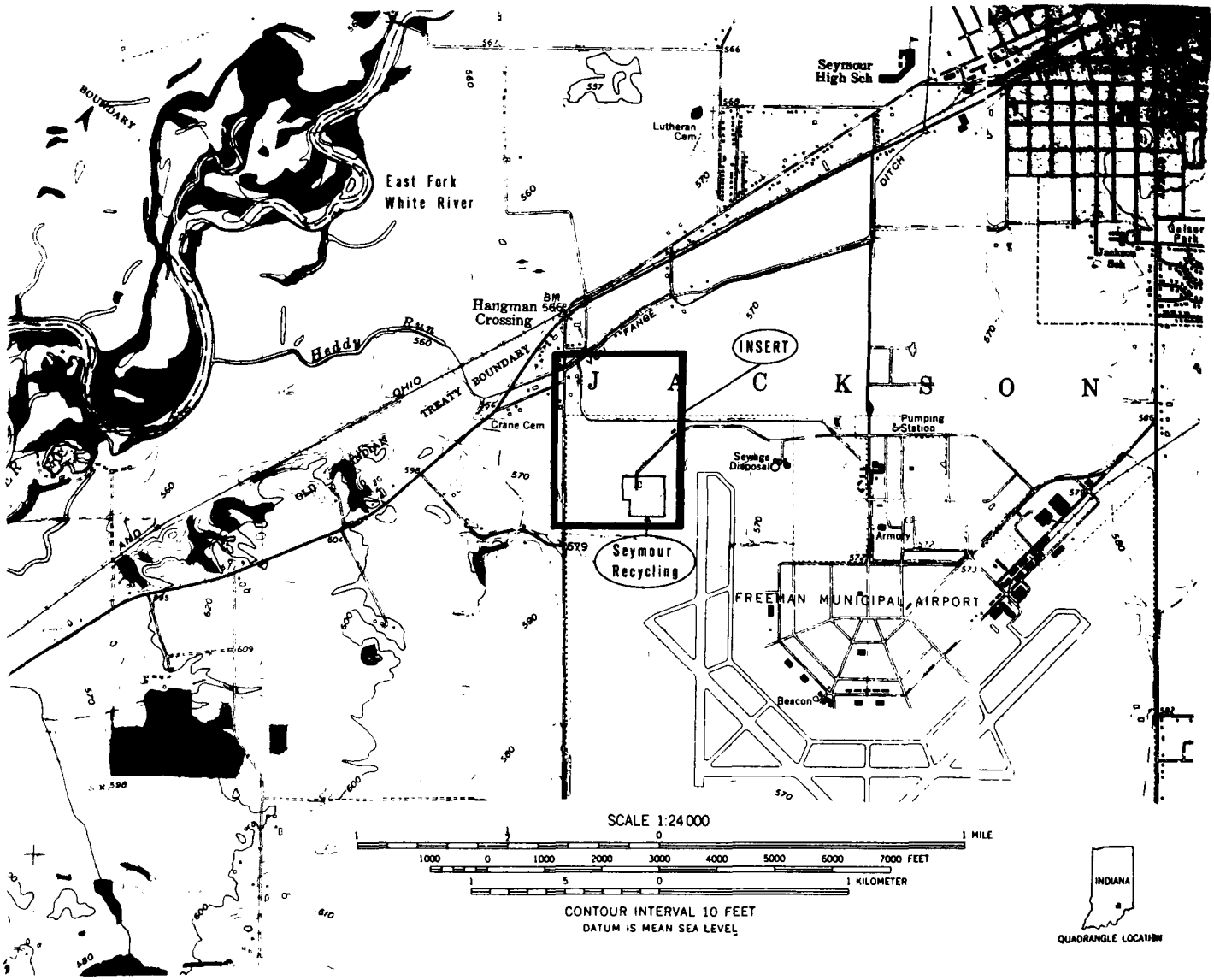

Figure 1.
Location of Seymour Recycling Site Showing Stream Areas
and Discharge to the East Fork of White River

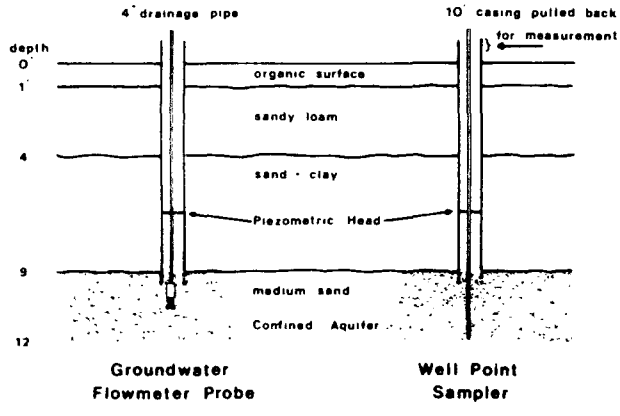

Figure 2.
Typical Soil Profile Adjacent to the Site

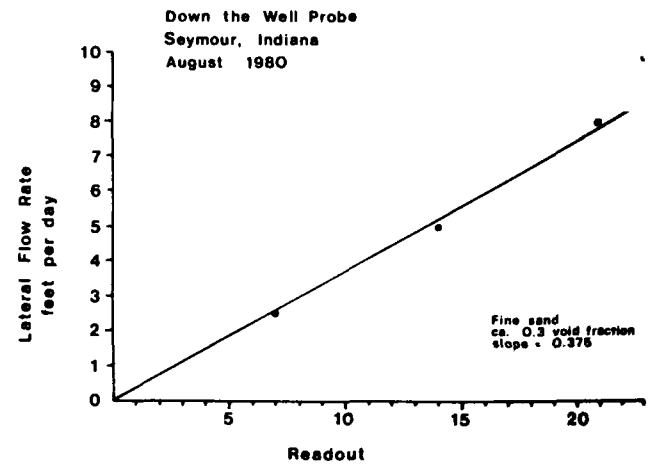

Figure 3.
Model 10 Dowser Calibration Curve for Water Bearing Strata

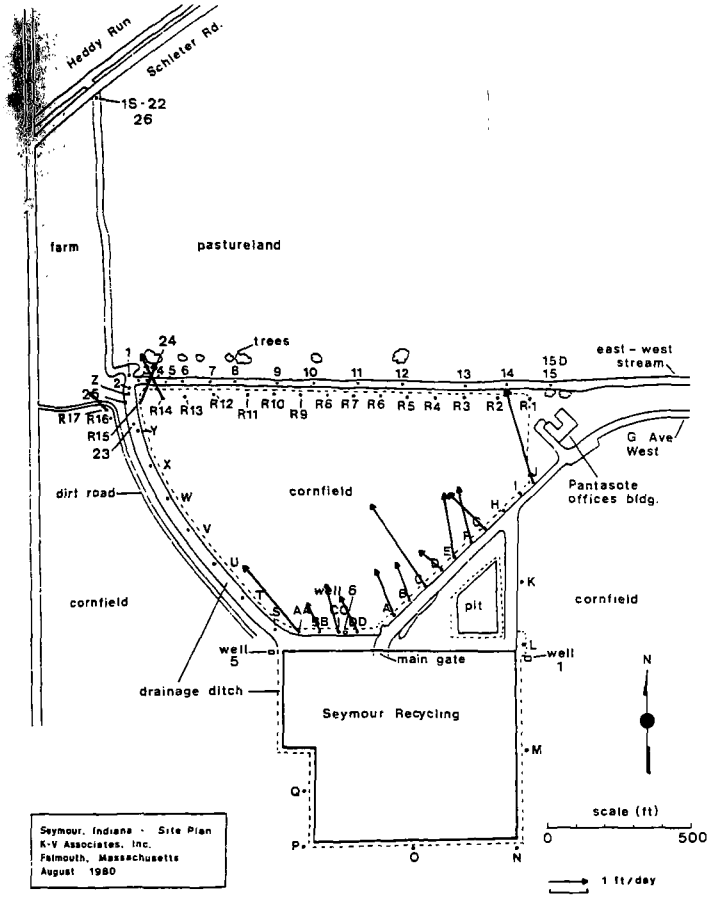

Figure 4.
Direction and Rate of Groundwater Flow Near Seymour Site

To avoid blockage of measurement by intrusion of the fine material, the hole was cased down to the porous strata. The hole was augered to 10 ft and a 10 foot section of 4 in. diameter drainage pipe installed. The gelled sand which had fluidized into the hole was bucketed out, allowing only washed sand from the aquifer to intrude up the interior of the pipe. The 2 in. down-the-well probe was then inserted into the sandy material at the base of the casing, the casing pulled back above the probe to avoid interference with capillary flow, and the probe oriented towards north before measurement. After initial measurement of flow, the probe was then rotated 180° and the measurement repeated to provide a check on the first determination. The results of field measurements taken from cased holes surrounding the Seymour site are given in Figure 4.

The Model 10 Dowser flow meter was calibrated for flow rate against the Seymour sandy aquifer material obtained from cased holes I and J placed in a 4 in. cylindrical flow chamber. Using a peristaltic pump, water of known volume was circulated through the chamber. With an independent measurement of porosity of the soil, the rate of movement in feet/day could be calculated. A calibration curve for the sandy water-bearing strata is plotted in Figure 3.

GROUNDWATER SAMPLING

Samples of groundwater were obtained with a Model 12 miniature well-point sampler (K-V Associates, Inc.). Two procedures were followed. With wells AA through J, the well-point sampler was inserted into hand-augered, cased holes (with 4 in. PVC draining pipe) and thrust through the sandy bottom to 2 ft. below the casing.

With uncased holes or cornfield sampling, the well-point was driven directly through the soil to approximately four feet below standing water level (piezometric head). A high ratio of striking force to crossectional area of the shaft (5/8 in. diameter) enabled the well-point to penetrate the sandy or clayey subsoil. Water was then withdrawn with the sampler into a silt trap, washed out, and refilled. A sample of the second pumping was taken for analysis by a field fluorometer and later scanning by a Perkin-Elmer Model 204 fluorescence spectrophotometer.

The conductance of groundwater and surface water samples was determined with a Model 1484-10 conductivity meter (Horizon Ecology Co.). Samples were obtained for cross-calibration in the laboratory.

SURFACE WATER TRANSECT

On August 20, surface water samples were taken along the stream course from west to east, progressing upstream. These samples were analyzed immediately for fluorescent aromatic content. The stream flows through a 2 to 3 ft wide channel as it meanders through a 30 ft wide man-made ditch between the cornfield and pastureland. Grass covers the sides of the stream bank in unshaded areas. The sandy stream bed is soft in numerous locations, apparently caused by upwelling waters from groundwater recharge.

Two increases in fluorescent organics were observed, one near Sample 2 at the opening of the storm drainage ditch from the Seymour site and in the vicinity of surface water Sample 7 taken near groundwater Sample R12.

FLUORESCENT ANALYSIS OF WATER SAMPLES

Fluorescence spectroscopy is well-known as an analytical tool for organic analysis because of its exceptional sensitivity and selectivity.[1] The U.S. Coast Guard Research and Development Center recently conducted a survey of the luminescence of hazardous materials.[2] A large number of hazardous organic compounds were identified as possessing useful fluorescence. Of 113 materials supplied to the Coast Guard study, 96 compounds were fluorescent at room temperature, although some admittedly weak. The stronger fluorescent compounds include the benzene and naphthalene derivatives common to petroleum products, numerous pesticides and herbicides, common solvents such as toluene and xylene, dye products such as aniline, and the polyaromatic hydrocarbons (PAH's) such as anthacene, chrysene, and pyrene.

Fluorescence has recently found increasing use as a tool in the analysis of complex mixtures of organics. Frank[3]

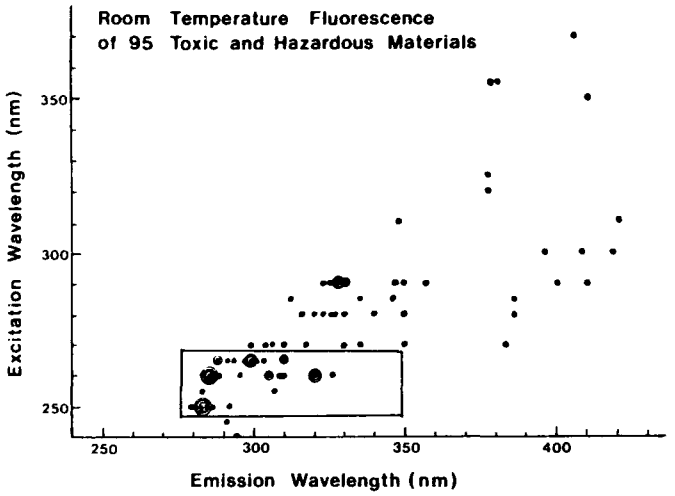

Figure 5.
Excitation-Emission Plotting of Fluorescence of 95 Toxic and Hazardous Materials. Region of Sensitivity of Field Fluorometer Indicated by Box

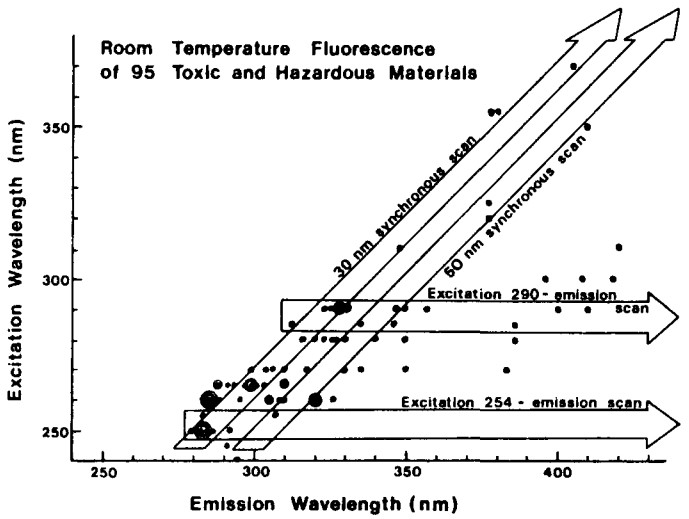

Figure 6.
Zones of Sensitivity of Fluorometer Scans of Water Samples

used excitation of samples at 290 nm and quantification of emission at 329 nm as a method of characterizing crankcase oils in situations not amenable to analysis by gas chromatography. Quantification of number 4 oil directly in water has been studied by Frank[4] for analysis of oil contamination. More recently synchronous scanning, accomplished by linking the excitation and emission monochromators together, has gained in popularity because of the elimination of scatter interferences.[5]

Field water samples were analyzed by excitation at 254 nm and emission from 280 nm to 400 nm. Upon return to the laboratory, the same samples were analyzed by three different scanning methods: excitation at 290 nm and emission scan from 310 to 450 nm (a procedure similar to Frank[3] for crankcase oil), and synchronous scans (30 nm and 50 nm separation). Results from the four methods are superimposed over a two-dimensional plotting of the peak locations of fluorescence of hazardous substances determined previously by the Coast Guard in Figure 6.

Results

The organic analyses yielded the following information:

(1) Between cased holes BB and D a substantial concentration of fluorescent aromatic organics occurred. All scanning procedures revealed a similar pattern with the highest concentrations coinciding with holes BB and D. The variety of scans also revealed two fluorescence peaks dominating the elevated regions:

Wave Length (nm Excitation/Emission	Class of Organic Compounds
290/324	phthalic acids, naphthalene
335/365	anthracenes, plasticizers, light oils

Previous gas chromatographic analyses of well water samples had identified naphthalene, diethylphalate, ethylbenzene, toluene and tetrachloroethylene exterior to the storage site.[6]

(2) Similarly, groundwater samples downflow of the site along a transect through the cornfield R1 through R17 revealed a rise above background from Samples R7 through R16.

(3) Surface water samples from the east-west creek indicated inflow of fluorescent aromatic organics in the vicinity of the drainage ditch confluence. The regions of infiltration were strongest in the vicinity of surface Samples 2 and 7 coinciding with the drainage ditch and the central portion of the subsurface plume.

(4) During a heavy thunderstorm, a substantial inflow of fluorescent aromatic organics was observed issuing from the drainage ditch to the east-west creek. The inflow was readily observable as a discernible pulse entering Heddy Run.

Based on these results, one can conclude that aromatic organics from the Seymour site are entering the east-west stream-Heddy Run confluence through two pathways:

(1) storm runoff through the western drainage ditch and

(2) groundwater infiltration into the east-west stream and from a large subsurface plume containing materials originating from a primary source at the site (as seen in holes AA through D) and a secondary source as infiltration into the aquifer of storm drainage from contaminants in the western drainage ditch.

Storm Runoff

On August 19, a violent thunderstorm occurred at 4:30 p.m., forcing abandonment of groundwater sampling. Instead, the leachate detector was moved to the confluence of the east-west stream and Heddy Run. Samples were removed from the stream from 4:50 p.m. to 6:00 p.m. at 15 min. intervals. At 5:30 a large surge of fluorescent aromatic compounds was observed at the confluence. At 6:15 samples were obtained from the outflow of the west drain-

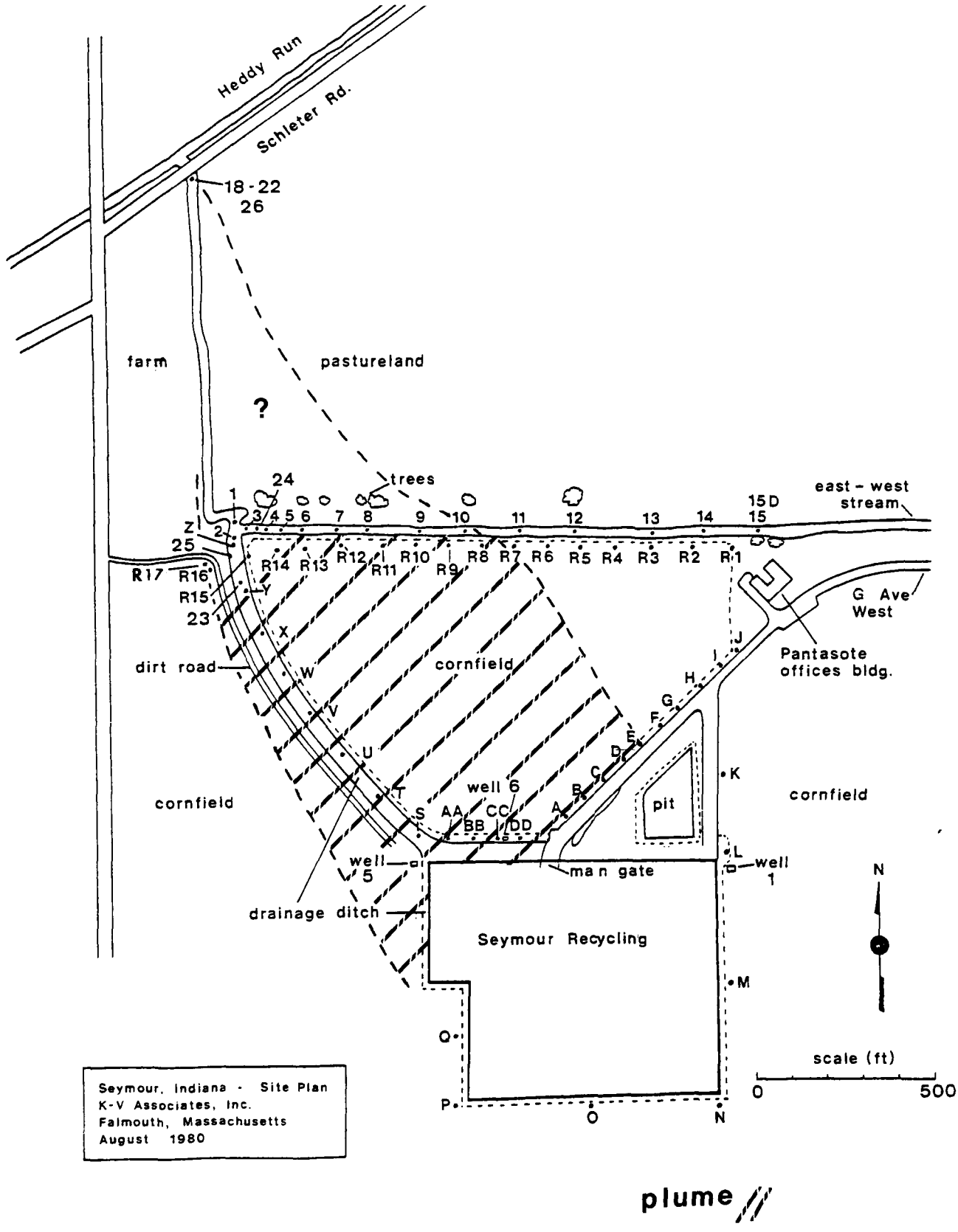

Figure 7.
Sampling Locations and Position of Observed Plume

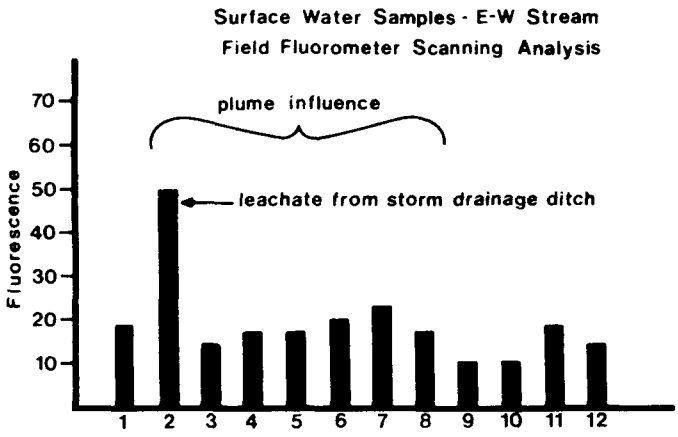

Figure 8.
Fluorescent Aromatic Concentrations Observed in Surface Water of East-West Stream

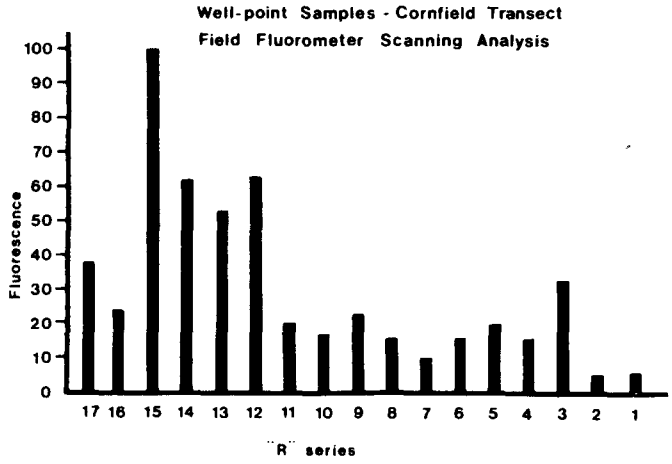

Figure 9.
Concentration of Fluorescent Aromatic Found in Groundwater from Cornfield Transect Adjacent to Stream

age ditch from the Seymour site and immediately upstream of the outflow along the east-west stream. Analysis of the water samples confirmed that the bulk of the discharge was issuing from the vicinity of the drainage ditch.

STRESSED VEGETATION

On edges of the cornfields, trees at various heights occurred and could be seen to be under vegetative stress. The position of various dead and stressed trees were plotted. Most were in the vicinity of the western drainage ditch, although a few trees occurred upstream along the east-west stream. The corn plants in the region would not be affected by groundwater contamination since their root systems are shallow and rest in the sandy loam above the aquifer. However, taller trees (>20 ft) have roots penetrating into the lower strata which may contain the transported organics.

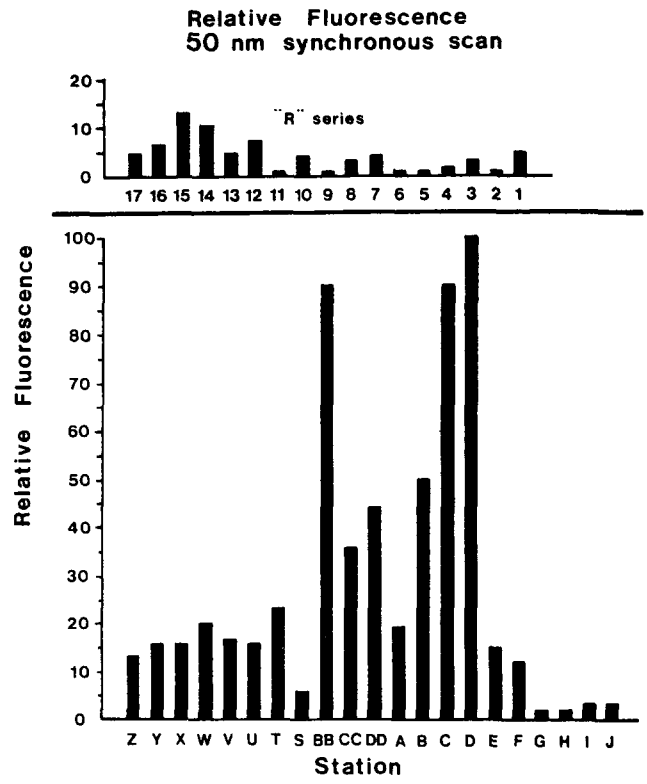

Figure 10.
Relative Fluorescence of Groundwater Samples Observed with 50 nm Synchronous Scan Procedure

Table I.
GWF Directions & Relative Rates
Seymour, Indiana August, 1980

Hole	Compass Direction	Rate (Readout)	Velocity (ft/day)***
A	338°	3.5	1.3
B	340°	2.5	1.0
C	327°	6.5	2.5
D	310°	2	.8
E	352°	4.5	1.7
F	347°	4	1.5
G	315°	3.5	1.3
H*	u		
I*	u		
J	344°	6.5	2.5
P**	Unstable		
AA	320°	6	2.3
BB	334°	2	1.8
CC	346°	3.25	1.2
DD	335°	2.5	1.0
R17	311°	1.5	.6
R14	335°	3.25	1.3
R15	23°	2.75	1.0

*H and I were unstable in flow characteristics and appeared to be influenced by a possible leak in a water pipe or other localized source.

**P was taken following rainfall and showed erratic flow (towards 83°E).

***0.375 x readout = ft/day.

u = Unstable.

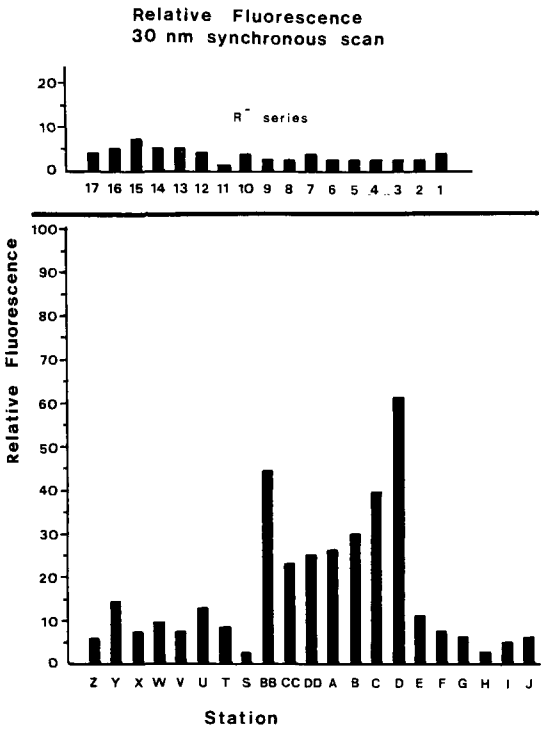

Figure 11.
Relative Fluorescence of Groundwater Samples Observed with 30 nm Synchronous Scan Procedure

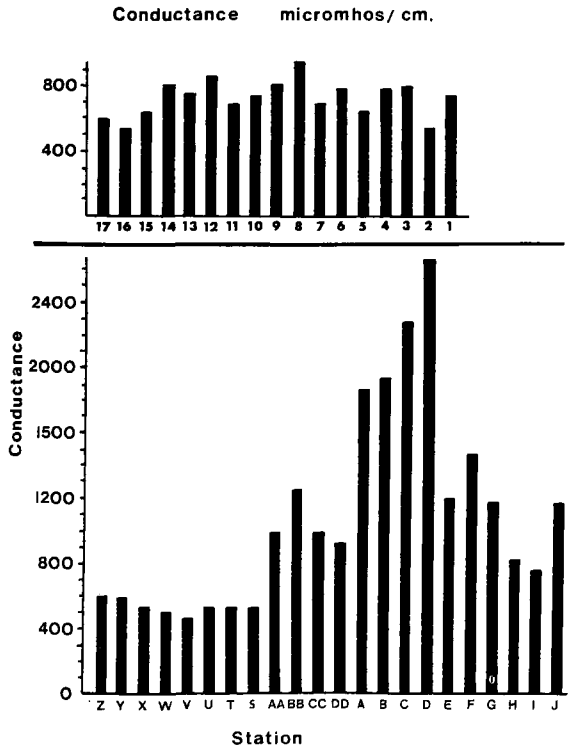

Figure 12.
Conductance of Groundwater Samples

STREAM INFILTRATION

The shallow (0.5-2.5 ft deep) east-west stream formed hydraulic continuity with the shallow aquifer. The water level of the stream on dry days was roughly 5.5 ft below the grade of the cornfield. This placed the sandy bottom of the stream at the top of the porous water-bearing strata. A hole was augered near Station Two to the aquifer and the difference in water head compared by inserting a primed hose between the hole and the shallow stream. The observed flow of water was rapidly towards the stream, clearly indicating infiltration of groundwater up into the stream.

To estimate the rate of inflow, Lee-type lysimeters were installed in the stream bed to determine the rate of groundwater infiltration in the vicinity of the plume intersection.

Site	Flow Rate	Infiltration ($ft^3/ft^2/day$)
1	246 ml/10 min	0.67
2	145 ml/15 min	0.26
3	60 ml/30 min	0.05
4	72 ml/20 min	0.10
	$\overline{X}$ =	0.27

The section under investigation averaged 2.6 ft in width. With an estimated 0.27 $ft^3/ft^2/day$ infiltration along a projected zone of length of 800 feet of stream bed intercepted by the plume, the rate of discharge would be about 560 ft^3/day or approximately 4200 gal/day.

WELL DEVELOPING

On August 22, existing observation wells were pumped for developing. The deep well occurring close to the drainage ditch south of the indicated position of well 9 was well-developed with no fines apparent upon successive pumping. Wells 1, 5, and 6 were found to penetrate to 10 ft below the top of the casing. Wells 1 and 5 were developed by drawdown and surging with 5 gal/mm centrifugal pump with hose to bottom of the casing. Well 6 was drawn down to the bottom of the screen with little or no apparent inflow. After two hours, only 2 in. of water had filled the well screen. This well did not appear capable of being developed. Well 5 had sustained slight damage due to earth operations in the vicinity. A 20° bend was apparent 2.5 ft below casing top (one ft below grade).

CONCLUSIONS

From August 16 through August 23, 1980, K-V Associates, Inc. investigated the extent of subsurface contamination of groundwater in the immediate vicinity of the Seymour Recycling Facility in Seymour, Indiana. Hand augering on the site revealed that water-bearing strata existed at depths of 8-9 ft below grade.

Thirty shallow observation holes were excavated across the site area and used to measure the direction and rate of groundwater flow. After the major direction of groundwater flow was determined, samples were taken of the

groundwater across the axis of flow with a portable well point sampler driven 14 ft below grade to determine the location of any material moving through the aquifer. Samples were analyzed for conductivity and petroleum-related aromatic organics (by UV fluorescence).

The following conclusions were reached:

- The mean groundwater flow direction was found to be away from the town of Seymour and in a Northwesterly direction (approximately 316° NW) evidenced by direct flow measurement and the location of a plume of organic leachate.
- A plume of petroleum-related aromatic hydrocarbons was observed extending from the site in a Northwesterly direction discharging into surface waters at a confluence of an east-west stream and Heddy Run South of Hangman Crossing.
- The position of the subsurface plume coincided with a zone containing numerous dead or dying trees, particularly larger trees with deeper root structures.
- The mean flow rate of the shallow aquifer was measured at 1.2 feet per day compared to a previous estimate of 0.016 ft/day. The combined influence of siphoning of flow to the nearby streams and restriction of lateral flow strata by natural clay deposits probably contribute to the more rapid flow than previously estimated.
- During storm period temporary changes in flow of the streams (direction) were observed in the aquifer flow when storm flooding occurred, further substantiating the connection between both water bodies.
- Since the shallow aquifer is intercepted by the stream bed of Heddy Run and in places by an east-west tributary, it is possible that the plume may have stabilized in position and is no longer moving laterally. Instead the contaminants are being diverted to surface waters during normal stream flow conditions.
- Profiling of the stream shoreline revealed the discharge of petroleum-related organic aromatics in the vicinity of the stream confluence. Substantial infiltration rates of water through the sandy stream bottom were measured in the vicinity.

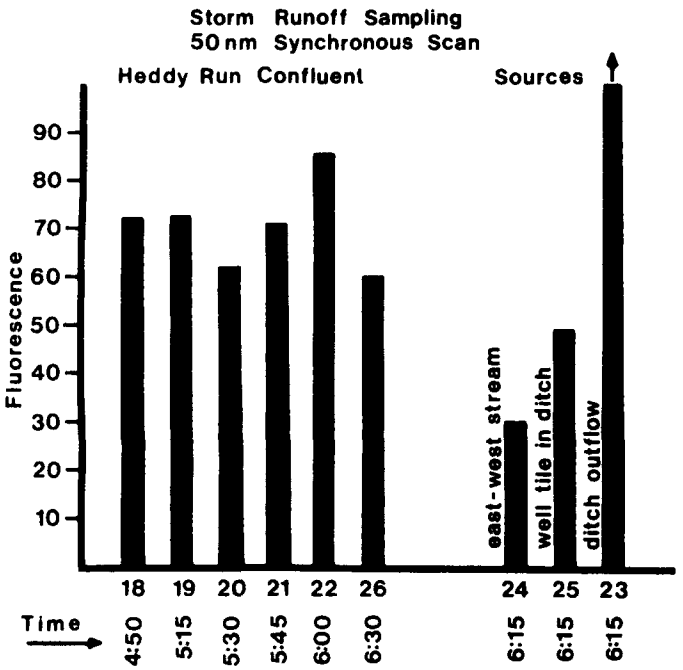

Figure 13.
Concentration of Fluorescent Aromatics Observed During Storm Flow

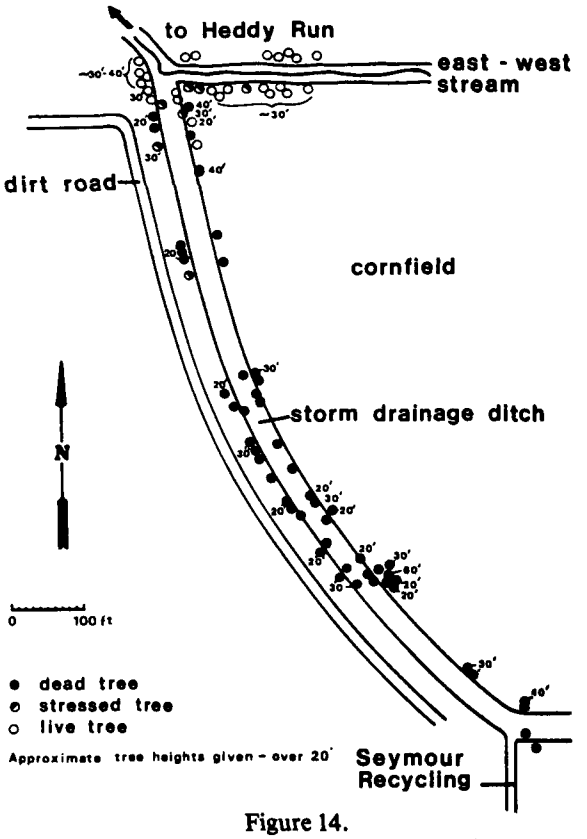

Figure 14.
Location of Dead and Stressed Trees Nearby the Seymour Recycling Site

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HAZARDOUS WASTE SITE INVESTIGATION SYLVESTER SITE, NASHUA, NEW HAMPSHIRE

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INTRODUCTION

In this paper, the authors describe the results of an engineering and hydrogeological investigation of the Sylvester Site undertaken by GHR Engineering Corporation and its principal subcontractor, Goldberg-Zoino and Associates (GZA). The investigation began in April 1980 and was completed in July 1981 with submittal of the final project report to the New Hampshire Water Supply and Pollution Control Commission (NHWS & PCC) and the U.S. Environmental Protection Agency (U.S. EPA.)[1]

The investigation of the Sylvester Site and adjoining properties was designed to:

(1) Define the extent of soil, surface water and groundwater contamination;
(2) Develop an engineering assessment of the hydrogeological and hydrological conditions governing contaminant movement from the site; and
(3) Evaluate alternative remedial actions on the basis of technical feasibility, estimated costs and environmental implications.

The evaluation of remedial actions included a laboratory-scale assessment of the feasibility of removing contaminants from groundwater in an on-site, above-ground water treatment plant. The final project report, including recommendations for remedial action, provided the basis for the first Federal/State cooperative agreement under Superfund, with $2.3 million being awarded to the State of New Hampshire in August 1981 for design and construction of remedial measures at the site.

SITE DESCRIPTION

The Sylvester Site is an approximately six-acre open dump located behind the C & S Disposal Company garage on Gilson Road in Nashua, New Hampshire. The site is a former sand pit which was excavated in places to elevations lower than seasonal high groundwater levels. Upon completion of sand mining operations, the pit was gradually filled during the 1970s with various types of refuse and waste materials, consisting primarily of construction/demolition debris, but also including large amounts of chemical liquids and sludges. The waste materials extend into the water table throughout much of the site. Several methods were used to dispose of hazardous liquid and sludge wastes at the site, including:

- Subsurface discharge of large volumes of liquid wastes through 2-3 ft diameter pipe extending into the site from the garage building
- Subsurface burial of drums of waste in at least two locations on the site
- Surface and subsurface disposal of sludge-like material in several areas of the site
- Stockpiling of 55-gal drums of chemical wastes on the surface of the site

In May and June 1980, all drums visible and accessible from the surface of the site were removed by Recra Research, Inc. of Tonawanda, New York under subcontract to GHR Engineering. A total of 1,314 drums were transported from the site for final safe disposal in New York and Ohio. A complete report on the drum removal work was submitted to the NHWS & PCC in July 1980.[2]

The area surrounding the site is primarily residential (Figure 1), although the land across Gilson Road to the south is undeveloped swamp and woodland. Directly adjacent to the east and north of the site are two large trailer parks. The closest residences, in the Rodger's Trailer Park, are within about 100 ft of the northeast perimeter of the site. The Thompson property, which abuts the site to the west, is a large, open parcel that is an active local source of sand and gravel.

As indicated on Figure 1, contaminated groundwater from the site flows northwesterly toward Lyle Reed Brook, which is about 680 ft from the site and the Nashua River. The contaminant plume from the site has already moved to and beyond Lyle Reed Brook. Fortunately, the residents of Jensen's Trailer Park are not dependent upon local groundwater resources for drinking water, since the trailer park is served by the municipal system.

Not so fortunate are residents along Route 111 in the path of groundwater flow. Their individual drinking water wells are in jeopardy, i.e., they will eventually be con-

taminated as the plume continues to expand. Trace levels of organic contamination have already been found in a ground-water observation well located between Tumblebrook Road and the Pennichuck Water Department well, which is not presently in use. In addition to drinking water supplies, a principal public health concern at the site is the Lyle Reed Brook into which contaminants moving in upper groundwater zones are being discharged, eventually being carried in surface flows to the Nashua River.

FIELD EXPLORATION AND TESTING PROGRAM

Upon completion of drum removal work in mid-June 1980, an extensive field exploration and testing program was carried out to develop the information needed to evaluate remedial options for the site. The complete exploration and testing program was a multi-phased effort that consisted of the following:

- Subsurface investigations of the disposal site by remote sensing (magnetometer and partial electrical resistivity surveys)
- Excavation of 34 test pits within the confines of the disposal site, which included soil sampling and analyses, groundwater sampler installations, and stratigraphic logging.
- Execution of 15 test borings with soil sampling, rock drilling and field analyses for organic chemical contamination
- Installation of permanent groundwater sampling systems, both conventional observation wells and gas drive samplers, at 23 locations in the vicinity of the disposal site (Figure 2)
- Installation of a 1.0 ft diameter well and execution of a 5-day aquifer pumping test.

The pumping test was conducted to:

(1) refine estimates of the hydraulic characteristics of the aquifer;

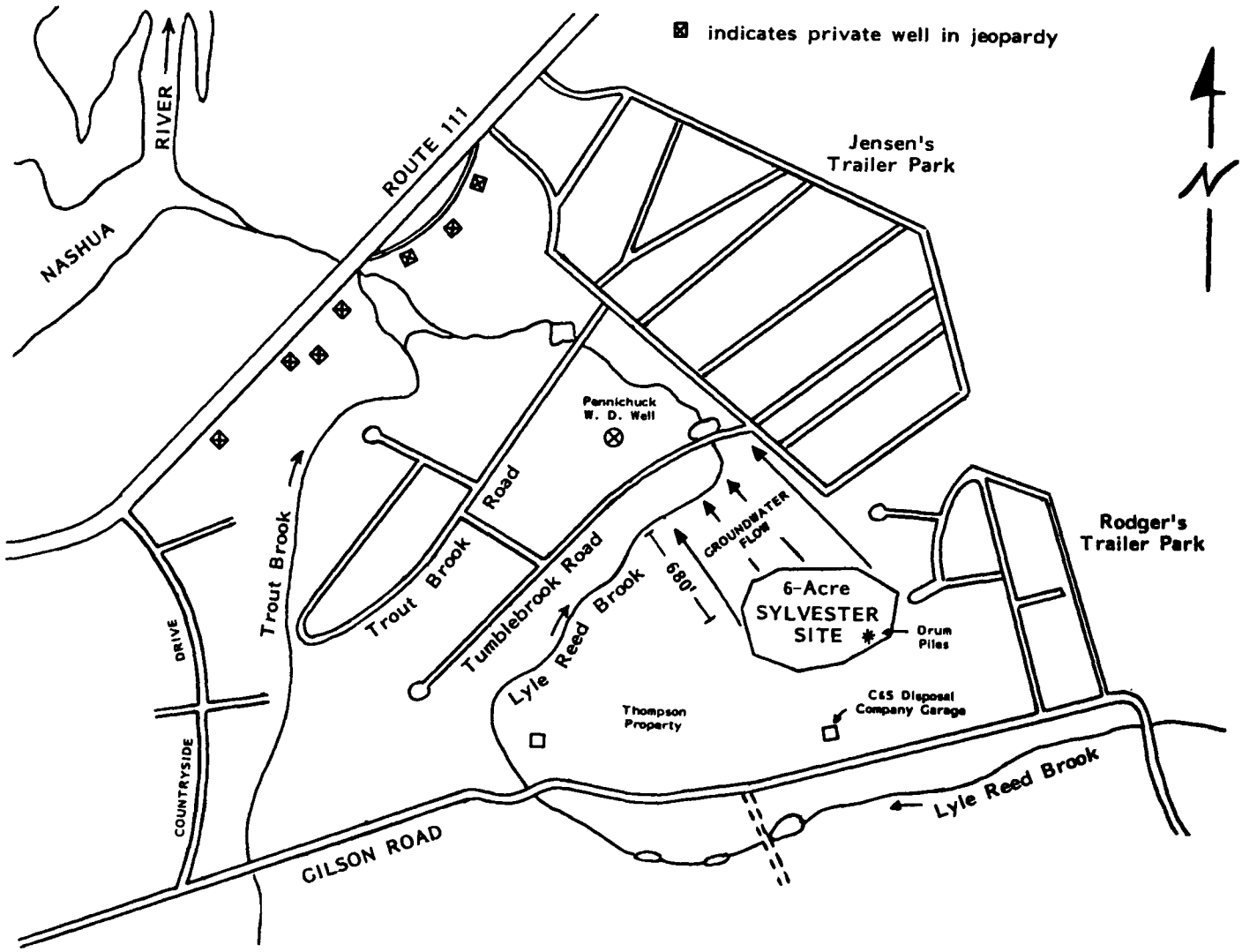

Figure 1.
The Area Surrounding the Sylvester Site
(Not to Scale)

(2) observe the impact of pumping on groundwater quality; and,
(3) collect a representative sample of the aquifer for use in laboratory-scale testing of the effectiveness of several alternative water treatment processes in renovating the contaminated groundwater.

Groundwater quality in the vicinity of the Sylvester Site has been monitored periodically since July 1979, beginning with the installation of a ring of 10 groundwater observation wells around the site by the NHWS & PCC. During the GHR/GZA site investigation, another 27 groundwater observation wells were added to the monitoring network. In addition, 42 private drinking water wells and 3 Pennichuck Water Department wells (1 production well, 2 observation wells) have been tested by the U.S. EPA as part of this site investigation. Surface water quality in Lyle Reed Brook and the Nashua River has been monitored by the U.S. EPA on several occasions since March 1980.

FINDINGS: CONTAMINATION LEVELS AND DISTRIBUTION

Types and Amounts of Contaminants

The site and its associated groundwaters are highly contaminated with a large variety of toxic organic and inorganic compounds. The groundwater contaminant plume extends from the disposal site to the vicinity of the Pennichuck Water Department well between Tumblebrook and Trout Roads.

The most contaminated groundwater zone extends from the disposal site to the vicinity of wells #5-D and #M-2 on the Thompson property; however, some mobile volatile organic compounds have travelled as far as the Pennichuck well. Several of these compounds, including primarily toluene and tetrahydrofuran (THF), have been consistently detected in Lyle Reed Brook in the 5 to 10 mg/l range since July 1980. The less mobile extractable organic and inorganic compounds known to be present in the groundwater contaminant plume have not been detected in Lyle Reed Brook to date.

A tabular summary of the types and amounts of contaminants detected in groundwater and surface water monitoring since July 1979 is presented in Table 1. The data in this table provide an indication of the extent of the adverse water quality impacts of the Sylvester Site and a general perspective on observed contaminant migration. However, the very dynamic temporal and spatial characteristics of the contaminant plume and its movement are oversimplified here. The ranges of the pollutant concentrations presented in Table I are the lowest and highest levels detected to date at sampling stations grouped as follows:

(1) Groundwater monitoring wells nearest to the downgradient perimeter of the Sylvester Site, including wells #2A, #3, #4, #M-1 and #A-4
(2) Groundwater monitoring wells located between the site and Lyle Reed Brook, including wells #A-2, #A-3, #M-2 and #5-D. In this area, only well #A-3 has been analyzed for extractable organics

The principal groundwater contaminants in terms of concentrations are volatile organic solvent compounds which, in total, have been found at levels as high as approximately 1,800 mg/l. Concentrations of non-volatile organic priority pollutants in groundwater have been in the 5 to 15 mg/l range. No priority pollutant pesticides or PCBs have been detected in groundwater. Arsenic levels in groundwater are elevated (within the 0.20 to 1.2 mg/l range) throughout much of the study area. Concentrations of total metals in groundwater are within the 100 to 1,000 mg/l range in the study area, with iron and manganese being by far the major inorganic constituents.

Volatile organic contaminants in groundwater from the Sylvester Site were first detected in Lyle Reed Brook in March 1980 and have been steadily increasing since. Contaminant levels in the brook in September and December 1980 were in the 7 to 10 mg/l range in the vicinity of Tumblebrook and Trout Brook Roads, and in the 2 to 3 mg/l range at the Route 111 culvert. The decreasing concentrations along the brook may reflect the effects of dilution, aeration, volatilization and biodegradation.

No contaminants other than volatile organics have been detected in the brook to date. The Nashua River has been tested by the U.S. EPA at a point approximately 1,000 ft downstream of where the brook enters the river, and no volatile contaminants present in the brook have been detected in the river at that point.

Contaminant Transport Mechanisms

The disposal site itself is a depression carved into the natural landscape as a result of sand mining operations. The subsequent waste disposal activities have left a very irregular surficial topography within the approximately 6-acre area now enclosed within a chain link fence. The ground surface immediately outside the fence consists of steep embankments to higher ground to the west and north, and relatively flat areas to the east and south. All surface runoff in the immediate vicinity of the site flows into the site; therefore, surface runoff is not a pollutant transport mechanism from the site itself. Surface transport of pollutants in the study area comes into play as contaminated groundwater is discharged to Lyle Reed Brook and then flows in the brook to the Nashua River.

The characteristics of the groundwater flow regime in the study area will ultimately determine the fate of pollutants released into the aquifer underlying the site, and it is apparent that the principal threats posed by the Sylvester Site are associated with groundwater. For this reason, the hydrogeologic properties of the aquifer, along with the characteristics of the flow regime, are of primary importance.

Groundwater contours developed from water table measurements made in December 1980 are shown in Figure 2. Assuming groundwater flow to be perpendicular to the contours presented, the principal direction of flow is to the northwest toward Lyle Reed Brook. Regional flow is also in a northwesterly direction toward the Nashua River and it is assumed that the Nashua River is the ultimate "sink" for groundwater leaving the disposal site. A portion of the flow reaches the river via Lyle Reed Brook and the bal-

ance remains as groundwater, probably flowing in a path roughly parallel to but beneath the brook.

Hydraulic gradients (taken as the slope of the water table) across the site range from less than 0.2% to approximately 0.8%, but typically average 0.3 to 0.4%. Anomalies in the gradient values as well as the overall shape of the groundwater contours were consistently observed in the vicinity of wells #A-2 and #M-2. Steepening of the water table slope at this point is potentially indicative of a localized decrease in aquifer transmissivity, possibly caused by a geological anomaly. Seasonal variations of the water table elevations observed at the site during the duration of the current study indicate that seasonal fluctuations will not have a significant impact on the groundwater flow regime or, correspondingly, on contaminant migration.

Based on a combination of pumping test data, soil grain size analyses and published information for the soil types encountered, the hydraulic constants of the aquifer were estimated. The estimated transmissivity of the fine to medium sands underlying most of the site is 700 to 2,400 ft²/day, representing a coefficient of horizontal permeability of 20 to 70 ft/day (based on a saturated aquifer thickness of 33 ft). For sand and gravel deposits encountered north and west of the disposal area, transmissivity is estimated at 3,300 to 6,600 ft²/day; corresponding coefficients of permeability are from 100 to 200 ft/day. The average linear or "transport" velocity of the groundwater at the site was estimated to be 0.8 ft/day for the fine to medium sands and approximately 1.6 ft/day in the areas north and west of the disposal site, where coarser deposits would be expected to control groundwater movement.

Based on the calculated transport velocities, travel times were estimated between selected points for transport of contaminated groundwater originating from the Sylvester Site. A summary of transport times from the midpoint of the disposal area to relevant points is tabulated below:

Location	Transport Time
Lyle Reed Brook	3-5 years
Pennichuck Well	4-6 years
Route 111	5-7 years
Nashua River	7-9 years
Nashua River (from Pennichuck well)	2-5 years

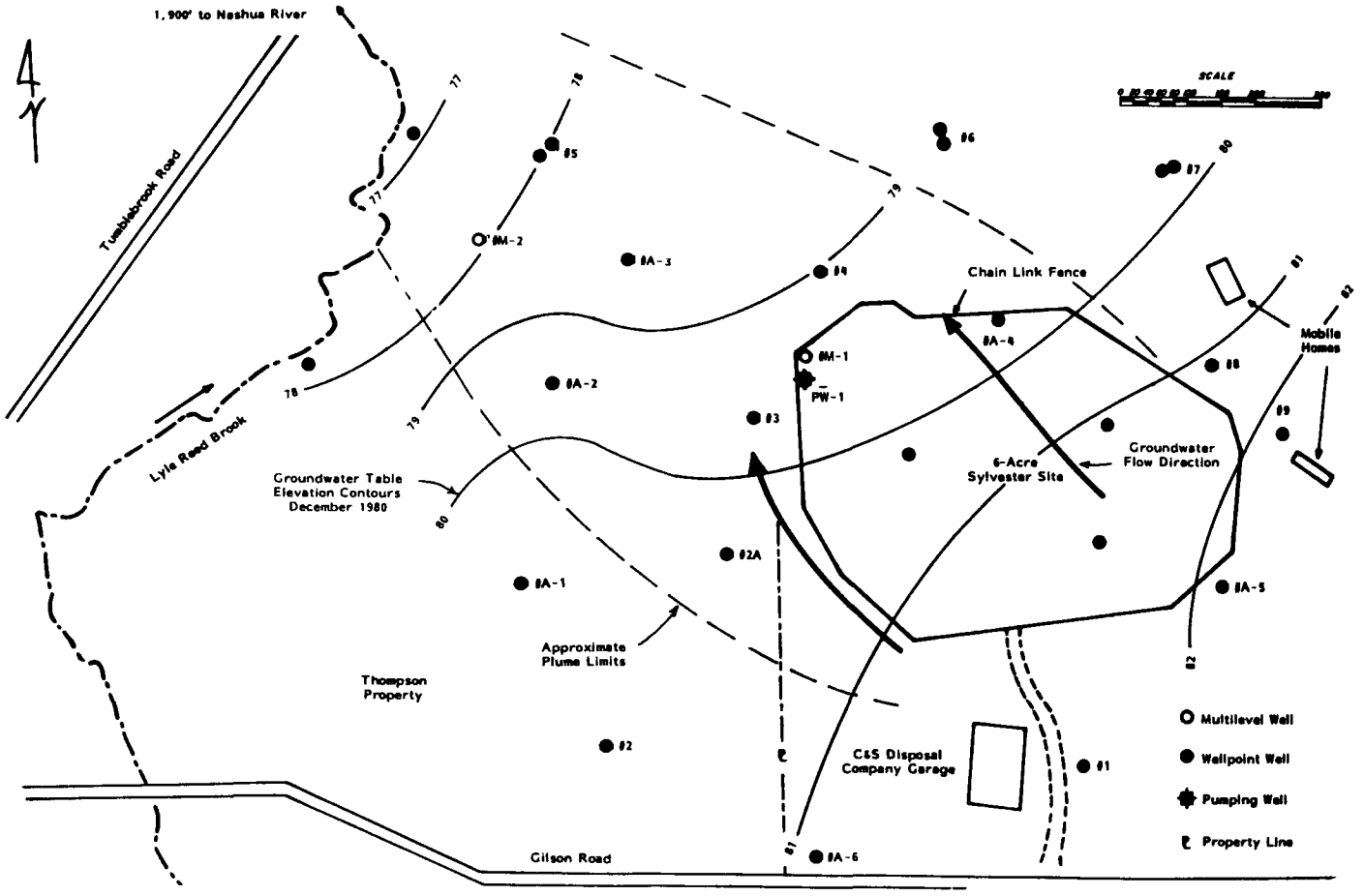

Figure 2.
Monitoring Wells, Groundwater Contours and Contaminant Plume Limits at Sylvester Site

Since the calculated travel times were based on a number of simplifying assumptions, they are considered to be approximations only. Total volumes of contaminated groundwater within various portions of the contaminant plume were estimated from assumed porosity values and observed saturated aquifer thickness. Considering the entire plume from the disposal site to Lyle Reed Brook, the total volume of affected groundwater is approximately 60 million gallons. Of this total, about 30 million gallons lie within the immediate confines of the Sylvester Site as delineated by the fenced area. The total estimated flow of groundwater through the disposal site, considering a cross-section across the width of the containment plume at multilevel well #M-1, is approximately 31,500 gal/day (with a range of from 13,000 to 65,000 gal/day).

Contaminant Distribution

At the Sylvester Site, the wide area over which waste disposal occurred has caused the formation of a correspondingly wide contaminant plume in the vicinity of the source (see Figure 2). As the contamination migrates northwest, the geometry of the water table contours tends to counteract the spreading effects of hydrodynamic dispersion, thereby limiting the width of the plume. The result is a fairly sharply defined zone of contamination whose southerly and easterly borders are confined to the immediate area of the site. As the plume approaches Lyle Reed Brook, a degree of spreading is inevitable as much of the contaminated groundwater flows into the brook, leaving the site as surface water. The balance of the plume flows beneath and parallel to the brook.

Interpretations of contaminant distributions at the Sylvester Site based on most recent analytical data are shown in Figures 3 and 4. Contours of pollutant concentration depicted on the figures are approximate, idealized and subject to change with time, but the representations adequately illustrate significant trends.

The observed distribution of volatile organic chemicals (Figure 3) closely resembles theoretical modeling of the migration of a contaminant from a continuous point source in a uniform flow field. The point source appears to be centered in the vicinity of the subsurface leaching trench found at the rear of the garage. From this point, lines of equal concentration form elliptical lobes which extend northwest in the direction of groundwater flow. Slight dis-

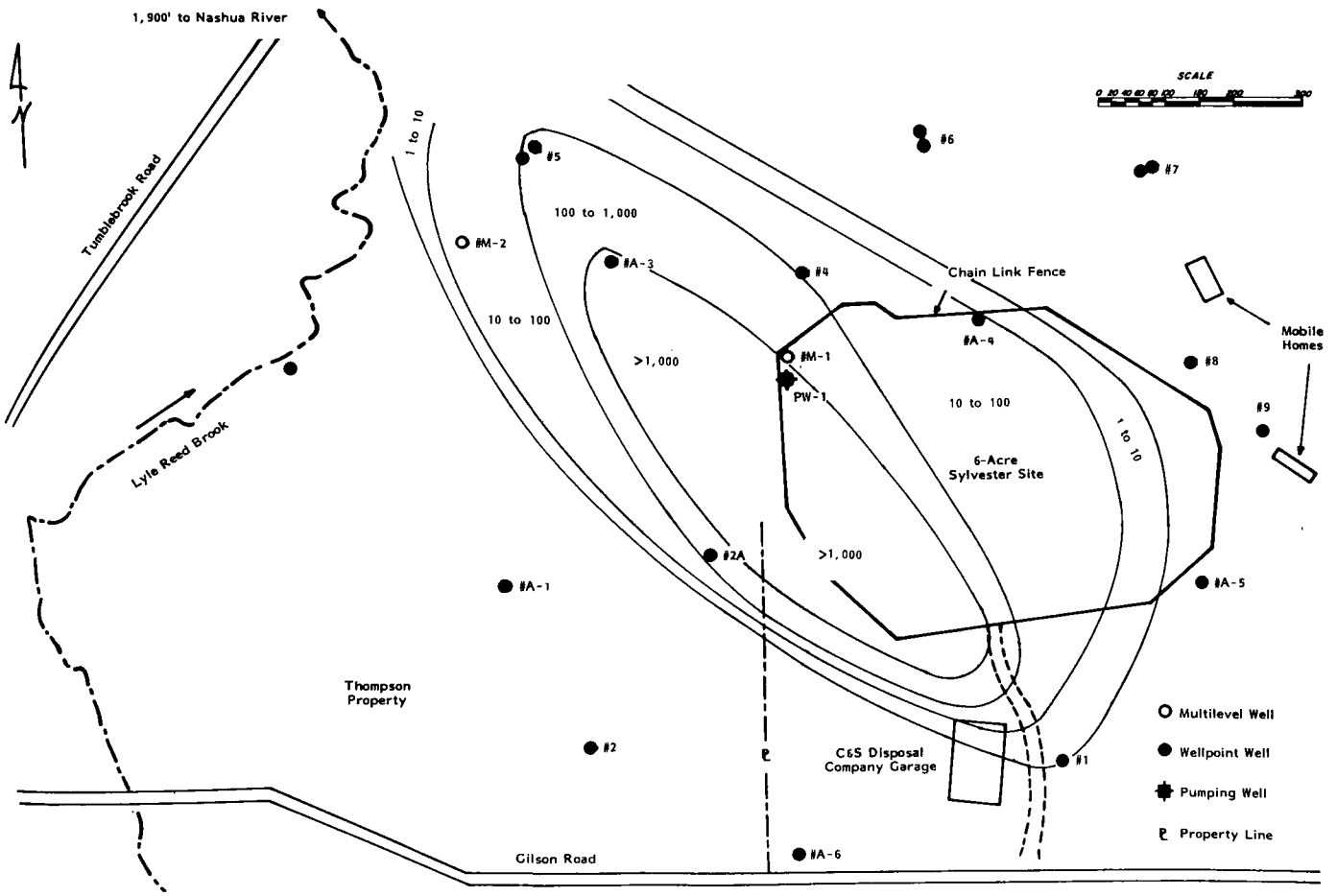

Figure 3.
Distribution of Total Volatile Organics in Groundwater
at Sylvester Site (in PPM, December 1980)

tortions of the contours are observed in the central and southern portions of disposal area and are probably the results of localized dumping incidents.

Within the main lobe of the contaminant plume, concentrations of the major constituent, tetrahydrofuran (THF) are often greater than 1,000 mg/l For the other principal volatile components of the waste, including toluened, methylene chloride, and MIBK, corresponding concentrations are generally one to two orders of magnitude lower. The distributions of these compounds and the additional volatiles detected typically display more irregularity than the corresponding distribution of THF. Localized "hot spots" or highly contaminated zones were observed for various compounds in test pits and observation wells on the premises of the site, probably indicative of "slugs" of pollutants percolating into the groundwater from the unsaturated zone.

The distribution of metallic compounds (Figure 4) observed in the vicinity of the Sylvester Site significantly differs from the pattern displayed by the volatiles. Marked lateral distortion of the theoretically elliptical concentration contours indicates either a large source area or multiple point sources. Highest concentrations of contaminants were observed in the central portions of the disposal area, suggesting that the primary source of the metals is not the liquid wastes from the leaching pit.

Although significant attenuation was observed with distance from the site, concentrations of total metals significantly higher than background values were detected up to 500 ft from the disposal area. Since metallic compounds are typically less mobile in groundwater than volatiles, this would suggest that the source of the metals is significantly older than the source of the volatiles.

Summary of the Extent of Contamination

Before discussing the various remedial alternatives, several important findings relative to the extent of the contamination problem should be summarized. While significant adverse environmental effects, i.e., degradation of surface water and groundwater quality, have already occurred in the study area, the worst is yet to come.

The groundwater contaminant plume is moving from the site toward the Nashua River at an approximate rate of from 0.8 to 1.6 ft/day. The leading edge of the plume extends to the vicinity of the unused Pennichuck Water

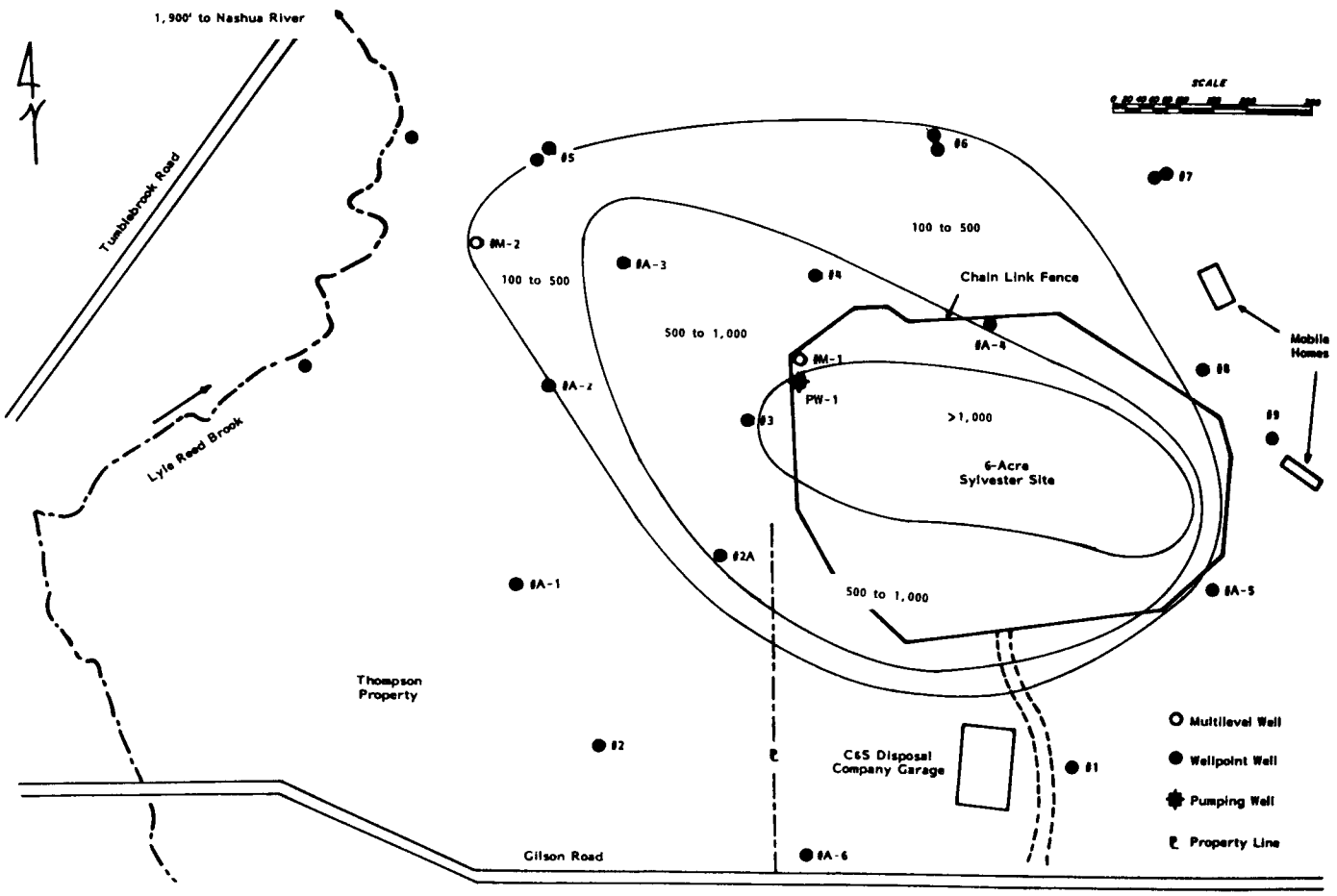

Figure 4.
Distribution of Total Metals in Groundwater at Sylvester Site (in PPM, October 1980)

Table I.
Summary of Types and Amounts of Contaminants in Groundwater and Lyle Reed Brook

COMPOUNDS/PARAMETERS	LEVELS FOUND IN WELLS NEAREST TO THE SITE[a].	LEVELS FOUND IN WELLS BETWEEN SITE AND BROOK[b].	LEVELS FOUND IN LYLE REED BROOK[c].
A. Volatile Organics (ppb)			
Vinyl Chloride*	ND to 950	---ND in this area---	---ND in brook---
Chloroethane*	ND to 320	---ND in this area---	ND to 11
Methylene Chloride*	ND to 47,500	ND to 122,500	---ND in brook---
1,1-Dichloroethane*	ND to 210	ND to 15	ND to 81
t-1,2-Dichloroethylene*	ND to 5,000	ND to 18,000	---ND in brook---
Chloroform*	ND to 1,600	ND to 31,000	ND to < 10
1,2-Dichloroethane*	ND to 890	ND to 7	---ND in brook---
1,1,1-Trichloroethane*	ND to 1,400	ND to 2,000	---ND in brook---
Trichloroethylene*	ND to 2,700	ND to 15,000	---ND in brook---
Tetrachloroethylene*	ND to 1,600	ND to 570	---ND in brook---
Benzene*	ND to 2,800	ND to 3,400	ND to < 10
Toluene*	< 10 to 100,000	< 100 to 29,000	ND to 2,700
Chlorobenzene*	ND to 2,700	ND to 1,100	---ND in brook---
Ethyl Benzene*	ND to 1,000	ND to 1,200	ND to 20
Xylenes	ND to 4,300	ND to 10,000	ND to 16
Tetrahydrofuran(THF)	44,000 to 1,200,000	4,400 to 1,500,000	< 100 to 7,650
Methyl Ethyl Ketone(MEK)	ND to 7,000	ND to 6,000	---ND in brook---
Methyl Isobutyl Ketone(MIBK)	ND to 33,250	ND to 13,000	---NC in brook---
Acetone	ND to 48,000	ND to 36,000	---NC in brook---
B. Extractable Organics (ppb)			
2- Chlorophenol*	ND to < 10	---ND in OW A-3---	---ND in brook---
2,4-Dimethylphenol*	ND to 40	---ND in OW A-3---	---ND in brook---
2-Nitrophenol*	ND to 15	---ND in OW A-3---	---ND in brook---
Pentachlorophenol*	ND to < 10	---ND in OW A-3---	---ND in brook---
Phenol*	ND to 2,700	6,464	---ND in brook---
o-Cresol	ND to 1,137	1,969	---ND in brook---
m-Cresol	ND to 864	3,672	---ND in brook---
Benzoic Acid	ND to 320	6,011	---ND in brook---
1,2-Dichlorobenzene*	ND to 88	---ND in OW A-3---	---ND in brook---
1,4-Dichlorobenzene*	ND to < 10	---ND in OW A-3---	---ND in brook---
Naphthalene*	ND to 45	---ND in OW A-3---	---ND in brook---
Bis(2-ethylhexyl)Phthalate*	ND to < 10	---ND in OW A-3---	---ND in brook---
Di-n-Butyl Phthalate*	ND to < 10	---ND in OW A-3---	---ND in brook---
Diethyl Phthalate*	ND to 47	---ND in OW A-3---	---ND in brook---
Dimethyl Phthalate*	ND to 110	---ND in OW A-3---	---ND in brook---
Pesticides*	---ND in this area---	---ND in OW A-3---	---ND in brook---
Polychlorinated Biphenyls*	---ND in this area---	---ND in OW A-3---	---ND in brook---
C. Inorganics (ppm)			
Arsenic*	.04 to 1.7	.006 to 1.05	---no data---
Barium*	< .1 to 2.5	.08 to .9	.06
Cadmium*	< .005 to .01	< .002 to < .005	< .005
Chromium(total)	.01 to .7	.01 to .19	.01
Lead*	< .01 to .5	< .01 to 1.01	< .01
Mercury*	< .0002 to < .001	< .0002 to < .001	< .001
Selenium*	< .01 to < .01	< .01 to < .01	---no data---
Silver*	.01 to .02	.01 to .01	< .01
Copper	< .01 to .6	.04 to .6	< .1
Iron	18. to 640.	16. to 580.	10.
Managanese	2.8 to 115.	.2 to 120.	4.2
Nickel	< .02 to .9	.2 to .9	.1
Zinc	< .005 to 20.5	.09 to 9.	.02
D. Other Parameters			
pH	5.9 to 6.8	5.9 to 6.8	---no data---
Specific Conductance (uMHOs)	250. to 4,092.	228. to 9,517.	---no data---
Total Organic Carbon (ppm)	12. to 7,600.	6. to 4,700.	---no data---
Chemical Oxygen Demand (ppm)	711. to 19,300.	---no data---	---no data---
Total Phenolics (ppm)	.298 to 18.5	< .005 to 25.2	---no data---

ND = not detected; NC = presence suspected, but not confirmed; * = a priority pollutant.

a. Wells nearest the site are: #2A, #3, #4, #A-4, and #M-1.

b. Wells between site and brook are: #A-2, #A-3, #M-2, and #5-D.

c. Brook sampling stations represented in table are: NHDB 04, 04A, 05, 05A, and 06. Inorganics data are available only for station NHDB 04A along this portion of Lyle Reed Brook.

Department well located between Tumblebrook and Trout Brook Roads. Contaminants (in groundwater) that have already moved to and beyond Lyle Reed Brook are, for all intents and purposes, not recoverable. Thus, the risk of organic contamination reaching private supply wells along Route 111 is high regardless of what is done at the site.

The estimated travel time for groundwater to move from the Pennichuck well to Route 111 is from 1 to 3 years (travel time to the Nashua River is estimated at from 2 to 5 years). It is also possible that contaminated groundwater is moving in bedrock joints. Thus, any bedrock wells located downgradient of the disposal site are in jeopardy.

The most contaminated zones extend from the disposal site to within from 100 to 200 ft of Lyle Reed Brook. If not prevented, these zones of highest groundwater contamination will reach Lyle Reed Brook within a year; the Pennichuck well in 1 to 4 years; Route 111 in 2 to 6 years; and the Nashua River in 3 to 9 years. Furthermore, if contaminants are not prevented from leaving the disposal site, then groundwater contamination between the site and the Nashua River will steadily increase for several years and then remain at high levels for an indefinite period.

Since a major portion of the groundwater plume is discharged to Lyle Reed Brook, pollutant concentrations in the brook would also increase for several years before stabilizing at high levels for an indefinite period. Of course, any increase in the pollutant load in the brook will be reflected in the Nashua River as well.

REMEDIAL ACTION ALTERNATIVES

During this investigation, several alternative measures available for mitigating the environmental and public health threats posed by the Sylvester Site were considered. These included:

- No Action—natural flushing in combination with frequent water quality monitoring
- In-place hydrologic isolation of contaminated soil and groundwater zones
- Interception and treatment of contaminated groundwater in the area between the site and Lyle Reed Brook
- Excavation of the disposal site for secure landfill disposal either in an existing facility in upstate New York, or in a new facility that would have to be built in the Nashua area for that purpose
- Combinations of the above

The various alternative remedial action measures are briefly discussed below.

No Action (Natural Flushing)

Under certain conditions, an appropriate means of dealing with an existing soil and groundwater contamination problem is to take little or no direct preventative action, thereby relying upon natural processes to dilute, disperse and degrade the contaminants over an extended time period. In terms of environmental protection, a no action policy is the least desireable alternative due to the high potential for adverse impacts on surface water and groundwater. The key unknowns are the magnitude of subsequent stream and groundwater contamination; and the time-span required before contaminant levels in water would decrease to "acceptable" levels. For the Sylvester Site, the "no action" option was considered to be unacceptable due to the extremely high contamination levels in groundwater, the mobility of the contaminant plume and the potential for long-term adverse environmental and public health conditions.

In-Place Hydrologic Isolation

Hydrologic isolation options for the Sylvester Site include the installation of a slurry cut-off wall around contaminated zones (possibly with bedrock grouting) and installation of an impermeable cover over the contaminated area. A slurry cut-off wall is a vertical, essentially impermeable barrier installed to prevent groundwater inflow and outflow from the contaminated zone. A slurry cut-off wall installed to surround contaminated zones would prevent clean groundwater moving above rock from becoming contaminated, and would prevent further leaching of contaminated groundwater from the isolated area.

There are two viable options for the location of the slurry trench cut-off wall around the site (see Figure 5). The first option would isolate only the immediate area of chemical dumping. The second option would encompass all of the area within the plume from the site to the edge of a bedrock valley which runs north-south roughly parallel to Lyle Reed Brook.

The second slurry wall option would isolate the bulk of the contaminant plume, while the first would have no remedial impact on the portion of the contaminated zone which has already moved beyond the confines of the site. In conjunction with the slurry cut-off wall, an impermeable surface cap consisting of either impervious soil (i.e., clay) or a synthetic liner would be required to prevent infiltration of precipitation through the enclosed waste.

Hydrologic isolation by a combination of a slurry wall and injection grouting of the bedrock carries the containment alternative discussed above one step further. In addition to the cut-off wall within the overburden and the impermeable surface cap, fractured bedrock along the designated perimeter line would be sealed by the injection of a bentonite/cement grout under high pressure. The ensuing reduction of rock permeability would be accompanied by a decrease in contaminant migration. At the Sylvester Site, bedrock has been cored in only one location (boring M-1) and was found to be moderately fractured.

The slurry wall/grout curtain alternatives would retard essentially all movement of contaminants across the contained area. Over a period of time, however, there is the possibility of leakage through the cut-off walls. For this reason, a monitoring system would be needed. An intrinsic problem with any hydrologic isolation system, is the inability to alleviate contamination which has already moved off-site. The limits of the containment area would have to be expanded beyond practical proportions to isolate all contamination associated with the site.

Groundwater Interception and Treatment

A preliminary assessment of the technical feasibility and estimated costs of an above-ground treatment system for renovating the contaminated groundwater underlying the Sylvester Site was prepared through a laboratory-scale treatability study. This study was conducted with assistance from Environmental Resource Associates, Inc. The purpose of the laboratory-scale treatment study was to develop a "first-cut" assessment of the treatability of the highly contaminated groundwater at the site. As such, the study was confined to a small number of alternative water treatment methods tested under a limited set of operating conditions. Using an integrated batch testing approach, the pollutant removal effectiveness of two alternative treatment process trains were evaluated:

- Air stripping followed by neutralization/precipitation followed by activated carbon adsorption
- Air stripping followed by neutralization/precipitation followed by biological treatment

Contaminated groundwater for the treatability study was obtained during the aquifer pumping test conducted during the period January 28-February 2, 1981. The raw groundwater sample was collected toward the end of the pumping in order to base the treatability assessment on feedwater that would be most representative of the effluent produced under extended pumping conditions.

Using the information developed during the laboratory-scale evaluations, preliminary design and cost estimates for a full-scale, on-site treatment system were developed. The conceptual treatment system proposed for the Sylvester Site groundwater is illustrated in the block flow diagram in Figure 6. Longer duration and more operationally flexible pilot-scale testing will be needed prior to final treatment system design. Among the key uncertainties to be resolved in pilot-scale testing area the need for a metals removal step and the optimum operating conditions for the biological and carbon adsorption processes.

Total Removal Alternatives

For comparison with the remedial measures outlined above, preliminary cost estimates were prepared for the so-called total removal options involving excavation of the disposal site for secure landfill disposal. Assuming an average depth of removal of 10 ft over the 6-acre site,

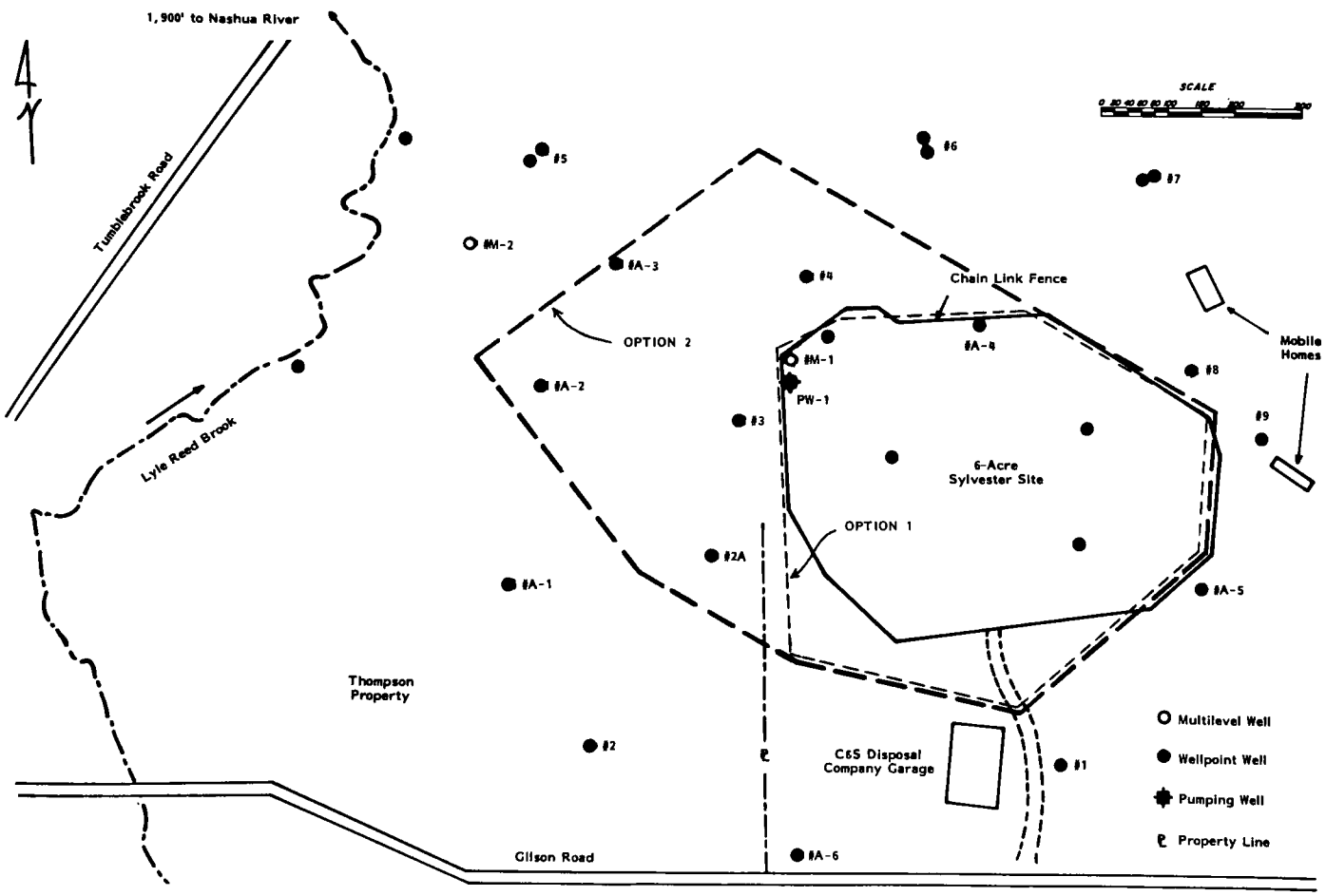

Figure 5.
Slurry Wall and Cap Isolation Options for Sylvester Site

the costs to excavate, transport and dispose of the material in an existing secure landfill facility in upstate New York and to design and construct a new secure landfill disposal facility in the Nashua area were estimated. The conditions at the Sylvester Site are such that, even with removal of the disposal site, an extensive groundwater interception and treatment system would be needed as part of a total removal plan.

RECOMMENDED REMEDIAL ACTION PLAN

The recommendation of the GHR/GZA Project Team was that the final remedial action plan for the Sylvester Site include both in-place hydrologic isolation of contaminated zones and interception of contaminated groundwater for on-site treatment. Specifically, it was recommended that the final plan consist of:

(1) Design and installation of slurry trench cut-off wall Option 2 to completely surround approximately 12.5 acres of the contaminated zone, including the 6-acre disposal site
(2) Design and installation of an impermeable top-seal over the isolated zone to prevent infiltration of rainwater
(3) Design and installation of a groundwater interception and treatment system to renovate that portion of the contaminated aquifer remaining outside the isolation zone
(4) Installation of 6 to 8 new multilevel groundwater observation wells to monitor the effectiveness of the slurry wall system and track the contaminant plume in the region between Lyle Reed Brook and the Nashua River

In addition to the design and implementation of the slurry wall/treatment system it was recommended that:

(1) Lyle Reed Brook be posted and fenced to prevent human exposure to the contaminated stream and
(2) city water be provided to those residences along Route 111 between Countryside Drive and Jensen's Trailer Park who now rely on private wells for drinking water.

The severly degraded condition of the groundwater in the area from the site to Lyle Reed Brook requires that the total remedial action plan for the site include groundwater interception for on-site treatment. The groundwater interceptor wells would be located downgradient of the selected slurry wall. Through strategic location of the wells, with respect to both areal orientation and depth, a minimal amount of contaminated groundwater flow will

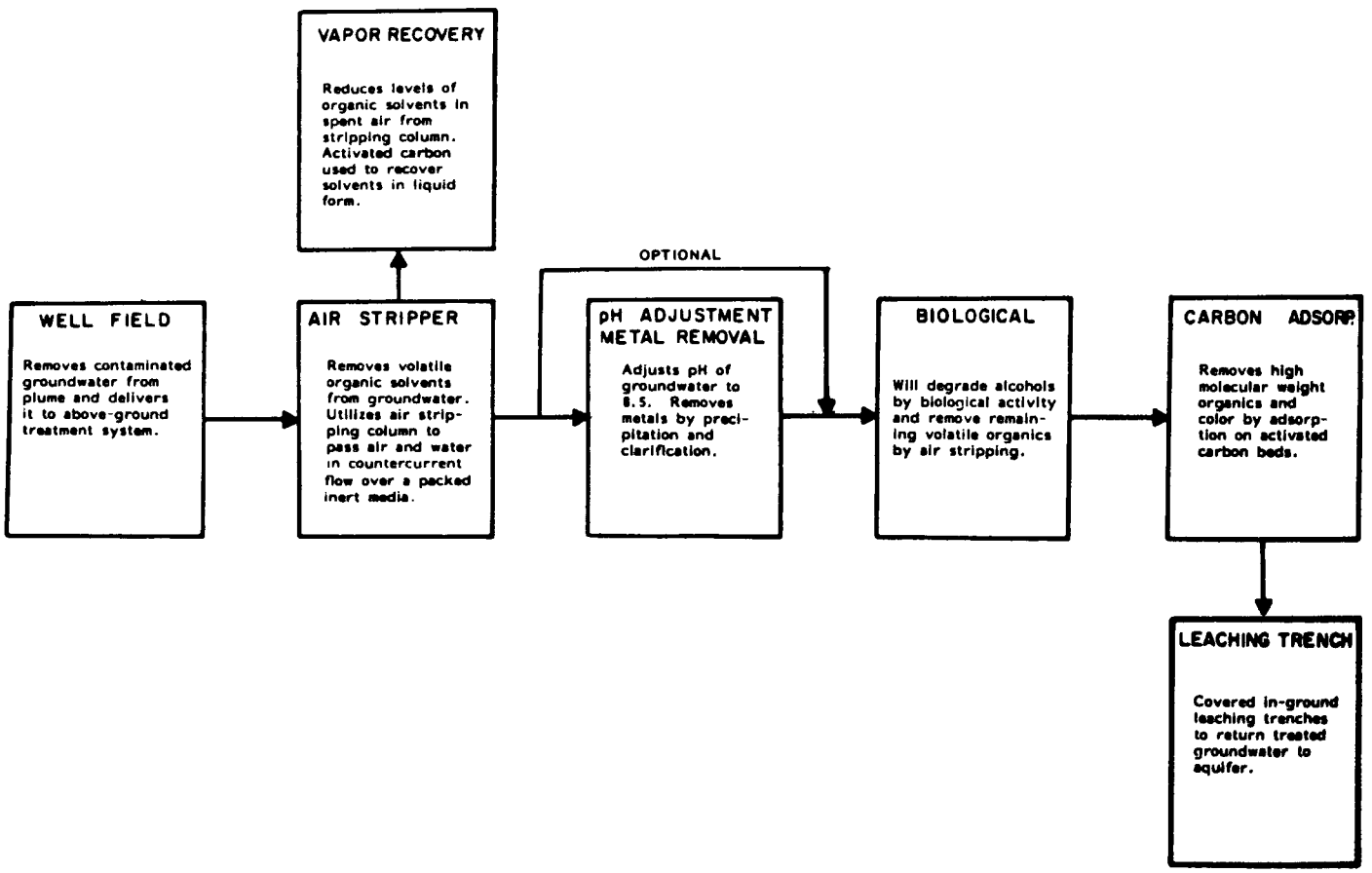

Figure 6.
Block Flow Diagram of Conceptual Treatment System for Groundwater Renovation at Sylvester Site, Nashua, New Hampshire

pass through the interception system to downgradient areas.

The principal variables with the interception and treatment scheme are:

(1) the treatment processes to be used,
(2) the degree of pollutant removal desired and
(3) the length of time that the treatment plant would have to be operated.

Based on aquifer volume calculations and interceptor system flow rates, the treatment periods required to treat given multiples of the initial contaminated aquifer volume were estimated. This was done for the two slurry wall options and the additional case of interception and treatment without hydrologic isolation. The results are provided on Table II. The effluent from the treatment plant would be recirculated back through the aquifer by discharging into a subsurface leaching trench to be located outside the slurry wall.

Table II.
Estimated Treatment Periods Required for Various Design Flow Rates and Hydrologic Isolation Options

Remedial Option	Pumping Rate (GPM)	Treatment Periods in Years Required for Various Aquifer Volumes 1	3	5
Treatment Without Hydrologic Isolation	25	4.3	12.9	21.5
	50	2.2	6.6	11.0
	100	1.1	3.3	5.5
Slurry Wall Option 1	25	2.1	6.3	10.5
	50	1.0	3.0	5.0
	100	0.5	1.5	2.5
Slurry Wall Option 2	25	1.0	3.0	5.0
	50	0.5	1.5	2.5
	100	0.25	0.75	1.25

Notes: 1. A 1-volume treatment period represents time required to pump a volume equal to the initial contaminated aquifer volume at given pumping rate.
2. Treatment periods represent times required to treat given multiples of initial contaminated aquifer volumes. For treatment without hydrologic isolation, the initial volume is 60 million gallons; for slurry wall option 1, the initial volume is 30 million gallons; and, for slurry wall option 2, the initial volume is 15 million gallons.

The critical aspect of the slurry wall alternative is the degree of contaminant isolation achieved. The major design consideration for the slurry wall will be to formulate a slurry mixture that will have not only the necessary very low permeability, but also the ability to resist chemical reaction and breakdown by the organic contaminants. The installation of an impermeable surface over the isolated area will prevent the build-up of liquids inside the slurry wall, thereby preventing development of a hydraulic head to promote leakage. Proper design and installation of the isolation system should result in minimal leakage through the slurry wall, and any leakage that does occur would be diluted by large volumes of groundwater.

It is anticipated that any leakage of contaminants through the bedrock underlying the recommended isolation area will be minimal due to absence of a driving hydraulic head. However, only an extensive program of bedrock drilling and permeability testing would reveal the quantities of flow (if any) from the area through bedrock units. Bedrock grouting was not recommended since the available data did not justify the expenditures that would be necessary.

Cost Effectiveness Analysis

To evaluate the cost-effectiveness of the recommended remedial action plan, the methodology used by the U.S. Environmental Protection Agency for municipal wastewater treatment projects was employed. Using this standard approach, the various remedial action alternatives for the Sylvester Site were evaluated in terms of their comparative present worth.

To provide a common basis for comparing the costs of the various treatment system alternatives, it was assumed that groundwater treatment would be provided for at least as long as necessary to treat five multiples of the initial contaminated aquifer volume (see Table II). This assumption was necessary in order that each alternative slurry wall/treatment system have an equivalent remedial benefit (i.e., treat five initial aquifer volumes). This assumption also establishes the approximate time period over which the treatment plant would have to be operated under each alternative, and thus sets the estimated number of years for which operating and maintenance costs would be incurred.

Using this methodology, the costs of the various alternatives were estimated on a comparative present worth basis; the results are presented in Table III. The present worth cost comparisons indicate that the recommended remedial action plan (Item 5a.) is the most cost-effective alternative.

By basing the comparative cost analysis on treating five multiples of an initial contaminated aquifer volume, the evaluation has ignored aquifer recharge through rainfall infiltration. In actuality, infiltration outside of the slurry wall and cap system will probably require a 50 gal/min interception rate under Option 1. As shown in the above tabulation, even if a 50 gal/min plant is combined with slurry wall Option 1 and is operated for only 5 years, the recommended Option 2 system still has a lower present worth. With the Option 2 slurry wall and cap, a 25 gal/min pumping rate will be sufficient to intercept the contaminant plume.

CURRENT STATUS

The recommended remedial plan was selected for implementation in late August 1981, the design phase of the slurry wall and cap isolation system was being undertaken and plans for pilot-scale treatment system testing were being formulated. Also, an interim (emergency) groundwater interception and recirculation system to reduce contaminated groundwater discharges to Lyle Reed Brook was being designed. These design efforts are being conducted

Table III.
Summary of Remedial Action Alternatives and Estimated Costs, Sylvester Site, Nashua, New Hampshire

DESCRIPTION OF REMEDIAL ALTERNATIVES	ESTIMATED COSTS
1. Total removal of dump site for secure landfill disposal out-of-state, and intercept and treat aquifer for 20 years @ 50 gpm (AS-N/P-BIO-GAC)	$ 19,000,000 to $ 28,500,000
2. Total removal of dump site for disposal in new secure landfill in NH, and intercept and treat aquifer for 20 years @ 50 gpm (AS-N/P-BIO-GAC)	$ 13,000,000 to $ 19,500,000
3. Aquifer interception and treatment alone for 20 years @ 50 gpm (AS-N/P-BIO-GAC)	$ 9,000,000 to $ 13,500,000
4. Slurry cut-off wall and clay cap Option 1 to isolate approximately 7.2 acres, with	
a. aquifer interception and treatment for 10 years @ 25 gpm (AS-BIO-GAC)	$ 3,420,000 to $ 4,850,000
b. aquifer interception and treatment for 10 years @ 25 gpm (AS-N/P-BIO-GAC)	$ 5,170,000 to $ 7,500,000
c. aquifer interception and treatment for 5 years @ 50 gpm (AS-BIO-GAC)	$ 3,110,000 to $ 4,360,000
d. aquifer interception and treatment for 5 years @ 50 gpm (AS-N/P-BIO-GAC)	$ 4,690,000 to $ 6,740,000
5. Slurry cut-off wall and clay cap Option 2 to isolate approximately 12.5 acres, with	
a. aquifer interception and treatment for 5 years @ 25 gpm (AS-BIO-GAC)	$ 2,770,000 to $ 3,810,000
b. aquifer interception and treatment for 5 years @ 25 gpm (AS-N/P-BIO-GAC)	$ 3,850,000 to $ 5,430,000
c. aquifer interception and treatment for 3 years @ 50 gpm (AS-BIO-GAC)	$ 2,720,000 to $ 3,670,000
d. aquifer interception and treatment for 3 years @ 50 gpm (AS-N/P-BIO-GAC)	$ 3,780,000 to $ 5,280,000

Notes:
1. Costs are comparative present worth values.
2. Present worth of estimated annual treatment plant operating and maintenance costs were computed using an interest rate of 7-3/8 percent as provided by U.S. EPA, Region I, Boston, MA.
3. Treatment plant assumed to operate for number of years necessary to treat 5 multiples of the initial contaminated aquifer volume.
4. Salvage values assumed to be zero.
5. AS = air stripping; N/P = neutralization/precipitation for metals removal; BIO = biological lagoons; GAC = granular activated carbon adsorption.

by GHR Engineering Corporation, again in conjunction with Goldberg-Zoino and Associates.

ACKNOWLEDGEMENTS

The successful investigation of the Sylvester Site required a high level of cooperation and commitment from many individuals. While it would be inappropriate to identify all major contributors to this effort, it is appropriate to acknowledge the guidance and cooperation received from Mr. Carl Eidam of the U.S. EPA and Mr. Michael Donahue of NHWS & PCC.

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CASE HISTORIES IN HANDLING UNKNOWN HAZARDOUS MATERIALS AT DUMP SITE LOCATIONS

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INTRODUCTION

The author's purpose in writing this paper was to present a series of case histories involving the cleanup of hazardous dump sites where the type or degree of hazard or some of the materials handled were unknown.

Each of the three case histories involved a different set of circumstances requiring decisions and techniques to determine as close as possible what was the nature of the problem, how best to handle or control the material and then, how to dispose of it.

CASE HISTORY #1
CHEMICAL CONTROL—NEW JERSEY

This location, at the beginning of the remedial action, presented a formidable challenge to state and cleanup individuals, mainly due to the wide variety of unknown chemicals and the extreme danger involved in handling them.

Initially, there were almost 500,000 laboratory size containers and bottles, indiscriminately mixed together in drums, cartons or stacked on tables. They ranged from unknown chemicals to correctly identified materials.

Classification System

The breakdown of each container into a specific category, not only for classification purposes, but also for disposal, created a situation which called for broad grouping with many divisions. Into each division, were subdivisions, which would allow the grouping of like materials and make it easy to combine those subdivisions so they could be disposed of at a secure landfill based upon the limitations and groupings required by the disposal company. For example, acids were classified as follows:

Class A. Inorganic
1. Fuming (liquid)
2. Non-fuming (liquid)

Class B. Organic Acids (liquid)

Class C. Crystalline

The disposal protocol called for taking Class A items and placing them into Group A (compatibility grouping of a disposal company) for disposal of laboratory packs. Class B items would be placed into Group D and so forth. It would be possible for grouping into any disposal company's compatability grouping. Following the need for classification was a necessity for record keeping, sampling and coding.

Record Keeping

This is probably one of the most tedious requirements at any dumpsite location. Record keeping at a major cleanup site requires the services of at least a full-time person and the cooperation of everyone.

All of the items that were located which were considered extremely hazardous (highly toxic, very unstable, explosives or highly reactive) had to be noted in the log book along with those items requested by the state or federal agencies which were followed with a chain-of-custody (evidentiary) protocol.

Coding of Drums

The coding of drums is not a problem when there are only several hundred drums or batches of drums with the same characteristics. When there are 50,000 to 60,000 drums with many different physical and chemical properties, then one has to establish a more sophisticated system.

At Chemical Control, a six digit coding was worked out with the following design. Starting inside the building with #1, then going in a clockwise position, Front #2, Back #3, Right Side #4, Left Side #6. Any materials from a source off the property would be #6. The next 5 numbers were the drum numbers for samples, identification and statistical purposes. In addition, each disposal location was coded with a letter beginning with A (for SCA). This system resulted in a drum so marked that one could determine exactly where it came from and where it was going. For example: DRUM #201109A. This designation meant that the drum came from the front of the building, was drum #1109 and was sent to SCA for disposal.

It is important to set up a clear, simple means of reviewing drums for statistical study and also as a means of tracking the drums.

All of the laboratory pack drums were packed with all bottles or containers identified and grouped into classes. Each drum had a list of contents which could be verified by subsequent inspection of the disposal company. This made for rapid evaluation by the disposal companies after the lists had been checked and verified. Once the system was set up, the transportation, checking and disposal proceeded quite rapidly.

Sampling

Sampling was a tedious and difficult project to set up and follow due to the large numbers of drums and solid materials that were sampled. Various sampling devices were used, ranging from a 40 in. by 3/8 in. PVC tube for drum samples to turkey basters made of plastic for the semi-liquid materials. There were also composite samples for use in a CG unit, which were collected in an 8 oz. bottle, then transferred to a 30 ml plastic container. It was difficult to write a six digit number with a wax crayon on a vial this small, so numbers had to be written on a plastic bag in which the vial was placed. Solids and liquids were collected in a variety of ways and coded with the same numerical system used on the drums.

Unexpected Situations

There was always a surprise or two each week at the site. Sometimes there were cyanide drums or acid drums leaking, evolution of H_2S gas near the building, drums containing metallic sodium and sodium anhydride would explode after a heavy rainstorm, malodorous leaks of multi-colored oil, greases and plastics periodically found their way out of the stacks of drums.

After a few of these episodes, it became a regular practice of the local Fire Department to find out if they could use water or sand and soda ash on a fire and what type of safety equipment should be utilized.

An explosion and fire occurred at the site about one year after the work commenced (and has been described in another paper in these Proceedings). Today it has been cleaned up and no longer is a threat.

CASE HISTORY #2 (PICILLO FARM, RHODE ISLAND)

This situation was different from Chemical Control because most of the drums were buried or partially covered in several large trenches filled with several feet of water. The area was remote and access to the site itself was limited. Working with state officials to determine the best plan to remove some drums that appeared to be sodium or aluminum anhydride called for an initial delay of six to eight weeks until the ground could dry up.

Sodium anhydride, when contacted with water, reacts violently with a tremendous heat release. Hydrogen gas is also released and a hot mixture containing caustic soda remains. When water is dumped into sodium anhydride, it is impossible to control the speed of reaction, hence it reacts in an explosive-like manner. For this reason, it was necessary to wait until the water had disappeared and the weather improved. The hydrogen gas, if not dissipated, could collect and explode.

The plan, worked out with the State Department of Environmental Management, was to remove the drums from the ground, sample and identify the contents, over-drum, if necessary and store for future disposition.

The drums were removed mechanically after the ground dried out and the surface soil was removed, if necessary, sampling was done with a 40 in. thief, the sample placed in plastic sample jars with screw caps. Analysis indicated both used and unused sodium anhydride were in the drums.

Temporary storage was in a box trailer with more permanent storage at an old ammunition silo at the National Airguard Air Station.

There were two options for disposal:

(1) React under controlled conditions to end products which could be disposed of locally. Cost between $350-$500/drum.
(2) Ship to an approved disposal site located in Nevada. Cost of disposal and transportation approximately $800-$1,000/drum. This method was ultimately selected due to the limited number of drums and disposal out-of-state.

Later on, as the monies became available, a more extensive cleanup at Picillo Farm was initiated by the state of Rhode Island. Most of the drums were buried or partially buried in shallow cells scraped out by a bulldozer, then dirt was pushed over the drums. Due to the geology of the area, the cleanup had to be done quickly to prevent both surface and groundwater contamination.

CASE HISTORY #3 (KIN BUC LANDFILL—NEW JERSEY)

This landfill situation differed from the other two because all of the drums and materials were completely covered with soil to a height of 80 ft above grade. The locatioan of the site was also a problem, since there were no good access roads to the area in which the work had to be performed.

Initially, the plan was to treat oily wastes which were leaching out periodically and finding their way through the marshlands to the Raritan River. The USCG and EPA had monitored this situation and decided to attempt to control the leachate which resembled an ongoing oil spill.

Workers sampled the deposits which were sent for analysis. In the meantime, since there was some old technical data available, it was examined as a logical safety protocol. GS/MS reports on the old samples showed 50 to 60 different organics. The atomic absorption reports indicated the presence of heavy metals, especially those highly tosic to humans and water supply systems: lead, cadmium, copper, chromium, zinc, barium and lanadium.

The old reports also indicated small amounts of PCBs, along with many benzene ring homologs. This information indicated that the initial work should be done with full face respirators, as well as protective suits, gloves, boots. Later on, as the level of PCBs and other phenolic and naphthenic compounds were quantified, the workers had to change their safety protocol.

The first step was to remove debris, set up filter fences and install both a disposable and a permanent oil spill boom. Due to the location of some of these boom and filter barriers, which had to be monitored daily, small boats were used to negotiate the marshlands. This was especially true after a heavy rain when the leachate volume increased.

When the volume of leachate began to reach 2 to 3 gal/min with a well defined black organic layer, skimming into drums was done in an effort to remove more of the organic layer of leachate instead of allowing it to course its way through the swampy marshlands into the Raritan River. The work recently has been accelerated and modified in an attempt to:

(1) Concentrate the leachate
(2) Treat the leachate, *in situ*
(3) Consider long term cleanup with either carbon or incineration

With a potential for a high flow rate of leachate, depending on local hydraulic conditions, Kin Buc will be a problem of immense proportions for years to come. Creating Kin Buc took many years, cleaning it up will take as long, if not longer.

SUMMARY

The three case histories presented, represent hazardous dumpsites in which the materials were:

(1) Above ground
(2) Partially buried
(3) Completely buried

While it is an oversimplification to state that each and every landfill has to be approached differently, there is no doubt that working with materials that are above ground is easier, although there is an inherent danger of spills and percolation into groundwater.

Buried materials still present a strong problem of aquifer contamination, however, this process may be slowed down depending on the nature of the materials, the condition of the containers or drums and the percolation rate of the soil surrounding the material. Those drums, partially buried, can exhibit a higher corrosion rate due to the metal/ground interface which causes a higher concentration of electrolytes to occur at the interface.

Of the three sites mentioned, the last one (Kin Buc) is still ongoing with a great deal of work to do. The capping of the dome-like dump reduced the percolation through the infrastructure of the dump. The problem of a varying effluent occurs with higher concentrations of organics and soluble inorganics in the leachate. This produces a paradoxical situation in that there is less leachate, but of higher toxicity.

CONTAMINATION CONTROL AT ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO

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INTRODUCTION

In response to requirements to contain or clean up contamination at Rocky Mountain Arsenal (RMA), Denver, Colorado, the Department of the Army (DA), began a program to mitigate the contamination problem at that installation in 1975. The approach initially taken by DA was to contain contamination at the installation's boundaries.

In 1978, a pilot wastewater treatment system began operations at the northern arsenal boundary to remove organic contamination from groundwater. The pilot system proved successful. It has been expanded to intercept all contaminated groundwater crossing that boundary. A similar system is also being designed to intercept all contaminated water crossing the northwest boundary. This paper describes the history and operation of these containment systems.

HISTORY OF THE CONTAMINATION PROBLEM

Established in 1942, RMA occupies 17,000 acres of land 10 miles northeast of Denver, Colorado. The northern and eastern borders are bounded primarily by agricultural land. Agricultural lands, an industrial area, and a housing development are located adjacent to the southern boundary. Residential areas are located along the installation's western boundary (Figure 1).

Within eight square miles north of the northern arsenal boundary, the land is primarily agricultural. Population density is 10-15 people per square mile. Water is supplied by approximately 90 wells. Thirty percent of these wells use water from the aquifer affected by contamination from the arsenal. Irrigation, stock, commercial and domestic wells are affected.

Constructed to support World War II, RMA manufactured and assembled toxic chemical end items and incendiary munitions. At the end of the war, RMA was placed on standby status. A small number of activities including demilitarization of obsolete hazardous and toxic munitions occurred at the arsenal until the beginning of the Korean War.

In 1946, parts of the installation were leased to private industry for chemical manufacturing. The major lessee, Shell Chemical Company (Shell), had used a large portion of these original chemical manufacturing facilities since 1952. That company has made additions to their leased facilities for manufacturing pesticides.

The arsenal was selected as the site to construct a facility to manufacture GB, a highly toxic, non-persistent nerve agent. This production facility was completed in 1953. Manufacturing of this chemical agent occurred until 1957, but filling of the munitions continued until 1970. RMA produced a biological anticrop agent from 1959-1962, and emptied cyanogen chloride and phosgene bombs between 1956-1969.

Unlined Lagoon Used

Industrial waste effluents resulting from past DA and lessee manufacturing activities were initially discharged into an unlined basin immediately north of the original "plants area" called Basin A. Basin A received these industrial wastes until 1957. When the GB facility was placed in operation, this basin was enlarged and new unlined basins were constructed northwest of Basin A (Figure 2).

In the summer of 1954, some farmers northwest of the arsenal complained that groundwater used for irrigation had damaged their crops. Precipitation was much less

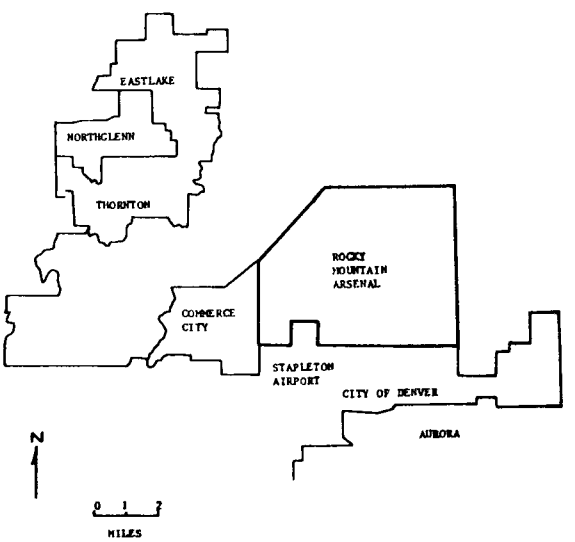

Figure 1.
Vicinity Map of RMA

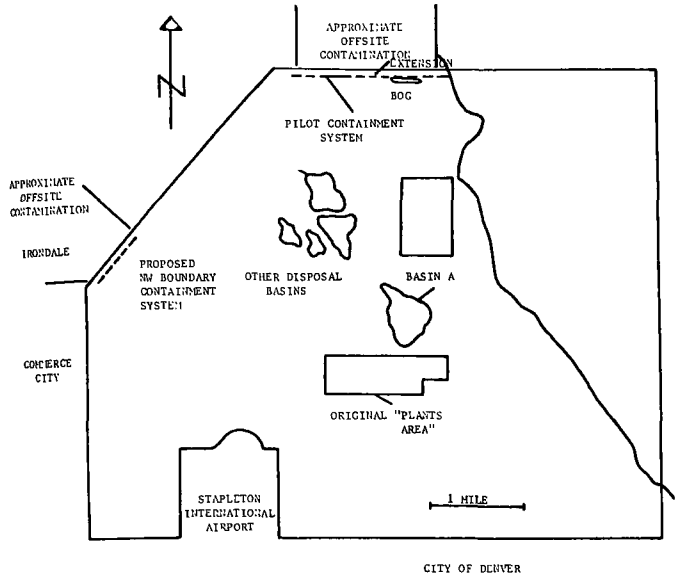

Figure 2.
Location of Features at RMA

than normal in 1954 and increased pumping from shallow irrigation wells occurred to support crop production. In response to these complaints and subsequent claims for damage, DA:

(1) Retained a firm of consulting engineers to investigate the problem of possible groundwater contamination described by the farmers.
(2) Requested the U.S. Geological Survey (USGS) to study water quality on RMA and in adjacent farms.
(3) Contracted the University of Colorado to initiate plant bioassay, geological and chemical studies to determine the identification and source of any contaminants causing crop damage.

Some stock and irrigation wells were abandoned because of high salinity, and compensation was paid to a few landowners for crop damage. Evidence suggested that high salinity resulting from groundwater migration from unlined basins on RMA was the cause of the problem.

New Storage Constructed

As a result of this investigating, Basin F was constructed. Built to hold 240 million gallons, it covered 93 acres. It was lined with an asphalt liner covered with one foot of soil. Upon completion in 1957, all industrial wastes produced by DA or Shell at the arsenal were deposited in Basin F. An attempt was made to transfer residues from the unlined basins into Basin F (Figure 2).

Contaminants Detected

In 1974, organic compounds were detected crossing the northern arsenal boundary. Diisopropylmethyl phosphonate (DIMP) and dicyclopentadiene (DCPD) were detected in surface water draining from a man-made bog at the north boundary of the installation. DIMP is a persistent material produced in small quantities during production of the GB nerve agent. It is not very toxic, but it is an excellent indicator compound because it originates from a single activity. DCPD is a chemical used by Shell in production of some of its pesticides. Though not very toxic, it has an extremely foul odor at extremely small concentrations making potable water in which it is contained unfit for consumption.

DA initiated several actions after detecting these compounds. A previously existing groundwater monitoring program was expanded. Tests for DIMP, DCPD, and several other compounds were added. These latter compounds were chemicals that could have been disposed of as a result of manufacturing activities at the arsenal. A dike was built to stop off-post discharge of surface water from the bog. The toxicological impacts of DIMP and DCPD were also evaluated.

In December 1974, the Colorado Department of Health (CDH) detected DIMP at less than one μg/l in an off-site well. The detection of both DIMP and DCPD in off-site surface water and subsequent discovery of DIMP in off-site groundwater led to issuance of administrative orders by the CDH in April 1975. These orders required an immediate stop to off-post surface and subsurface discharge of these contaminants, preparation of a plan to prevent their further discharge and implementation of a water quality monitoring program to demonstrate compliance with the first two requirements.

Subsequent to issuance of these administrative orders, other organic compounds have been detected at the northern boundary. The most significant of these compounds is dibromochloropropane (DBCP), a soil fumigant manufactured by Shell. DBCP has been reported to cause male sterility and is a possible carcinogen. A drinking water standard has not yet been established for this chemical.

In May 1980, contamination of groundwater off-post northwest of the arsenal (Figure 1) was detected in wells. Potable water sources contained between 0.2-0.4 μg/l DBCP.

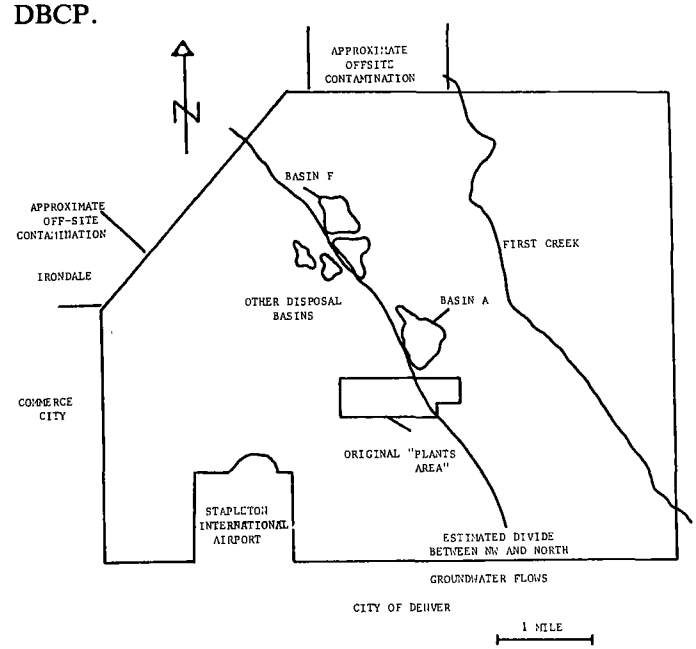

Figure 3.
Estimated Divide between Northwest and North Groundwater Flows

GEOLOGY AND HYDROLOGY

The bedrock consists of shale and claystone with lenses of siltstone and sandstone. Alluvium and windblown deposits cover this bedrock. Silty clay, silt, sand and gravel form these unconsolidated deposits of alluvium. In many places, wind-deposited silts and sand cover this alluvium. The alluvium ranges in thickness between 5-80 feet. The alluvium contains the majority of the highly permeable materials.[1,3,6]

Based on previous geohydrologic studies, groundwater flow is believed to be continuous through the shallow RMA aquifer.[4,6] If the alluvium is dry, water flows in the upper bedrock formation.[3,6] North of the original "plants area," water flows in a northerly, northwesterly and northeasterly direction. Water underneath Basin A flows to either the northwest or north boundary of the arsenal[4,6] (Figure 3). Basin A received large quantities of potentially hazardous contaminants.

Groundwater flow across the northern boundary occurs in both the alluvium and sands in the bedrock. The aquifer is defined as all sand and gravel, gravel and sand units that are unconfined above an impermeable barrier. The alluvium and sands are hydraulically connected and should be considered to be one hydrogeologic unit. Groundwater flow, however, occurs primarily in the alluvium because permeability values in the coarser sand and gravel strata of the alluvium is much greater than the permeability of the silty and clayish sands.[5]

Permeabilities of sand, and sand and gravel units were estimated to be 3,000 gpd/ft^2 (400 ft/day) and 5,000 gpd/ft^2 (668 ft/day), respectively, based on aquifer tests. Units containing appreciable quantities of silt had permeabilities of an order of magnitude less. Units containing clay had negligible permeability compared with permeability of sand, and sand and gravel units.[7]

Aquifer thickness varied from zero on bedrock highs to about 40 feet about 1 mile south of the northern arsenal boundary.[3,8] Analysis of cross-sections indicated that this aquifer is generally continuous.[3,8] The aquifer thickness consists of permeable materials above and below the water table. The saturated thickness was determined by calculating the difference between the potentiometric and bedrock surface. The potentiometric surface was initially evaluated in 1978, before construction and operation of the contamination containment system. It was generally toward the north with an average gradient of 0.006 ft/ft.[8] Subsequent measurements taken in 1979, after the contamination containment system had begun operation, showed similar flow characteristics. Gradients between 0.006 to 0.008 ft/ft were observed along the north boundary.[8]

The clearest picture of contamination migration and distribution affecting the north boundary can be provided by considering the underlying aquifer as two separate bodies of groundwater. The most significant body moves beneath Basin F toward the north boundary in a northeasterly direction. Contaminants leached from the surface waste basins (e.g., Basin A) are carried by this subsurface flow across the northern arsenal boundary. The other body of groundwater flows northwesterly parallel and beneath First Creek. It is generally free of contamination and has much higher volume than the body of groundwater flowing underneath Basin F. In the vicinity of the north boundary, water table contours of both bodies become parallel to that boundary. Contamination, therefore, is carried directly north across the boundary.[3,8]

IMPLEMENTATION OF CONTAMINATION CONTROL PROCEDURES

Introduction

Contaminated groundwater has been detected crossing both the northern and northwestern arsenal boundaries (Figure 2). Contamination crossing the northwestern boundary was detected in 1980. Consequently, containment strategies there are only presently being designed. The focus of this discussion, therefore, is on containment strategies undertaken along the northern boundary.

A two-step approach was implemented. A pilot containment system was installed to evaluate the feasibility of the overall approach. Once satisfied that the pilot system could be operated successfully, the containment system would be extended to intercept and treat contaminated groundwater crossing along the entire affected part of the northern boundary.

Pilot Containment System

The pilot containment system was designed to demonstrate the feasibility of containing off-post groundwater contaminant migration across the northern arsenal boundary. It was placed in operation in July 1978 and its performance evaluated in the summer of 1979.[1]

The pilot containment system is composed of:

(1) Dewatering well subsystem
(2) Treatment plant
(3) Recharge well subsystem
(4) Impermeable barrier
(5) Monitoring well subsystem

For a flow schematic of the system and plant layout see Figures 4 and 5 respectively.

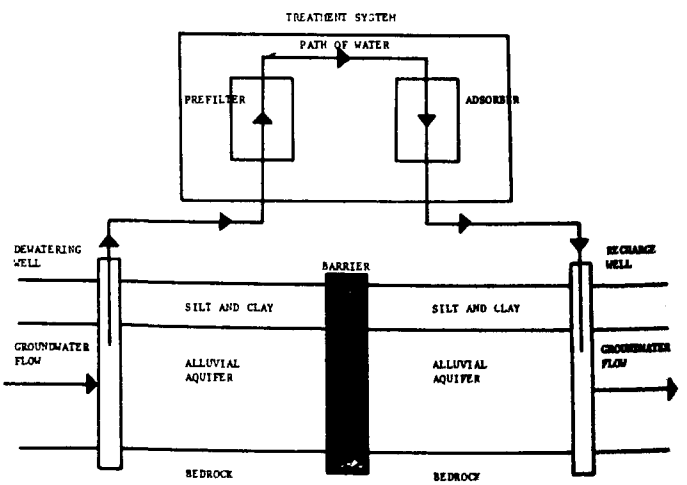

Figure 4.
Schematic Diagram of Pilot Containment System

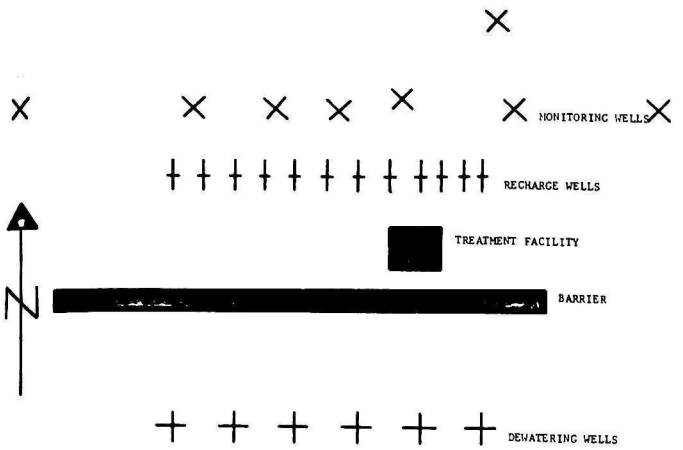

Figure 5.
Overview of Pilot Containment System (not to scale)

Flow of contaminated water across the arsenal boundary is stopped by the impermeable barrier. Dewatering wells remove water from the aquifer for treatment in the treatment plant. Recharge wells inject water back into the aquifer.

Dewatering Well Subsystem

This subsystem is composed of six 8-inch diameter wells placed within 30-inch diameter gravel-packed holes. The wells are screened through the entire alluvial aquifer thickness. They are approximately 225 feet apart. Each well has been provided with a flow control system and submersible pump. The pumping system was designed to keep a constant head within each well. Sensors were used to recycle water back into the well instead of to the treatment system when the pumping water level fell below a predetermined level.

Treatment Plant Subsystem

The contaminated water removed by the dewatering wells is discharged into a sump. This water is then pumped through a filter to remove suspended solids. The water is passed through an activated granular carbon column to remove organic contaminants (e.g., DIMP, DCPD, DBCP). The treated groundwater is discharged to the recharge well system and then back into the aquifer by gravity drainage.

Contaminated water is pumped through the treatment system at a controlled rate (design flow is 10,000 gal/hr). A flow control system regulates flow to the treatment system from the sump on the basis of water level in the sump. Contaminated water is filtered to remove particles before being passed through the packed carbon column. Two filters are used. Each filter contains four feet of filter media. This media is a blend of graded coal and sand. The filters are operated in parallel.

Backwashing is required periodically because the filters become plugged with particulates. Backwashing can be done manually or automatically on a preset time interval. Premature filter plugging is indicated by a high pressure drop alarm. Backwashing is done one filter at a time using filtered water from the onstream filter for a pre-established time period. The backwashed filter is automatically returned to service when this operation is finished. The particle-laden backwash water is collected in a sump where the particles are allowed to settle out. The decanted water is reprocessed through the treatment plant.

Pressure is used to move water from the particle filters to one of two columns packed with 20,000 lbs of activated carbon (Figure 6). Only one column is used at a time. Water flows down through the column and the activated carbon packed into the column absorbs the organic contaminants. The treated water flows to the recharge wells by gravity for reinjection into the aquifer.

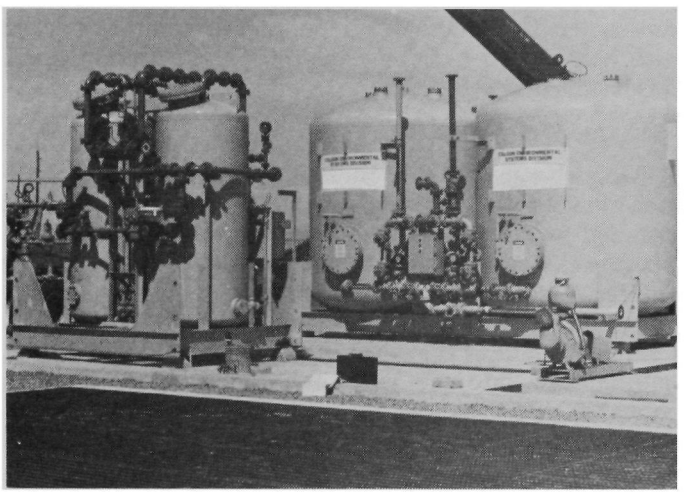

Figure 6.
Treatment Facility Prefilters (left) and Adsorbers (right)

Spent carbon must periodically be replaced with fresh activated carbon which is delivered to the treatment facility in specially designed trailers. Transfer of the carbon from this trailer to the column is accomplished by filling the trailer with treated water to slurry the fresh carbon. The treated water had been stored in the empty column prior to arrival of the trailer. Spent carbon is transferred to and from the trailer as a slurry by pressurizing the column or the truck with compressed air. The slurry water is drained into the sump and then processed through the treatment system.

A major consideration in deciding to use carbon adsorption columns was the ease of operation and small manpower requirements. Downtime of the treatment facility was less than 1% during FY-79. Only simplistic problems typical with system start-up were encountered. Flow recorders did not operate properly, pump seals needed replacement and a faulty solenoid valve required repair.

Breakthrough

To determine when the carbon in a column requires replacement, the concentration of DIMP in water being

discharged from a column is monitored. When the DIMP concentration approaches 50 μg/l, new carbon is ordered. This level was selected so that the column could still be used until the trailer containing fresh carbon arrives.

DIMP was selected as the indicator compound because previous testing had shown that it was the compound that "breaks through" the carbon before any of the other organic compounds. To monitor DIMP passing through the column, samples of influent and effluent were collected daily. An example of a typical DIMP "breakthrough" curve is given in Figure 7.

Pilot bench studies had suggested that the carbon needed would be 1.10 lb carbon/1000 gal of wastewater. Between July 1978 and June 1979, two columns were changed. The ratios were 1.90 and 1.29 lb/1000 gal of wastewater, respectively. The higher than expected carbon usage rates were attributed to bed siphoning and subsequent formation of air pockets in columns packed with carbon. To overcome this problem a siphon break was installed.[1]

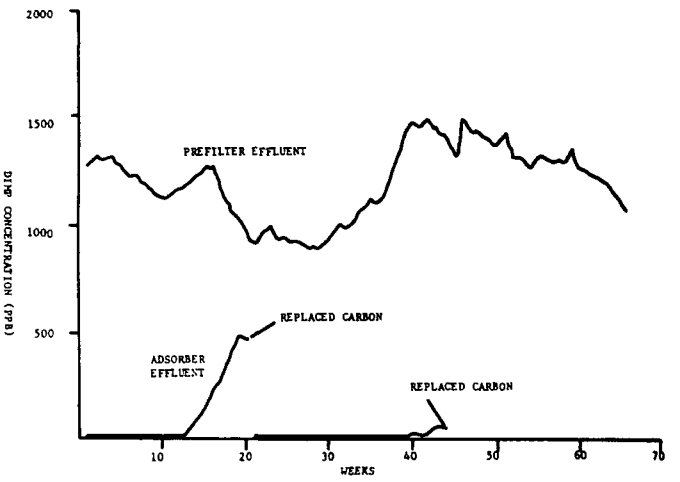

Figure 7.
Graph of DIMP Breakthrough Curve During Pilot System Operation

Recharge Well Subsystem

The recharge well subsystem is composed of twelve 18-inch diameter wells approximately 100 feet apart. They are installed within 36-inch diameter gravel-packed holes. These wells are screened along the full thickness of the aquifer. Treated water is injected continuously by gravity unless the level of water in the well rises above a pre-determined level. At that time, a float control valve closes, halting flow into the well until the water level drops enough for flow to resume.

Impermeable Barrier

A 1500 foot impermeable bentonite barrier anchored approximately 2 ft into bedrock was installed between the dewatering and recharge wells. It was installed to physically prevent flow of the groundwater through the aquifer, isolating upgradient and downgradient flow at the treatment system site. This barrier prevents mixing of contaminated and treated groundwater.

Monitoring Well Subsystem

Observation wells were installed both upgradient and downgradient of the pilot containment system. They were small diameter PVC casing screened within the alluvial aquifer. Water levels and chemical quality of the groundwater are monitored periodically at each of these wells.

Evaluation of System Performance

In June 1979, the performance of the pilot containment system was evaluated to determine its ability to remove organic contaminants from the groundwater. If the system operated successfully, it would be extended to intercept and treat contaminated groundwater crossing along the northern arsenal boundary.[1]

The results of the evaluation were:

(1) The carbon column removed organic contaminants from the groundwater. The contaminants could not be detected using gas chromatography. Eventually, contaminants were detected because the adsorptive capacity of the activated carbon became overwhelmed. Therefore, successful operation requires periodic replacement of the activated carbon.

(2) Downgradient flow of groundwater was essentially unchanged. This latter consideration is as important as the first requirement in a water-scarce area.

Expansion of the North Boundary Pilot Containment System

Construction of the expanded containment system was begun in early 1981. It is scheduled to begin operations in August of 1981. It consists of 42 additional dewatering recharge wells, and monitoring wells, increased treatment capacity, and extension of the bentonite barrier 4500 feet to the east and 1500 feet to the west of the present pilot containment system barrier. The design of this addition was based upon the performance of the original pilot system.[2]

Northwest Boundary Containment System

As described earlier, DBCP contamination was detected offsite at the northwest arsenal boundary. A containment system is being designed to address that problem. Presently, the situation is similar to the north boundary system with one exception. Preliminary calculations indicated that the dewatering wells alone could effectively remove contaminated groundwater from the aquifer. Two rows of dewatering wells are planned approximately 800 feet apart. Therefore, an impermeable barrier was not included in design of the system.

SUMMARY AND CONCLUSIONS

DA has implemented a containment strategy to prevent off-site migration of contaminants at RMA. Initially, a pilot containment system was constructed along the north boundary to test the feasibility of this containment ap-

proach. The pilot containment system demonstrated that the approach:

(1) Removed organic contaminants of concern to below detectable units from the groundwater
(2) Did not adversely affect the flow and distribution of the groundwater downgradient from the system

As a result, an extension was designed and is being constructed to treat contaminated groundwater along this boundary. The concept is also being implemented to contain contaminants in groundwater crossing the northwest boundary.

Though this approach works, there are important questions remaining to be answered:

(1) The length of time required to run the system must be determined. Containment could cost more than clean up in certain situations because of the costs associated in operating a containment system for many years. The maintenance associated with operating a system for many years must also be considered.
(2) The impact on land use options caused by use of a containment strategy needs to be addressed. In the arsenal's example, sale of land may be precluded unless the new owners accept responsibility for operation of the system. Use of contaminated land is also restricted during the time frame that contaminants continue to migrate from that land.

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THE EFFECTIVE USE OF RESOURCE RECOVERY IN THE CLEANUP OF UNCONTROLLED HAZARDOUS WASTE SITES—BASED ON THE CALIFORNIA EXPERIENCE

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INTRODUCTION

One of the most important environmental concerns today is the location and management of uncontrolled hazardous waste sites. Normally, an uncontrolled site is identified through anonymous tips and/or governmental surveillance activities. Once the location of such a site becomes widely known there is much pressure exerted by the news media and the public on governmental agencies to remove the hazardous waste from the site as quickly as possible.

Very often the most expeditious way of cleaning up a site is removal of the waste for disposal at a permitted hazardous waste disposal site; this is not necessarily the most prudent way of solving the problem. Furthermore, California and the rest of the country are now experiencing increasing difficulty in siting new hazardous waste disposal sites. Concurrently, permitted sites are facing increasing public pressure to close. For example, even after obtaining 185 permits the five-year-old Earthline hazardous waste disposal site in Wilsonville, Illinois was closed as a public nuisance.[1]

Therefore, if the limited number of currently operating hazardous waste disposal sites are filled, the states will be faced with frequent incidents of illegal dumping of hazardous wastes and/or firms going out of business because there is no facility which can accept their waste.

In addition, until recently, only surface and groundwater protection were generally considered in the location of a hazardous waste disposal site, but now there are also concerns about air pollution and public health effects due to emissions of hazardous waste from disposal sites. Recently, several papers[2, 3, 4] have addressed the problems of air quality deterioration and the control of air emissions from hazardous waste sites.

According to a 1980 EPA contracted study[5] of nine uncontrolled hazardous waste sites in the United States, the remedial action technologies usually employed were on-site containment and surface/groundwater monitoring, and waste removal for landfill burial or incineration at permitted facilities. Only once was resource recovery employed as part of a cleanup program. In the long run, even though it usually takes a longer period of time for a site to be cleaned up through resource recovery, it is probably, in many instances, the soundest solution. Sometimes it may take a joint cooperative effort of everybody concerned for resource recovery to work. Furthermore, landfill disposal and/or on-site containment measures may be only temporary solutions.

Four California case studies of uncontrolled hazardous waste sites are presented. For the purposes of this paper, an uncontrolled or abandoned hazardous waste site is defined as having one or more of the following characteristrics:

(1) is no longer used or is inactive and is no longer maintained,
(2) is a location of unpermitted or improper waste disposal
(3) has no known owner, and
(4) containment and monitoring techniques are inadequate.

Hazardous waste is defined in the *California Administrative Code*,[6] as any "waste material or mixture of wastes which is toxic, corrosive, flammable, an irritant, a strong sensitizer or which generate pressures through decomposition..."

Due to requests for confidentiality or to pending litigations, the names and locations of some of the following studied sites have been deleted from this paper.

CASE A: CONTRA COSTA COUNTY, CALIFORNIA

The site was formerly used by its previous owner for the fabrication of steel. One of the operations was a galvanizing mill, which was used to coat steel pieces with zinc from a zinc acid solution so as to protect the steel pieces from corrosion. Apparently the spent galvanizing solutions were ponded from 1960 until 1975 when the plant closed. The pond was built in existing marshes where soils vary from clay to sandy silt. In 1977, the property was sold. The responsibility for the maintenance of the pond was then transferred to the new owner.

During 1977, the pond overflowed. Subsequently, dikes were constructed to contain future overflows. In the same year residents registered complaints about the pond and emissions from the pond. During 1978, the runoff rate from the nearby railroad company's fill was periodically exceeded which led to the pond overflowing once more and into San Pablo Bay.

Over the years, wastes continued to seep from the pond and some seepage had even reached the Bay although mon-

Table I.
Summary of Analytical Results for
Contra Costa Steel Plant Lagoon

Parameter	Units	Composite Pond Water Sample	Pond Bottom Surface Sediment	CORE SAMPLES Station 1 0-4"	Station 1 11-14"	Station 2 0-4"	Station 2 9-13"	Station 3 0-4"	Station 3 13-17"	California TTLC *	EPA EP Toxicity**
pH	Units	1.9	1.5	2.1	2.7	2.4	3.2	1.8	1.9	≤2 (corrosive)	≤2
Sulfate	Mg/Kg(1)	15,400 Mg/ℓ	51,000	15,000	2,980	2,650	1,260	109,000	56,000	--	--
Cadmium	Mg/Kg(1)	0.62 Mg/ℓ	0.85	0.97	0.68	< 1.00	1.60	0.88	4.55	10	1.0
Hexavalent Chromium	Mg/Kg(1)	0.02 Mg/ℓ	<0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	50	--
Trivalent Chromium	Mg/Kg(1)	3.15 Mg/ℓ	18.6	37.4	18.5	14.1	31.3	34.2	45.5	250	--
Total Chromium	Mg/Kg(1)	3.15 Mg/ℓ	18.6	37.4	18.5	14.1	31.3	34.2	45.5	--	5.0
Lead	Mg/Kg(1)	0.10 Mg/ℓ	190	214	23.9	191	28.1	26.3	81.9	50	5.0
Zinc	Mg/Kg(1)	2,530 Mg/ℓ	5,570	2,910	2,050	416	413	9,650	15,700	200	--
Total Solids	% (2)	--	51.6	66.9	83.4	71.8	80.5	57.6	56.9	--	--

(1) Mg/Kg expressed as Wet Weight

(2) Oven Dry (103°C) Weight Basis

* TTLC's (Total Threshold Limit Concentration) are from the California Assessment Manual for Hazardous Wastes, p. 66-67.

** These values are not equivalent to California TTLC but are the same as STLC (Soluble Threshold Limit Concentration).

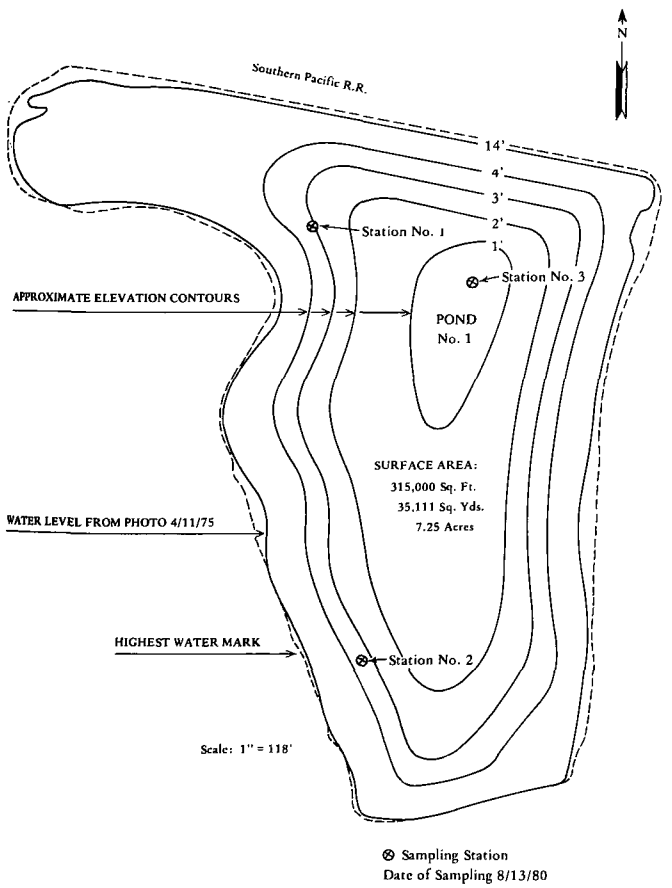

Figure 1.
Core Sampling Points at Pond

itoring of the ground water, which is approximately three feet below ground, indicated no contamination.

Remedial Actions

The remedial actions employed were basically containment measures, for example, diking. During these years there were also proposals to treat the pond wastes for discharge into the sanitary sewage system and San Pablo Bay, disposal of the waste at a Class I hazardous waste disposal site[7] or to permit the liquid to evaporate from the pond so the pond bottoms and adjacent contaminated soils could be excavated and hauled to a Class I site for disposal.

In 1980, the owners authorized a commercial laboratory to sample and analyze the pond water and adjacent soils. This was done to ascertain the alternatives for deposition of the pond's waste water and the contaminated soils. As the analytical report (Table I) indicates, three core samples (the core samples were collected at the locations indicated in Figure 1), a bottom surface sediment sample, and a composite water sample were collected and analyzed. Basically, the results indicate that all samples are considered hazardous by the California Department of Health Services per the *California Assessment Manual for Hazardous Wastes*[8] or *CAM*.

Subsequently, the Department's California Waste Exchange (CWE) became involved. The CWE realized from the analytical results that the primary chemical compound, zinc sulfate, dissolved in the waste water is used in the agricultural industry.[9,10]

Sulfur, assimilated as the sulfate ion, is considered a secondary plant nutrient for protein synthesis and sulfur deficiencies exist in California soils at the eastern foothills

in the San Joaquin Valley, the central coastal range and the Sacramento Valley. Zinc, a micro-nutrient, needed for terminal plant growth, is assimilated as zinc ions. As with sulfur, zinc is often found deficient in California soils.

A nearby firm, Veale Tract Farms, when contacted by the CWE, expressed an interest in the three million gallons of pond water for use as a micronutrient on its marginal soils. Veale Tract Farms proposed to dilute the pond water to an appropriate level before application to their soil. Thus far, of the two proposals received by the owners, one for hauling and disposal at a Class I site and the other for hauling and application at Vale Tract Farms, the latter was less costly by $700,000.

As for the pond bottom surface sediment and the contaminated soil, they may also be beneficially used by rototilling at a 1:100 ratio with native soils, so as to reduce the lead content to an acceptable level. In this way all of the waste on-site could be recycled.

At this point, the most economic identified remedial action technology is still resource recovery. Finally, the California Department of Health Services has estimated that cleanup of the site through disposal at a Class I site can cost as much as $29,000,000.

CASE B: CONCORD, CALIFORNIA

Prior to 1964 the site was owned and used by a salvage company operator. In 1964, the site was sold but the seller retained one half of the mineral rights to the eastern portion of the site where the salvage operation had been located. Apparently, the operator had used the site over the years to dispose of 60 to 70 tons of material from the nearby Allied Chemical's Union Collier Plant. The piles of material disposed are believed to have been spent coke filters used in sulfuric acid production (see Figure 2).

In 1972 the U.S. Navy acquired the above site as part of a two mile buffer zone around a munition's area. During 1980, the site camed to the attention of the California Department of Health Services when it was identified as a site that had received industrial wastes in the U.S. Congress' Eckhardt Survey.

Figure 2.

California Department of Health Services

Table II.
Summary of Analytical Data for Solid Waste Piles at Allied Chemicals' Union Collier Plant
Mg/kg

Parameter	Coke Pile #1	Coke Pile #2	Calif. TTLC
pH	3.1	2.2	2
Ag	26 ± 14	89 ± 19	
As	—	251 ± 44	50
Ba	—	—	1,000
Bi	—	—	
Cd	—	—	10
Co	—	—	
Cr	—	—	—
Cu	31 ± 8	48 ± 8	150
Fe	3,800	1,670	—
Hg	—	—	2
Mn	58 ± 20	23 ± 16	—
Mo	14 ± 6	—	3,500
Ni	16 ± 8	—	200
Pb	1,600	4,120	50
Sb	—	—	1,000
Se	972	7,030	10
Sn	—	—	—
Sr	244	23 ± 6	—
Tl			50
V	36 ± 24	—	240
Zn	77 ± 10	48 ± 8	200
Br	14 ± 4	44 ± 8	—
Rb	33 ± 6	—	—
Y	37 ± 10	—	—
La	—	—	—
Ge	—	—	—
Th	19 ± 18	—	—
Te	552	1,550	—
Ti	—	113 ± 44	—

Note: The analytical error for metal determination is approximately ± 10%, unless otherwise indicated.

Preliminary results (see Table II) on samples collected and analyzed by the California Department of Health Services indicated that the coke piles were acidic, pH 2.2 to 3.1, and contained high levels of metals: lead, 1600 to 4120 ppm; arsenic, 251 ppm; selenium, 972 to 7,030 ppm; and tellerium, 552 to 1550 ppm. Since these concentrations of heavy metals exceeded the Total Threshold Limit Concentrations in the Department's *CAM* for lead and arsenic, the coke piles are designated as hazardous wastes.

The site is presently unsecured; there are no fences and based on preliminary information there may be leaching of heavy metals into the surrounding soil. In addition, the piles of waste have been cited by the California Regional Water Quality Control Board (CRWQCB) as a source of contaminated runoff to tidal and navigable waters. How-

ever, since the site is not adjacent to a residential area there appears to be no imminent threat to human health.

Remedial Actions

During early 1981, the Department requested the present owner, the U.S. Navy, to perform extensive sampling and analysis of the coke piles and the adjacent soils to determine the average concentration of the contaminants in the coke piles and the extent of soil contamination or leaching. Additionally, the U.S. Navy was requested by the CWE to analyze the coke piles for sulfur.

Two California oil refineries contacted by the CWE expressed interest in the coke piles as a low grade fuel pending results of the sulfur concentration analyses. The 60-70 tons of coke in the piles is to be blended by the refineries with their coke so as to produce a low-grade fuel with acceptable heavy metals and sulfur concentrations, in this context, the coke piles would be a very small fraction of the final fuel.

CASE C: OAKLAND, CALIFORNIA

The site near the Oakland Coliseum was formerly used by Pacific Oxygen, which manufactured acetylene. Acetylene is produced from a reaction between calcium carbide and water.[11]

$$CaC_2 + 2H_20 \rightarrow Ca(OH)_2 + 134 \text{ kcal/mole.}$$

The by-product or waste is hydrated lime, $Ca(OH)_2$.

According to the local health agency, the Alameda County Health Department, the site had been inoperative since 1976 but prior to that Pacific Oxygen used the site to dispose of their acetylene sludge, $CA(OH)_2$ (See Figure 3). When the site closed down 1,000-2,000 tons of acetylene sludge had accumulated.

In August 1979 a "concerned citizen" contacted the Department via the Alameda County Health Department to report that children had ventured onto the unsecured site, the chain fence had been knocked down, to play in the acetylene sludge piles. The site also had an open sump 6 ft x 8 ft x 3 ft deep which was three-quarters full of liquid.

Subsequently, samples of the acetylene sludge and sump liquid were collected and analyzed by the California Department of Health Services. The results (see Table III) indicate that although the acetylene sludge contain relatively low amounts of toxic heavy metals, the pH was high, 12.3, indicating that the sludge is corrosive and therefore a hazardous waste under California regulation. The pH of the sump liquid was 11.04; therefore it is a likely irritant, which makes the liquid also a hazardous waste.

In April, 1980, when the City of Oakland obtained title to the Pacific Oxygen site, the Department's CWE was contacted for assistance in recycling the wastes that were on the site. The CWE determined that the wastes may be recycled in several ways:

- as a soil amendment,
- as an agent to precipitate heavy metals from waste waters at a sewage treatment plant,
- to formulate a paving material for road construction.

Eventually a local paving company, Gallagher & Burk, Inc., was located to recycle the wastes. The wastes would be mixed with rock and gravel to improve the sand equivalent of gravel for use as a road base.

Result

1,000-2,000 tons of lime sludge and liquids were recycled at no cost to the City of Oakland. This was the single largest waste transfer the CWE facilitated during 1980. With the sludge and liquids removed, the City of Oakland

California Department of Health Services

Table III.
Summary of Analytical Results for Pacific Oxygen
Mg/kg

Parameter	Sump liquid*	Acetylene Sludge** Pile 1 1' below surface	Acetylene Sludge** Pile 2 1½' below surface	Calif. TTLC
pH	11.04	12.3 ± 0.1	12.3 ± 0.1	≤2 or ≥12
As	5	___	26 ± 5	50
Fe	1,033	823 ± 81	139 ± 19	___
Mn	___	___	20 ± 16	___
Ni	34	44 ± 13	38 ± 8	200
Sr	122	186 ± 18	29 ± 7	___
Zn	___	21 ± 7	___	200
Ti	___	___	72 ± 52	___
Y	___	___	10 ± 5	___

*Results were reported on 9/12/79
**Results were reported on 7/17/80
Note: Only results for all metals above the detection limit of the X-ray fluorescence spectrometer are reported.

is now proceeding with plans to develop the site into a park and recreation area.

CASE D: NORTHERN CALIFORNIA

The owner had apparently been using the site for unauthorized storage and treatment (Figures 4 and 5) because an investigation by the Department of Health Services' surveillance and enforcement staff in mid 1980 revealed that the owner has never applied for a hazardous waste facility permit. The owner had been, for a period of time, hauling in drums of ink waste, ink wash, glues, waste oils and solvents for storage until he could find a recycler. Otherwise, the waste was hauled to a Class I site.

Although the site was used to store flammable waste, the Department of Health Services staff saw no fire extinguishers and safety showers. Because of these and other deficiencies the State Fire Marshal believed that a fire at the site would cause the closing of an adjacent freeway.

The above site was also unsecured and unpaved. From time to time, there had been numerous spills of hazardous wastes. In addition, glues, ink waste and ink wash wastes were disposed into unpermitted plastic-lined pits. An analysis of contaminated soil by the California Department of Health Services in mid 1980 showed relatively high levels of chromium, copper, lead and zinc. Finally, there was no containment provisions for any spills which could threaten the pollution of surface and ground waters.

Remedial Actions

In late 1980, the CRWQCB issued a Cleanup and Abatement Order (CAO) to the site owner after inadequate responses to informal requests for cleanup. The order reaffirmed previous informal requests to have all removed materials (soils) disposed at a Class I disposal site. The second part of the Order required that containment berms and impermeable surfacing be constructed for all tank drum storage and handling areas.

Figure 3.

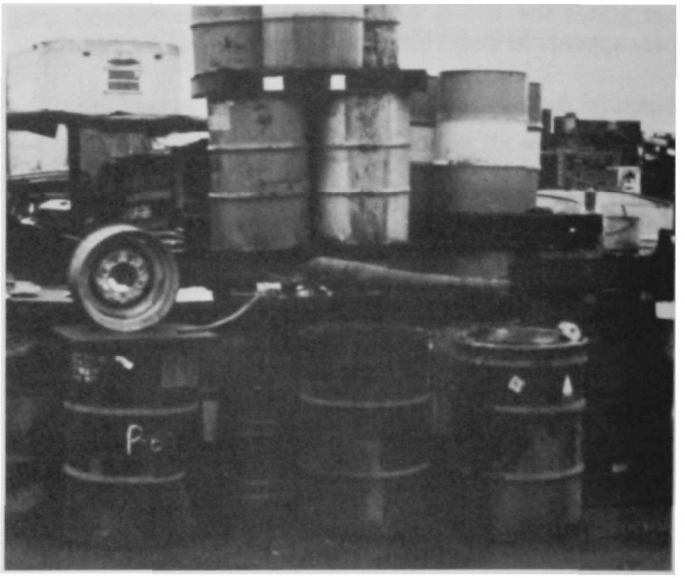

Figure 4.

Figure 5.

Subsequent inspection by this Department and other governmental agencies in early 1981 indicated that the above storage/treatment site posed a clear and present threat to public health and the environment. Drums of hazardous waste were seen deteriorating. Accordingly, the Department urged the local authority to proceed with the enforcement and cleanup of the site pursuant to the *California Health and Safety Code*.[12]

To expedite the identification of the wastes, firms whose hazardous waste were observed were contacted. Upon learning of the situation the Department's CWE provided names of recyclers who might be of help in the site cleanup. Eventually, the CWE with the help of recycling contractors, facilitated the recycling of 900 of the 2100 drums of flammable waste. In addition, 607 drums were recycled. However, 150 drums of fiberglass and foaming resins

were not recycled primarily because the producer insisted they were cleanup residues and therefore they be disposed of at a Class I site as originally intended.

ROADBLOCKS AND REMEDIES

Once an abandoned or uncontrolled hazardous waste site has been identified, an immediate qualitative assessment of the problem site must be made. Specifically, information (i.e., the presence of toxic and/or flammable vapors and toxic heavy metals) must be quickly gathered to ascertain if there is imminent hazard to human health and/or the environment. If an imminent hazard exists, then governmental agencies working with the responsible owner, if there is one, should immediately construct containment measures or even temporary ones, if necessary. Regardless whether or not an imminent hazard exists, the site should be secured from public access.

Once the problem site becomes public knowledge, the involved government agencies should educate the media and concerned groups about the situation. If in the opinion of the governmental agencies, resource recovery can be used to clean up the site, the media and all concerned groups should be so informed. The benefits of resource recovery over land disposal should be extolled. Education and allowance of input from concerned groups by government agencies will help to allay public distrust and anxiety.

After an uncontrolled site has been identified, to assess whether an imminent hazard exists, sampling and analysis should immediately commence and almost concurrently a comprehensive program for sampling and analysis should be prepared. At this point, the resource recovery staff should be consulted for recommendations on the parameters the sampling and analytical programs should be addressed.

Until recently, the Department's CWE usually became aware of a problem site only after sampling and analysis of the site had been performed. Any lack of communication will unnecessarily delay the recycling of the wastes because in many instances of the long turn-around time (months) between sampling and the completion of the chemical analyses and the lengthy time needed in many instances to locate recyclers. The Resource Recovery staff should be involved as soon as possible. The time to locate recyclers may be significantly reduced if a Resource Recovery staff has access to a computer-based waste exchange. Instead of a quarterly catalog of wastes available, which is now distributed by most clearinghouse waste exchanges, a daily update would be available from the computer data base to all interested parties. Presently, the CWE is planning to complement its program through the assistance of a computer-based waste exchange.

In addition, instead of depending on a response to a catalog or computer listing of available wastes, the Resource Recovery staff should also actively engage in the matching of the waste with potential recyclers. Finally, because sometimes wastes are recycled over great distances (i.e., 1000 miles) there should be attempts to locate recyclers on a regional instead of a State basis.

REMEDIAL ACTIONS AND FLOWCHART

Any remedial action program for an uncontrolled hazardous waste site should consider the possibility of cleanup through resource recovery. The following proposed schematic (Figure 6) for maximizing resource recovery of hazardous wastes from an uncontrolled site incorporates the above remedies to roadblocks. Just before efforts are initiated to qualitatively identify imminent human health and environmental hazards, the Resource Recovery staff should become involved. This early inclusion of the resource recovery staff allows additional time for the location of potential recyclers. It has been the experience of the CWE that approximately 2 weeks is frequently necessary to determine whether there is a potential for resource recovery.

The resource recovery potential is assured when there are known and willing recyclers. However, this is not the usual case and the potential for resource recovery, in many instances depends on the vision which is basically a function of the knowledge and experience in analytical and industrial chemistry of the Resource Recovery staff.

To maximize the resource recovery potential of a waste, the literature should be reviewed for uses for the chemical constituents in the waste. Reference texts such as the *Encyclopedia of Chemical Technology*[13] *Condensed Chemical Dictionary*[14] *Chemical Sources*[15] *Directory of Chemical Producers in the U.S.*,[16] *California Manufacturers Register*,[17] etc., have been found to be useful by the CWE. The first four books identify the uses for a particular chemical. The last book, which is updated annually, lists companies by geographic region, industry, and SIC number and therefore permits identification of potential recyclers for the hazardous chemical waste.

Oftentimes, the waste cannot be recycled as is, but must be treated by biological, chemical and/or physical techniques to reduce or remove certain chemical constituents before recycling is possible, economics notwithstanding. If this is the case, then the feasibility of recycling of a waste will also depend on the treatment costs. In the end a waste is only recyclable when it is both technologically and economically feasible.

CONCLUSION

California has proven through its recent experience that resource recovery can be an effective tool for the cleanup of uncontrolled hazardous waste sites. Resource recovery means recovery of raw materials and energy. In addition, land is saved for future generations. As the problems of siting new hazardous waste disposal sites increases and resource recovery becomes more publicized remedial action programs for uncontrolled hazardous waste disposal site will consider resource recovery as a matter of course.

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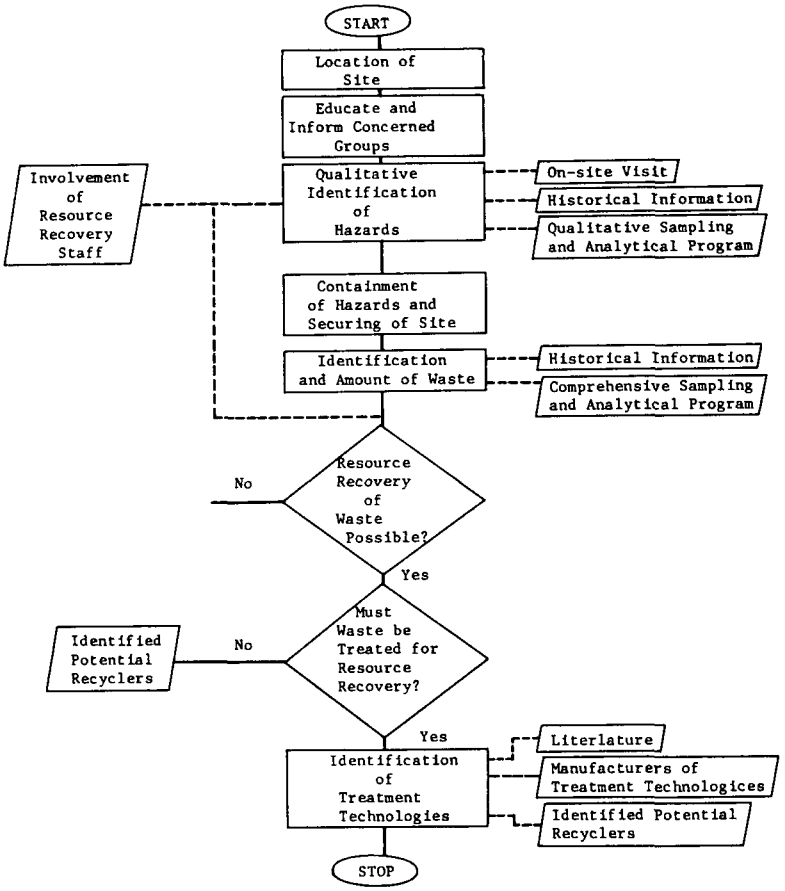

Figure 6.
Flowchart for Resource Recovery of Wastes
From an Uncontrolled Site

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THE GENERATOR'S LIABILITY FOR PAST HAZARDOUS WASTE DISPOSAL PRACTICES

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INTRODUCTION

One need only pick up any newspaper to be reminded that improper disposal sites were used by industry as hazardous waste burial grounds over the past decades. Most new federal, state and local legislation and regulations deal prospectively with the disposal of hazardous waste. They leave for the courts the difficult task of determining who will bear the legal responsibility for cleaning up the hidden horrors which threaten public health and natural resources. In this paper, the authors review the many complex technical and legal issues involved in assigning and apportioning this liability and provide some practical guidance to hazardous waste generators on future precautions.

In discussing the potential liability of generators for past hazardous waste disposal practices, the authors are not focusing on owners or operators of hazardous waste treatment, storage or disposal facilities or even the haulers who brought the waste to such facilities. In most cases, their liability is determined on a statutory basis, under certain circumstances going back to the Refuse Act of 1899[1] and more recently the Resource Conservation and Recovery Act ("RCRA")[2] and the Comprehensive Environmental Response, Compensation and Liability Act ("Superfund").[3] What the authors do address is the legal responsibility of a typical hazardous waste generator who hired someone to haul hazardous waste to an off-site disposal facility.

BACKGROUND

The "Throw Away Mindset"

Just a few years ago, before the recent hazardous waste catastrophes raised the public's consciousness level, the industrial mindset with respect to hazardous waste disposal was generally "out of sight, out of mind." Most industries assigned their purchasing agents the task of arranging for the disposal of industry's unwanted product: its hazardous waste. Purchasing agents were, for the most part, unfamiliar with the nature of the wastes or the proper disposal methods required. Faced with relatively insignificant disposal costs, even for the most toxic wastes and relatively limited technology or interest in recycling such wastes, arrangements for the disposal of hazardous waste were routinely made, with little consideration as to its ultimate disposition. Rarely would a generator take the time to establish and apply transporter or disposer selection criteria other than price. It was the atypical generator who even considered examining the transporter's equipment, inquiring about its reliability or reputation, or even determining from regulatory authorities whether it had valid permits to conduct its business or any enforcement proceedings pending against it.

Perhaps most important of all, many generators never even inquired as to the transporters' intended disposal location and few, if any, ever followed a waste shipment to assure that it reached the proper destination. Other than in those rare instances where a generator had ample land adjacent to its plant on which to dispose of its waste,[4] little care was taken to make certain that hazardous wastes were disposed of properly.

The Love Canal Syndrome

The tragedies that beset the community of Niagara Falls, New York, captured the nation's attention and have held it for the past several years. It was impossible to escape reading or avoid seeing on television stories about the anachronistically labelled "Love Canal." There followed soon on the heels of this disclosure the discovery of other hazardous waste nightmares such as the Valley of the Drums in Kentucky, the dumping of PCBs along the roadside in North Carolina, and the frequent midnight dumping of hazardous waste in the back woods of New England.

Today, every state has its own litany of hazardous waste horrors—monuments to unbridled industrial waste disposal. And as if these hazardous waste exposures to the soil, surface and groundwaters from these incidents were not enough, the fire and explosion of chemical wastes stored in Elizabeth, New Jersey, lifted into the air for miles around toxic fumes deadly enough to threaten millions of people with immediate harm. The notion became aware that there were ticking timebombs, on and above the ground which made everyone vulnerable to hazardous waste impacts from a variety of environmental pathways.

Enter the Government

As is so often the case, government rushed into the breach with new legislation and regulations. The narrow focus of the Toxic Substance Control Act ("TSCA")[5] with its ambitious regulatory program requiring preregistration of new chemical substances and the lengthy de-

lays in implementing RCRA—the two major federal legislative efforts in 1976—demonstrated the need for further legal authority to specifically address past problems. Similarly, as states prepared to accept delegation of various federal regulatory programs, the need to adopt new state hazardous waste laws and regulate the siting of new hazardous waste facilities became evident.

Although hazardous waste legislation and the educational benefits of the implementation of such programs will prove to be helpful in the future, there was still no direct mechanism for providing the requisite funds to clean up the hazardous waste disposal sites which continue to contaminate the environment. The issue then shifted to one of economics which was compounded in large measure by the insolvency of most illegitimate transporters (i.e., the midnight dumper), the nonaccountability through insolvency or disappearance of the owners and operators of improperly run sites, and an overlay of extremely complex legal and scientific problems.

Congress finally addressed these issues, albeit less clearly than anticipated, by the passage of Superfund which was signed into law in December, 1980. The approach adopted was to establish a $1.6 billion fund to be used by the federal government to respond to the most serious hazardous waste disposal site problems on a priority basis, 88% of which would be raised by a tax on the petroleum and chemical industries starting April 1, 1981. Since even this ambitious undertaking would be inadequate to clean up all such sites, it was left for the legal system, through the application of statutory and common law principles, to develop standards to determine and apportion liability among the various participants in the hazardous waste disposal chain.

RESPONSIBILITY FOR PRIOR PRACTICES

Typically, a hazardous waste disposal site will be discovered where the transporters involved and site owner and/or operator are incapable of responding to environmental problems, either because they are bankrupt or have fled the jurisdiction. Combining this fact with the public's jaundiced view of industries, as having amassed great profits from their manufacturing activities while generating and improperly disposing of tons of hazardous waste, quickly results in pressure to place the clean up responsibility on the generator.[6] Support for this approach is founded on the philosophy that industry can either internalize the clean up costs, adversely impacting only the generator's shareholders, or externalize them through higher costs of goods to the consumers. Industry counters this view by suggesting that the public bear the expense through general tax revenues, like some of the present proposals to clean up the Three Mile Island nuclear plant, since it was the public at large that created the demand for and presumably benefitted from the products manufactured.

As this debate on the liability issue continues, the public has grown more distrustful of corporate officials and with the slow pace at which governmental officials have been able to attack these problems—both technologically and fiscally—the public's confidence in their ability to rescue them has also waned. At the same time, scientific methods have developed the capability to determine down to one part per trillion the presence of contaminants in the environment. It is in this setting that the battle lines have been drawn pitting against each other teams of experts to determine the extent of needed clean up and the question of who should bear the legal and financial responsibility. Such determinations will not come swiftly.

COMMON LAW LIABILITY

The General Rule

Where a generator directly disposes of hazardous waste, rather than hiring an independent contractor to remove the waste for proper disposal, his liability is more easily determined under the various statutory and common law theories. Thus, it will be difficult for a generator of hazardous waste to escape liability where it can be shown that he dumped the waste at a site which was known or which should have been known to be improper. Since most generators did not dispose of their own wastes, this area will not be discussed further; instead, the more common pattern will be emphasized: the generators who hired independent contractors to remove hazardous wastes from their plants for off-site disposal.

The general common law rule is that an employer is not liable for the acts of its independent contractor.[7] This rule is based on traditional contract principles where one is free to shift responsibility to another independent actor who is competent to perform the task. However, over the years the courts have carved out important exceptions to this rule resulting in significant limitations on its applicability.

The Exceptions to the General Rule

NEGLIGENTLY HIRED CONTRACTOR. First, a generator will be held directly liable for the acts of its independent contractor which cause physical harm to third persons if the generator has been negligent in, or fails to exercise reasonable care over, the hiring of a skillful contractor.[8] The applicability of this exception will depend upon the generator's compliance with an evolving set of standards dealing with the degree of investigation of the transporter's competence, reputation and license status.

In making an assessment of the independent contractor-transporter, some predictable questions arise:

(1) Did the hauler have a prior record of violations?
(2) Had there been adverse press about the transporter's practices?
(3) Were the transporter's prices significantly lower than his competition?
(4) Was the transporter's equipment in good operating condition?
(5) Did the generator check the transporter's references?

In short, liability may be established upon this principle where it can be shown that the generator knew or should have known of deficiencies in the transporter's qualifications. Assuming that the generator is found to have conducted a sufficient investigation of the independent contractor selected to remove the hazardous waste or that the

generator can show that even had such an investigation been conducted, it would not have disclosed any negative information, the generator has only addressed the threshold issue in attempting to escape liability.

STRICT LIABILITY. The second exception to the independent contractor rule involves principles of strict liability for ultrahazardous or abnormally dangerous activities.[9] This theory is premised on the need to find that the generation of hazardous waste is "abnormally dangerous" and involves such a high degree of risk that no matter who is hired to remove the hazardous waste and no matter how extensive the investigation of the independent contractor may have been, the generator should be held liable for any harm caused by the wastes.

The traditional example of an ultrahazardous activity is the manufacture of dynamite, which has been found by the courts to be so abnormally dangerous that the manufacturer remains liable for harm caused by the dynamite's explosive characteristics. Concluding that an activity or material is ultrahazardous and thereby imposing a standard of strict liability merely makes a societal judgement that while the conduct or material itself should not be banned, it carries such a high degree of risk that the producer must be held absolutely accountable for any resulting harm.

Much of the recent legislation has attempted to define retroactively certain activities involving hazardous waste as "ultrahazardous", or "abnormally dangerous."[10] This raises a myriad of questions as to whether the waste becomes ultrahazardous at the time it is improperly disposed of, or whether it retains an ultrahazardous character from the point of its generation. This area is extremely complex and raises such fundamental issues as the constitutionality of the retroactive application of statutory declarations and the precise factual determinations necessary to form the underpinnings of a plaintiff's case.

DIRECT LIABILITY FOR A PECULIAR RISK. If the generator properly selected an independent contractor and principles of strict liability do not apply, he may still be directly liable for harm caused by the hazardous waste if it posed a "peculiar risk" against which special precautions should have been specified but were not.[11] Here, much will depend upon the nature of the waste and the specific arrangement between the generator and the independent contractor as to the recognized peculiar risks and the concomitant precautions that were specified.

Information about the hazardous nature of the waste and the precautions necessary to be taken in handling it should have been communicated to the independent contractor if the generator is to discharge its obligations in this area. However, some of the many unanswered questions include determinations of whether the risk was "peculiar" and the specified precautions were reasonable.

VICARIOUS LIABILITY. Even assuming the generator is able to escape direct liability, he still faces the possibility of being found vicariously liable. For example, even if special precautions were identified by the generator but the independent contractor failed to implement them and harm resulted, the generator may be held vicariously liable.[12]

Similarly, the generator may be vicariously liable for a nuisance or trespass caused by the independent contractor depending on the extent of the generator's knowledge or the foreseeability of such results.[13] Until more courts address these issues, the standards of common law liability will still be evolving and the establishment of direct or vicarious liability will turn on the particular set of facts.

Possible Defenses to Common Law Liability

Assuming that a court would find a generator liable under any one or more of the common law rules described above, there are defenses that may be available to avoid generator liability.

1. Where negligence is an element of the cause of action against the generator, contributory or comparative negligence may be asserted as a defense. For example, where the operator of the disposal facility that wrongfully accepted the waste sues the generator for the resultant harm, the generator could point to the consent of the operator or other acts in an attempt to shift the liability.
2. Lack of causation linking the generator's waste to the site or to the harm will most certainly be raised by generator-defendants. Here the generator could show that although the waste was improperly disposed of it did not create harm or even the likelihood of harm, that the likelihood of harm was not foreseeable, that the waste was not a substantive factor in causing the harm or that the waste cannot even be traced back to the particular generator.
3. The statute of limitations for the cause of action may already have run. The key question here is when did the cause of action against the generator arise: Was it when the disposal took place, the subsequent discovery of the waste site, or the subsequent injury? Often the type of action brought will define the length of the applicable statute of limitations and the court's answer to the above questions will determine the number of years that have elapsed prior to suit.

Finally, assuming that liability is established, there are significant questions as to the measure of damages and the way in which such damages are to be apportioned. These issues may turn on the extent to which cleanup is necessary and the value of the property before the injury as compared with its present value. In addition, there are extremely critical issues to resolve as to the apportionment of liability among many defendants, methods of contribution, and joint and several liability. Answers to each of these questions may dictate litigation posture, strategies and settlement possibilities.

FEDERAL LAW ENFORCEMENT

Prior to the adoption of Superfund, the federal government had proceeded against hazardous waste generators for past practices primarily under the emergency provision of RCRA, Section 7003,[14] which was amended in 1980 to require the government to prove only that an imminent and substantial endangerment to public health and welfare may exist.[15] To date, all but one court has held

this provision to be jurisdictional only and the courts have required the government to prove its entitlement to relief under the substantive standards established by the federal common law of nuisance.[16] Although the courts have not yet held hazardous waste generators liable under this RCRA provision for their disposal of hazardous waste through independent contractors, there are likely to be many cases filed by the federal government on this theory as well as by affected landowners under similar common law theories.[17]

Superfund was heralded as the tool which the federal government would use in the future to impose strict liability on hazardous waste generators for past disposal practices. Conceptually this is analogous to the standard of liability in the products liability area.

Congress relied on the standard of liability established in Section 311 of the Clean Water Act[18] for establishing strict liability. It is important to recognize that "hazardous substances," the term used under Superfund, is very broadly defined[19] to include hazardous pollutants under Section 112 of the Clean Air Act,[20] hazardous and toxic substances under Sections 304, 307 and 311 of the Clean Water Act,[21] toxic substances under Section 7 of TSCA,[22] and hazardous waste under Section 3001 of RCRA.[23] In addition, Section 102 of Superfund[24] authorizes the Administrator of EPA to list additional substances as hazardous not already included within this broad definition. It is obviously all inclusive.

The first requirement imposed under Superfund was the reporting of sites not registered under RCRA which had been used as hazardous waste disposal facilities.[25] Based on these reports, EPA will be able to identify and evaluate thousands of potential sites for priority cleanup.

Included within the class of persons covered under the liability section of Superfund are operators, owners, transporters and generators.[26] The exposure is quite broad covering the costs of removal and remedial action incurred by the government or other persons consistent with the provisions of the National Contingency Plan.[27] These costs would include not only site investigations, but measures ranging up to and including the temporary or permanent relocation of residents and the provision of alternate water supplies, as well as reimbursement for damage to natural resources under certain circumstances. There is a significant requirement limiting the extent of site cleanup under Superfund to actions that are cost-effective which takes into account the limits of the fund and the need to respond to other priority sites. However, that liability for personal injury claims was specifically deleted in a compromise effort to pass Superfund.

The defenses available under Superfund are intentionally very limited, covering releases of hazardous substances caused solely by acts of God, war and a third party not in a direct or indirect contractual relationship with the generator. In order to come within this last defense, the generator must show by a preponderance of the evidence that he used due care, taking into consideration the nature of the waste, and took precautions against foreseeable acts of third parties and the consequences of such acts. The true scope of the Superfund defenses will have to await judicial review on a case by case basis before their availability can be fully evaluated.

As indicated, Superfund would appear to foreclose a generator from asserting many of the common law defenses previously described; however, there is serious question as to whether the retroactive application of this statute will withstand constitutional challenge. Also, while the liability provisions of Superfund purport to be immediately effective, many of the statutory prerequisites, such as revisions to the National Contingency Plan, the need for state participation and the establishment of a priority list, have not yet been implemented, so that a court may be persuaded that asserting liability under Superfund may be premature.

Also, President Carter's Executive Order[28] delegating much of the authority to various federal agencies, primarily EPA, is coming under close scrutiny by the new administration. On the other hand, the government will argue that Superfund was intended to be used as an immediate stopgap measure to clean up sites before they create human disasters and that relief need not await the completion of the regulatory process or strict adherence to procedural preconditions. Obviously, this is another issue which must await judicial interpretation.

STATE LAW ENFORCEMENT AND RECENT DEVELOPMENTS

An example of the changing legal theories of liability potentially applicable to hazardous waste generators is no more evident than in Pennsylvania. Until September, 1980, the Commonwealth of Pennsylvania relied primarily on the Clean Streams Law[29] which regulates the pollution of surface and groundwater essentially through a permit program. This law provides for vigorous enforcement, abatement actions and the assessment of penalties against, among others, landowners of contaminated property.

Pennsylvania courts have held landowners to be strictly liable for the cleanup of their property even if the damage was caused by a prior owner.[30] In the context of generator liability, however, unless it could be proven that the generator "discharged" or "permitted the discharge" of hazardous waste into the surface or groundwater, the Clean Streams Law was not an effective means of imposing liability. In instances where a generator did nothing more than contract with a transporter for the disposal of hazardous waste, courts would have to stretch the "permit to discharge" language to establish liability.

Prior to its amendment in 1980, the Pennsylvania Solid Waste Management Act ("Act"),[31] proved quite ineffectual since there was no meaningful provision for direct enforcement against hazardous waste generators and penalties were limited to $300 per day. However, the 1980 amendments to this Act[32] provided a comprehensive hazardous waste program including a manifest system, permits, licenses for transporters (which exceed the RCRA requirements for transporters) and a variety of administrative, civil and criminal penalties, ranging up to $500,000 and 20 years imprisonment. However, unless the provision declaring certain hazardous waste activi-

ties "ultrahazardous" and thereby subject to strict liability for any resulting harm (which on its face is retroactive) includes the act of generating hazardous waste, generators may still be able to escape direct liability for the prior off-site disposal of hazardous wastes.[33]

Perhaps the trend of judicial decisions in this area can be seen in *New Jersey v. Ventron Corp.* (see footnote 6) which interpreted the New Jersey Spill Compensation and Control Act[34] strictly and apportioned liability jointly and severally against two parent corporations of wholly owned subsidiaries. While the case is arguably limited to its facts and is strictly an application of New Jersey statutory law, it reflects the judiciary's attitude on hazardous waste disposal issues (in this case, mercury) that wherever feasible, the defendant most financially able to effect a remedy is likely to be responsible, since the potential adverse public impact of improper hazardous waste disposal is astronomical.

WHAT'S A GENERATOR TO DO? SOME PRACTICE ADVICE

Once a generator has been sued, he obviously will have to defend himself in court against the various theories of liability claimed by the plaintiff, many of which have been described in this paper. Open questions that will invariably be litigated include the burden of proof necessary to establish causation, applicability of joint and several liability, bases of apportionment, constitutional limits on retroactive application of statutes and statutes of limitation.

Prior to suit, a generator can attempt to uncover potential problem areas and take certain actions to be in the best position in the event litigation is brought.

The generator can audit its hazardous waste disposal records as far back as he can (since there may be no time limitation) to determine whether its waste was hazardous. This determination can be accomplished by consulting with his engineers and chemists, reviewing raw material records, etc. Next, the generator can review the names of each of his transporters and disposers to see whether they are any longer in business and whether any are now being investigated or have already been prosecuted.

All contract forms for any waste disposal activities should be reviewed to determine whether any "special precautions" were identified. All personnel involved in hazardous waste disposal activities should be interviewed and the facts memorialized for future reference.[35]

Generators should review their insurance policies to see whether or not there is any possible coverage should there be claims arising out of hazardous waste activities. The "sudden and accidental" exclusions in most policies have now given way to more liberal coverage for environmental impairment, but questions as to applicability for past practices are obviously quite important to any determination of coverage. In addition, there is at least one reported case where courts have interpreted insurance policies and found coverage.[36]

The authors can do no more than note the problems that they can foresee arising over the next few years in the area of generator liability for hazardous waste practices. Very few "hard" answers can be given since very few have yet been furnished; instead, most answers are merely arguments for judges and juries, whose decisions will become "the law." Then and only then will we know what consequences will be meted out to generators of hazardous waste for their past disposal practices.

REFERENCES AND FOOTNOTES

1. 33 U.S.C. §407.
2. 42 U.S.C. §6901, *et. seq.*
3. 42 U.S.C. §9601, *et. seq.*
4. A generator with an on-site hazardous waste disposal facility was still required to obtain the necessary permits and approvals and to comply with existing operating requirements. By using plant property, the generator only avoided the risks of employing a transporter for off-site disposal and the lack of control inherent in such practices.
5. 15 U.S.C. §2601, *et. seq.*
6. For example, the court stated in *New Jersey v. Vention,* _____A.2d_____, 1 Chem. and Rad. Waste Litigation Rptr. 348 (Super. Ct. Ch. Div., August 29, 1979):

   > As we become more sensitive to our environment and more aware of the impact of pollution on our environment, we must demand that the unchecked development of products which release pollutants into our environment be controlled. It does not offend this court's sensitivities nor infringe upon a manufacturing defendant's constitutional rights to impose strict liability upon a defendant who, during the course of a profit making venture discharges into the environment a dangerous or hazardous pollutant which results in damage or harm to the public, notwithstanding an absence of intent or negligence on the part of the defendant.
7. Restatement (Second) of Torts §409.
8. Restatement (Second) of Torts §411.
9. Restatement (Second) of Torts §427A. An "abnormally dangerous" activity is defined in Restatement (Second) of Torts §520 to include the following factors:
   - •Existence of a high degree of risk of some harm to the person, land or chattels of others;
   - •Likelihood that the harm that results from it will be great;
   - •Inability to eliminate the risk by the exercise of reasonable care;
   - •Extent to which the activity is not a matter of common usage;
   - •Inappropriateness of the activity to the place where it is carried on; and
   - •Extent to which its value to the community is outweighed by its dangerous attributes.
10. See Pennsylvania Solid Waste Management Act, 35 P.S. §6018.401(b):

    > The storage, transportation, treatment and disposal of hazardous waste are hereby declared to

be activities, which subject the person carrying on those activities to liability for harm although he has exercised utmost care to prevent harm, regardless whether such activities were conducted prior to the enactment hereof.

Also, in the legislative history of Superfund it is stated that:

For the purposes of this act, Congress declares that manufacture, use, transportation, treatment, storage, disposal and release of hazardous substance are ultrahazardous activities. 126 Cong. Rec. S 14972 (daily ed. November 24, 1980).

Note, however, that the Pennsylvania language does not include "manufacturer" or "generator", whereas Congress did include the former term in its legislative intention.

11. Restatement (Second) of Torts §413.
12. Restatement (Second) of Torts §416.
13. Restatement (Second) of Torts §427B.
14. 42 U.S.C. §6973.
15. The pre-1980 version of RCRA's imminent hazard section required the government to prove that "the handling, storage, treatment, transportation or disposal of any solid waste or hazardous waste *is presenting* an imminent and substantial endangerment to health or the environment. Now, all the government has to prove is that the listed activities "may present" such an endangerment.
16. See *United States v. Midwest Solvent Recovery, Inc.*, 484 F.Supp. 138 (N.D. Ind. 1980); *United States v. Solvents Recovery Service of New England,* 496 F. Supp. 1127 (D. Conn. 1980). Contra, *United States v. Diamond Shamrock,* _____F.Supp._____ (E.D. Ohio 1981).

    Further, in light of the holding in *City of Milwaukee v. Illinois,* 451 U.S._____, 68 L.Ed.2d 114 (Sup. Ct. 1981), that the federal commonal law of nuisance has preempted in the water pollution area, it may also be held to be inapplicable to waste disposal matters.
17. In *Ewell v. Petro Processors of Louisiana, Inc.,* 364 So. Rptr. 604 (Ct. App. La. 1978), generators who had actual knowledge of improper waste disposal practices were held liable for damages to a neighboring landowner's property.
18. 33 U.S.C. §1321.
19. 42 U.S.C. §9601.
20. 42 U.S.C. §7412.
21. 33 U.S.C. §§1314, 1317, 1321.
22. 15 U.S.C. §2607.
23. 42 U.S.C. §6921.
24. 42 U.S.C. §9602.
25. 42 U.S.C. §9603.
26. 42 U.S.C. §9607.
27. The National Contingency Plan was developed under the Clean Water Act to describe the procedures and criteria for responding to oil spills. 40 CFR Part 1510. Under Section 105 of Superfund, 42 U.S.C. §9605, it is to be significantly revised to incorporate procedures, priorities and methods of responding to releases of hazardous substances.
28. 46 Fed. Reg. 9901 (January 19, 1981).
29. 35 P.S. §691.1 *et. seq.*
30. *National Wood Preservers Corp. v. Pennsylvania Department of Environmental Resources,* 414 A.2d 37 (Pa. 1980).
31. 35 P.S. §6001 *et. seq.*
32. 35 P.S. §6018.101 *et. seq.*
33. Future off-site disposal activities by generators is highly regulated in Pennsylvania and the Act specifically cuts off liability for civil and criminal penalties provided a generator uses a licensed transporter and the waste is received by an appropriate permitted storage, treatment or disposal facility. 35 P.S. §§6018-605, 6018-606.
34. 58 N.J.S.A. 10-23.11 *et. seq.*
35. It is important to consider the discoverability of any written memoranda prior to their preparation so that appropriate safeguards can be instituted.
36. *Lansco Inc. v. New Jersey Department of Environmental Protection,* 138 N.J. Super. 275, 350 A.2d 520 (Ch. Div. 1975) aff'd. per curiam 145 N.J. Super. 433, 368 A.2d 363 (App. Div. 1975).

RECOVERING DAMAGES TO NATURAL RESOURCES UNDER CERCLA

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INTRODUCTION

Until recently, pollution damages to publicly owned natural resources were seldom paid for, due to the difficulties of establishing "ownership", assessing physical damage and deciding on monetary values of the resources. Increased oil and hazardous substances spills with the last two decades, together with improved knowledge of the functions of natural resources, have led to the recognition that these functions warrant compensation for damages even though they are not explicitly traded in the marketplace. The 1980 Comprehensive Environmental Response, Compensation and Liability Act,[1] otherwise known as the Superfund Act, establishes liability for damages or injury to, destruction of or loss of natural resources resulting from hazardous substances releases, including the reasonable costs of assessing such damages (section 107 (a)). Further, in order to facilitate damage recovery, the Superfund Act establishes a Hazardous Substances Response Fund which can be used by the government to clean up spills and resource damage losses recover. Consequently, the federal government has the unprecedented opportunity to codify some damage assessment techniques by promulgating regulations specifying analysis procedures (section 301 (c) (1)).

The economic theory of externalities[2] holds that the optimal compensation procedure will extract from polluters an amount equivalent to the social value of the damage. Otherwise, disregarding effects of income distribution, society will lose, due to misallocation of its resources. In this paper, the authors briefly outline the economic theory underlying resource damage assessment and highlight some obstacles to establishing estimation methods. Further, methods currently employed in legal proceedings are reviewed and an alternative is considered that can be applied under the Superfund Act. As such, the paper's focus is on deriving a monetary measurement of the damages rather than assessing physical damages, such as identifying the pollutant, determining the contamination level and the effects caused by the pollutants.

PLACING MONETARY VALUE ON DAMAGED NATURAL RESOURCE

According to economic theory, the appropriate valuation of damages should be based on the demand that existed for the natural resources before they were injured. The primary obstacle economists face is the non-market-goods nature of open-access natural resources, such as public beaches, state parks, open lakes or rivers. Because these resources are not traded in the market place there is no price from which monetary damages can be derived.

In such cases, economists resort to the concept of the willingness of the users to pay for the natural resources. A person's willingness to pay for a resource is the amount of money he or she is willing to accept in place of using the resource. When travel and equipment expenditures are incurred, for example, by a user of a natural resource, the willingness-to-pay figure must be reduced by these costs, resulting in a "net" willingness-to-pay. For example, if a sport fisherman is willing to pay $5.00 for catching a trout, and the travel and equipment expenditures per trout is $3.00, the net gain to him is $2.00 per trout.

The value of a natural resource, therefore, is the willingness-to-pay net of the costs incurred to use the resource, aggregated for all of the users or potential users. The value of the damage is the reduction of this aggregated net willingness-to-pay that is caused by the incident. This measure reflects society's welfare loss due to the damage.

Economic techniques developed to measure net willingness-to-pay[3] generally are expensive and time-consuming. Moreover, many are designed for research rather than damage recovery. The most widely used technique surveys users of the resource and attempts to elicit their willingness to pay. In order to obtain accurate results, the survey must be a valid and sufficiently large sample of the user population. Construction of such a sample often requires a substantial effort.

Another economic technique relies on changes in property values to estimate damage values. However, the uses of this latter technique thus far have been mainly limited to valuing the benefits of clean air.

TECHNIQUES USED IN LEGAL PROCEEDINGS

In the past, the considerable time and expense requirements of the economic methods discussed above, limited their application in legal proceedings. Further, courts lacked the technical expertise necessary to arrive at a consistent framework to value the damages. In fact, only recently have courts begun to hold the polluters liable for

damages to open-access natural resources, under the concept of public trusteeship. Nevertheless, courts had to develop methods that would quantify the damages so that compensation could be made to the plaintiff. The following subsections discuss these traditional assessment methods.

Replacement Costs

In cases involving injury to a natural resource, replacement costs are sometimes awarded by courts as a component of restoration damages.[4] For example, a court may order the defendant to pay for the cost of replacing a grove of destroyed fruit trees with a comparable type and number of seedlings. Similarly, a court may award a plaintiff damages to cover the cost of restocking a polluted stream or lake with fish and other aquatic life. In these cases, the replacement cost is intended to compensate for the loss of economic uses of natural resources and restores the injured party to his or her pre-injury position.

Replacement costs also have been used to determine the value of non-economic uses of natural resources. In *State of Tennessee ex rel. Goodrich v. Riggen,*[5] the State sought to recover the value of deer killed by negligent use of an herbicide. At the trial, the State presented a number of expert witnesses testifying as to value of the deer. Surveys found that deer hunters spent $1,035-$1,727.47 for each deer killed. Wildlife experts placed the recreational, aesthetic, economic and ecological value of a deer at $2,500-$5,000.[6] The plaintiffs sought $2,500 per deer killed[7] based on the aesthetic, ecological and recreational value of the deer. The court rejected the plaintiffs' assessments of the value of the deer and instructed the jury to consider instead:

> "the average cost per deer, cost affected by the survival ratio, restocking cost, the fact that deer reproduce themselves, transportation costs for the deer and economic benefits which you find the proof the State of Tennessee may receive (sic), including that from deer hunters; to reach an amount which would fairly compensate the State of Tennessee for its alleged loss of deer and unborn fawns."...[8]

An important fact which perhaps influenced the court is that in a different part of the State deer were so overpopulated that many would starve without control measures.[9] The jury finally awarded the State of Tennessee $1,119, based on testimony which asserted that the cost of catching and transporting deer from the overpopulated area was $100 per deer.[10] The State lost on appeal.[11]

The replacement cost valuation technique was recently employed by the plaintiffs in *Commonwealth of Puerto Rico vs. SS. Zoe Colocotroni.*[12] This case arose from an incident in which an oil tanker dumped 1.5 million gallons of crude oil in order to free itself after running aground on a reef. The oil came ashore in Bahia Sucia, a Puerto Rican lagoon which, prior to the spill was a "healthy, functioning estuarial ecosystem" in which the angrove forests functioned as breeding, feeding and nursery grounds for fish, shrimp and benthic organisms as well as being the primary food-producing agents of the organic materials available to the aquatic food chain.[13]

The oil spill resulted in the death of more than 92 million marine animals in a 20 acre area for which no market value, in the sense of lost market profits or revenues, could be ascribed.[14] In addition, the oil penetrated the mangrove forests, resulting in a significant increase in the mangrove mortality of the area.

More than five years after the incident, the mangrove community showed a significant reduction in the number of species of macrobiota, the number of molluscs and crustaceans, and other marine organisms. The seagrass community showed a significantly altered pattern of plant biomass and the number of species and population density of marine organisms.

The district court awarded the following damages: for the more than 92 million marine organisms killed, the defendants were to pay $5,526,583.20, a figures derived by referring to the prices of marine organisms from biological supply laboratories.

> "The lowest possible replacement cost figure is $.06 per animal... Accepting the lowest replacement cost, and attaching damages only to the lost marine animals in the West Mangrove area, we find the damages caused by Defendants to amount to $5,526,-583.20."[15]

For damages to the mangrove forests, the court awarded damages for the 23 most affected spots in the West Mangrove area. It found that the best means of reestablishing these areas was by the intensive planting of mangrove and restoration of this area to its condition before the oil spill. Evidence showed that planting mangroves costs about $16,500 per acre, and that the five year monitoring and fertilization program would cost $36,000 per year or $180,000 for the five years. The total damage of the pollution to the West Mangrove equalled $559,000. The court also awarded $78,108.80 in cleanup costs incurred by the plaintiffs. The total award granted by the district court was $6,164,192.09.

Contribution to Productivity

The contribution of a given resource to ecosystem productivity had been used to place a value on the damaged resource, on at least one occasion. In *State of Florida v. Bruce,*[16] the administrative law judge assessed the value of the detrital production of some felled mangrove trees. The judge accepted the State's contention that detrital value, the accumulated leaves, branches and seeds which serve as an essential element in the estuarine food chain, should be the basis for calculating damages. Its value is defined from its contribution, through the food chain, to the support of recreational and aesthetic fish species. The court agreed that lost detrital value could be derived from the size of the lost canopy cover, which could be found by aggregating the measure of the cut mangrove tree diameters. Thus, in this instance 2000 square feet of canopy was lost. The value for the lost 2000 square feet was estimated to be $2,760. This sum was derived by assuming a $4000 per acre year value, which was multiplied by 15, the number of years required for a mangrove seedling to reach maturity.

In addition to showing that the lost detrital production was a factor to be considered in calculating the value of the damages, the State also argued that mangroves served many other functions, such as water cleansing, pollution control, nutrient uptake and assimilation, shoreline stabilization, flood prevention, water conservation, oxygen production and sequestration of heavy metals and other poisonous substances. However, compensation was not sought for the latter values.

Willingness-to-pay Survey

A technique for estimating the value of damages caused by a pollution incident by surveying people's willingness-to-pay for recreational uses of those resources was prepared by plaintiffs for presentation to a court. Unfortunately, no decision was reached in that case as to the method's legal validity. *In the Matter of the Complaint of Steuart Transportation Company,*[17] a claim arose from a spill of 250,000 gal of #6 fuel oil into the Chesapeake Bay.

As a result of the spill, thousands of waterfowl were killed, 27 miles of wetlands were fouled, many invertebrates were killed, many oyster beds were extensively polluted.[18] Both the Commonwealth of Virginia and the United States filed suit, the former seeking $731,500 in damages to waterfowl and other costs, the latter seeking $487,000 in cleanup costs and $1 million for loss of waterfowl.[19] The defendants eventually settled out of court for $115,000.[20]

As part of its evidence as to the value of the damages caused, the United States introduced a study which estimated the lost hunting value resulting from the bird kill.[21] An expert witness applied the results from a previously completed study, which concerned the hunting expenditures made by waterfowl hunters in the seven states lying within the Pacific Flyway, to the facts in *Steuart.*

In that study, randomly selected hunters were sent a questionnaire concerning household income after taxes, number of seasons of experience in hunting waterfowl, hunter's cost per season, hunter's seasonal bagged waterfowl harvest and the hunter's estimate of how much his costs would have had to have risen above present costs before he would have decided to totally abstain from waterfowl hunting during the season. Using a statistical formula, the marginal value of a bagged waterfowl for a representative hunter was obtained.

Lost Business Opportunity

Damages to open-access natural resources can injure business opportunity if business uses the resources as an input, such as an oyster farm using clean open-water in *Skansi v. Humble Oil & Refining Company.*[21] In this case, the defendant argued that the plaintiff should not receive more than his expected net profit on oysters destroyed through water pollution. The court disagreed, saying that the plaintiff had lost not only his net profits but also all of the expenses of planting and cultivating, which were included in the sales price.

In *Carr v. United States,*[23] the court refined the lost revenue valuation technique used in *Skansi* by limiting the compensation to the net loss sustained by the plaintiff. This figure was derived by multiplying the estimated foregone yield in bushels by the average price per bushel for that year and subtracting the costs of tonging and marketing. Since the plaintiff had not expended money for tonging and harvesting, the court was economically correct in eliminating those costs from the estimated lost value. Consequently, the plaintiff received lost profits plus those expenses that were already incurred.

Discussion

The above valuation methods, which were actually used in legal proceedings, all attempt to measure the social values of the damaged resources. Yet the methods are not consistent: for the same damage, different values resulted, depending upon which method was employed. These methods also vary in their strengths and weaknesses. Replacement costs only address the supply side of the resources, ignoring the level of demand for the resources (i.e., should lost resources always be replaced or restored at whatever cost?).

If only the supply side is considered, society might replace or restore resources whose costs exceed their social value. The contribution to productivity method is more useful when parts of ecosystem are damaged, disrupting the aggregate function of the ecosystem. However, this method's usefulness is limited if the functions or products of the ecosystem are not well defined and not traded in the market place.

The expenditure survey method has the strongest economics basis, since it directly measures the users' willingness-to-pay for the damaged resources. Its only weaknesses are that: (1) costly surveys may be necessary and (2) the accuracy of the results depends on the sincerity of the people surveyed and on their interpretation of the questions. For example, in *Steuart Transportation* the answer to the question of how much the costs of waterfowl hunting would have to rise above the present cost before the hunter would decide to abstain from hunting may lead to inaccurate results if the hunter is not constrained by his actual income in answering.

The lost business opportunity method only applies when a business using the open-access resources is injured by damages to those resources. Hence, the method does not address the value of the resources in public uses. In fact, in the context of the Superfund Act, such private damage recovery is excluded from the use of the Fund.

The applicability of the above methods under Superfund is limited by the potentially large number of spills and types of natural resource damage. In order for the Fund to process the claims expeditiously, the damage valuation methods have to be, as Congress intended, simple and require minimal administrative cost.

AN ALTERNATIVE SCHEME UNDER SUPERFUND

The damage valuation method under the Superfund damage assessment procedure must strive for a balance between conceptual validity and procedural simplicity. The underlying concept is that a relationship exists between the costs of conducting the damage valuation and the

benefits of accurately identifying the damage in monetary terms. Because the social costs of miscalculating the value of a unit of damage—the benefit of accurate valuation—may be small in small releases,[24] the use of expensive valuation methods can not always be justified. Realizing this, Congress divided the damage assessment regulations into two types:

> "Such regulations shall specify (A) standard procedures for simplified assessment requiring minimal field, observation, including establishing measures of damages based on units of discharge or release or units of affected areas and (B) alternative protocols for conducting assessments in individual cases to determine the type and extent of short and long-term injury, destruction, or loss." (CERCLA) section 301 (c) (2)).

The Use of Value Tables for Small Releases

When the units of discharge or of affected resources are small, Superfund can adopt value tables along the lines of those used by the States of Virginia, Florida, Washington and California.[25] In general, these tables set the values of fish and game (except California, which includes other natural resources, such as sand and flatworms) so that damages can be recovered accordingly. In Virginia, the court accepted the table as evidence of the value of the lost fish in *Commonwealth ex rel State Water Control Board v. Weaver Mirror Co.* No. 4722 (Franklin Co. Virginia Circuit Court, June 2).

Florida promulgated its table of values as regulations.[26] Subsequently, the Florida Supreme Court accepted these fish values in *State Dept. of Pollution Control v. International Paper Company.* It held that the values were proper and relevant.[27]

The State of Washington published its *Guidelines For Evaluating Fish Kill Damages and Computing Fish Kill Damage Claims* (hereinafter Guidelines), which bases the value of fish on its production cost at the state fish hatcheries. California used its table to assess compensation in *State of California v. Alice B. Copeland Vincilone,*[28] which arose after the defendant conducted leveling and filling activities in "Big Hole," a complex of island, water channels and land masses along the Colorado River.

Alaska also uses a table to assess pollution damage, but with a different approach. Alaska's tables consist of a schedule of penalties for oil discharges, which vary according to: (1) whether the oil enters a freshwater, brackish, or saltwater environment or public land (2) the toxicity, degradability and dispersal characteristics of the oil and (3) the sensitivity and productivity of the receiving environment.[29] This approach, although simpler than the previous tables to administer, in that does not require counting the damaged units, may not reflect the actual value of the damage.

Although these value tables only cover a small portion of the resources that can be damaged by hazardous waste releases, they certainly can be expanded under Superfund to include groundwater, wetland and other natural resources. These tables can also be constructed on a regional basis so for a given resource to reflect regional difference in values. However, several weaknesses in the existing value tables requires correction if they are to be used for damage assessment under Superfund. The construction of the values should be made more consistent and be based on sound economics. Several examples will help illustrate this need.

The fish values used in Virginia for example, are constructed from the average purchase price of the fish. This is valid as long as the price is below the consumer's willingness-to-pay for the fish. When the demand for the fish is low the cost of replenishing the fish, including transportation and labor costs, may be an excessive compensation to award.

This criticism also applies to parts of the *Guidelines* of the State of Washington, which depends on replacement or restoration costs. The Florida value table was derived from a mixture of hatchery costs, expenditures and commercial values. Expenditures of the recreational fishermen cannot be used as the value, since they do not represent willingness-to-pay for the fish. Again, commercial value is also not accurate because the price includes other costs of harvesting.

It is also questionable whether the price of the commercial fish can be applied to species that are also in demand for recreational fishing; there is no market where open-access fish are allocated between commercial and recreational fisherman.

The California table sums several types of values: replacement costs, use value and psychic value. This approach reflects the complexity of natural resources that have multi-uses. However, the summation of the values may result in double-accounting, since these values are not always complementary. For example, the bird that a hunter wants cannot be used for bird watcher.

Learning from the past experiences, value tables under the Superfund can be constructed more consistently and accurately. Consistency can be gained by employing the best components of the state schemes and applying them, to the extent suitable, to all small releases. Accuracy can be improved by basing the techniques on more solid economics. The economies of scale can allow careful construction of the values through willingness-to-pay surveys and other techniques presently used in economics research. It is likely that more than one technique will be used, due to the different types of the resources (e.g., fish, wetland, groundwater, lake and river).

When using surveys, the samples should be taken on a regional basis, so that regional differences in uses will be reflected in the values. Although simpler, value tables corresponding to units of discharge may be difficult to defend, due to their theoretical weakness that the specific resource itself and its uses are not considered.

Use of Economic Techniques for Large Releases

When a hazardous waste release is large enough that costs of conducting a case-by-case valuation can be justified, several economic techniques and approaches can be used, including willingness-to-pay surveys, travel cost, household production and revealed preferences. Although these techniques are cumbersome, they can be simplified in

terms of procedure and understandability with minimal loss of analytic rigor. Their chief advantage is that they are all based on widely accepted economic principles.

This does not mean there is always consensus on how the techniques are used. In fact, disputes do arise from difference in the empirical estimation procedures. It is advisable, therefore, to determine which estimation procedures appear to have the support of most economists practicing in this area.[30] The procedure should be adhered to as much as possible to minimize variation in the values resulting from different estimation procedures.

Another advantage of the case-by-case techniques is that the values are generally derived from the sample of the people who actually or potentially use the resources in question. The resulting values, unlike those of value tables, cannot be repudiated by the argument that the values do not reflect the users of the specific damaged resources.

The main objective to the case-by-case approach is its high dollar and time costs. But with the status of rebuttable assumption in court that is granted by the Superfund, the techniques can be greatly simplified to reduce cost and time. Elegance and rigor would have to be partially foregone; the confidence interval of the estimates would have to be increased. This often means small sample sizes and short survey periods. Such sacrifices are worth the benefits of bringing sound valuation techniques into the effort to protect the nation's diminishing natural resources.

FOOTNOTES

1. P.L. 96-510, 945 Stat. 2767 (Dec. 11, 1980)
2. Externality theory is concerned with divergences between private and social cost. For example, Firm A emits smoke during its production process which soils laundry cleaned by Firm B. The marginal social cost of Firm A's activity is greater than the marginal private cost and, consequently, the firm is producing more than is socially optimal. According to A.C. Pigou, the correct policy would be to levy a tax equal to the difference between marginal social and marginal private costs. This tax would induce the firm to produce the "right" socially efficient output—that at which price equals marginal social cost.
3. *See* Freeman, A.M. III, "The *Benefits of Environmental Improvement*" (Baltimore: Johns Hopkins University Press, 1979) for a discussion of the techniques.
4. See, e.g. *Commonwealth of Puerto Rico v. S.S. Zoe Colocotroni*, 456, f. Supp. 1327 (1978)
5. Shelby Law No. 3 (1947)
6. Assignments of Error and Brief of Appellant, at 19.
7. Michael J. Bean, "Law and Wildlife and Emerging Body Wildlife Law," Environmental Law Reported, Vol. 7 March 1977, p. 50020.
8. Assignments of Error and Brief of Appellant, at 8.
9. John J. Tomanson, counsel for appellant, personal communication, May 20, 1981.
10. Jim Allison, counsel for appellant, personal communication, May 21, 1981.
11. Assignments of Error and Brief of Appellant, at 28.
12. 628 F. 2d 652 (First Cir. 1980).
13. 456 F. Supp. 1327 (1978), at 1339.
14. Id. at 1344.
15. Id. at 1345.
16. DER Case No. 80-1481.
17. 495 Fed. Supp. 38 (D. Va. 1980).
18. James D. Range and Millicent A. Feller, "Congressional Perspectives on the Need for Estimating Environmental Damage from Oil and Hazardous Waste Spills, "*Proceedings of the 1979 U.S. Fish and Wildlife Service Pollution Response Workshop,*" St. Petersburg, Florida: U.S. Department of Interior, September 1979.
19. General Accounting Office, *Total Costs Resulting from Two Major Oil Spills,* Washington, D.C.; Government Printing Office, CED-77-71, June 1, 1977.
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26. In a case brought by commercial fishermen for damages resulting from the Santa Barbara oil spill, the plaintiffs had difficulty establishing a base figure of average commercial fish yield. And catch figures normally vary widely and in addition are only separately reported, making them uncertain. Determining lost profits with certainty was further dampened in this case by additional damage the fish caused by unrelated flooding, Philip E. Sorenson, Environmental Damage in Economics and Law: The case of the Santa Barbara Oil Spill, *Proceedings, Annual Meeting of the Southern Economics Association,* Atlanta, Georgia, November 1976, pp. 115-119.
27. Fla. Stat. Ann. 403.141 (3) (1973) Doct. No. 15156, California District Court, Riverside Superior Court.
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29. As 46.03.758.
30. For example, the Department of Interior could establish a panel of economists expert in the area of damage assessment.

SITE CONTAMINATION AND LIABILITY AUDITS IN THE ERA OF SUPERFUND

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INTRODUCTION

Industrial managers responsible for corporate real estate or environmental affairs are often not fully aware of the legal and financial ramifications attending contaminated properties. With rapidly escalating government efforts to locate and remedy abandoned or uncontrolled hazardous waste sites, the need to inventory corporate real estate, examine relative contamination potentials, define potential liability exposure and institute control mechanisms is being recognized.

In this paper, the authors briefly outline the statutory and common law initiatives and various liability pathways. However, the focus is on the presentation of a structured multidisciplinary methodology, the Site Contamination and Liability Audit, designed to identify site contamination and liability problems and establish a framework for their control. Examples are used to demonstrate the need for such audits and to illustrate the audit process.

The emphasis in the paper is placed on the property screening aspects or early phases of the audit process. The property screening phases are designed to obtain a reasonable qualitative assessment of possible site contamination problems with a minimum of effort and expense. Site screening aspects are of particular value in an era of increased corporate merger activity. Careful screening for site contamination problems can prevent the acquisition of severe liabilities.

FORCING STATUTORY AND COMMON LAW INITIATIVES PREDATING SUPERFUND

Prior to enactment of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund), persons involved as defendants in litigation related to inactive or abandoned contaminated hazardous waste sites entered the courts under a variety of statutory and common law provisions. The types of actions which were initiated can be divided into the following broad areas:

(1) Enforcement under Federal and State statutory provisions
(2) Emergency powers provided by Federal and State statutes
(3) Citizen actions taken pursuant to Federal and State statutes
(4) Actions initiated by government pursuant to Federal and State common law
(5) Private suits brought by injured parties pursuant to Federal and State laws

Enforcement Provisions under Federal and State Environmental Laws

All Federal and State environmental laws have enforcement provisions making violation of specific sections of the law either civil or criminal violations, depending on the circumstances. Prior to Superfund, the most widely used enforcement powers were those under RCRA, the Clean Water Act, the Refuse Act and their state counterparts.

The Clean Air Act, Safe Drinking Water Act, Toxic Substances Control Act and their state equivalents have seen more limited use. Since most of these statutory provisions only address activities conducted after enactment dates, effective use for abandoned or inactive waste sites has been limited. Successful government actions have most often occurred where the site has involved ongoing disposal activity.

Use of Statutory Emergency Powers

Most recent environmental statutes give Federal and State officials broad authority if an environmental or human health hazard is imminent. However, in using these powers, the government must first demonstrate that an emergency exists. Federal and State courts have varied widely in their interpretation of what constitutes an imminent hazard situation. Once this burden of proof is met, the government has a wide range of remedies in equity available under Section 7003 of RCRA, Section 504 of the Clean Water Act, Section 303 of the Clean Air Act, Section 1431 of the Safe Drinking Water Act, Section 7 of the Toxic Substances Control Act, various state equivalents of these statutes and a number of State general environmental policy laws. These remedies have included actions such as:

(1) Order immediate restraint of an activity
(2) Require determination of the extent of contamination or environmental and health damage
(3) Require development of remedial plans

(4) Require implementation of containment or removal measures
(5) Require installation of monitoring networks
(6) Order permanent restoration of the site
(7) Order installation of permanent alternative water supplies
(8) Require posting of financial security through a variety of mechanisms

Citizen Actions Pursuant to Federal and State Statute

Each of the Federal environmental laws enacted in the last decade and most comparable State laws contain so-called "citizen suit" provisions. Generally, under such provisions, any person or group of persons may commence a civil suit against any party allegedly in violation of any requirement of the act in question. These provisions also generally provide for citizen suit against the administering regulatory agency for failure to perform an act or duty under the law which is not discretionary with that agency.

Persons commencing such actions must first notify the respective regulatory agencies and alleged violators of the intention to bring action. No separate action may be brought under these provisions if EPA or a state has begun and is diligently pursuing the same action.

Government Common Law Actions

Federal and State agencies have used common law principles in seeking relief against abandoned or uncontrolled hazardous waste sites. The common law theories used have included nuisance, negligence, trespass, restitution and strict liability.

EPA has been particularly interested in imposing a joint, several and strict liability standard on hazardous waste generators, transporters and facility owners and operators. For the most part, the courts have been sympathetic to this approach. Typically, Federal and State government attorneys have used the "shotgun" approach in seeking relief under every possible avenue, citing common law theories along with the various statutory environmental authorities available.

Private Common Law Actions

Plaintiffs have brought suit under the common law tort theories of negligence, nuisance, strict liability, trespass and restitution. For the most part, these private parties have found it difficult to muster the evidence necessary to satisfy the strict burden of proof requirements of the common law tort theories. The government, owing to their greater level of resources and clearer statutory authority to enter property for the gathering of evidence, has been more successful in obtaining judgments pursuant to the common law tort theories.

INITIATIVES AVAILABLE UNDER SUPERFUND

The legal remedies available prior to the enactment of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund) pale as insignificant before the awesome arsenal of authority now available to government pursuant to the new Superfund legislation. Essentially, the government now has a free rein in its apparent power to address the problems presented by inactive, abandoned or uncontrolled hazardous waste sites. Major sections of the new law of particular importance to this discussion include:

(1) Section 103(a)—requires that the National Response Center be notified of the release of any reportable quantity of a hazardous substance.
(2) Section 103(c)—requires that by June 9, 1981, any person owning or operating, or who at the time of disposal owned or operated, or who acting as an transporter selected storage, treatment and disposal facilities for hazardous substances, must have reported to EPA the existence of such facilities, hazardous substances received, and known, suspected or likely releases of hazardous substances from known facilities (RCRA permitted or interim status facilities are excluded).
(3) Section 104—grants the government authority to respond to hazardous substance contamination incidences or suspected incidences by directly employing investigation, remedial, or removal actions (government discretion in these matters is implied).
(4) Section 107(a)—assigns strict financial liability for response, remedial action, removal and destruction or damage to natural resources to facility owners and operators, past owners and operators, transporters selecting facilities for disposal and persons contracting for disposal at such facilities.

While clearly possessing the power to act, the government will most likely begin exercising its new authority slowly. A myriad of complicated plans, administrative procedures and regulations required by the law remain to be developed.

As the government acts, the regulated community and potential defendants are not expected to sit back while federal and state response teams descend upon them incurring large financial charges on their behalf. Structurally, the law provides numerous opportunities for potential defendants to question and challenge government actions. However, before the proper questions can be asked and meaningful challenges mounted, affected parties must come to fully understand the scope and magnitude of their specific site contamination problems.

The Site Contamination and Liability Audit process presented herein has been designed to provide industry executives and middle level managers with a flexible outline of the actions needed to find and define their problems and the potential liabilities presented. After problem definition and understanding, informed corporate response can be fashioned.

SITE CONTAMINATION AND LIABILITY AUDIT PROCESS

The Site Contamination and Liability Audit is a logical stepwise procedure designed to find hazardous substance site contamination problems, define these problems and set the stage for informed corporate response. The audit

Table I.
Site Contamination and Liability Audit Phased Structure

Screening Phases	Phase 1	Initial Property Inventory
	Phase 2	Classification and Identification of Potential Problem Properties
	Phase 3	Preliminary Field Screening
	Phase 4	Prioritization of Problem Properties
Emergency Action Phase	Phase 5	Immediate Emergency Stop Action Response
Detailed Site Investigation and Remedial Phases	Phase 6	Detailed Site Field Investigation
	Phase 7	Definition of Remedial Strategies, Risk and Financial Liability Assessment and Remedial Cost Effectiveness
	Phase 8	Selection of Preferred Remedial Strategy
	Phase 9	Implementation of Remedial Action
	Phase 10	Certification of Performance and Addressing Future Potential Liability Issues

Table II.
Elements of Phase 1, Initial Property Inventory

Objective	Gain understanding of the number, location and use of all properties under corporate control (own, rent or lease) or planned property acquisitions.		
Assignment of Responsibility	Corp. Level Director of Envir. Affairs Director of Property Mgt Environmental Counsel	Division Level Director of Envir. Affairs Director of Property Mgt Environmental Counsel Chief Engineer	Plant or Facility Level Plant or Fac. Mgr. Plant Engineer Environmental Engineer
Info. and Data Req'd. for Initial Inventory	•Topographic map of site area (U.S.G.S. Quadrangle Map). •Site layout map showing property boundaries, acreage, building locations and adjacent property owners •Period of time property under control •Prior use of property, if known •Activity summary (e.g., property is manufacturing location for chlorine gas) •SIC (Standard Industrial Code) designation(s) •Number of employees •Number of production employees •Summary of present environmental regulatory status of site (e.g., RCRA Part A permit application filed for sludge storage lagoon, no present enforcement problems) •Clearly indicate status of known contamination problems		
Info. and Data Sources	All of the required information for this phase should be readily available to or from the designated responsible individuals		
Equip. and Services Needed	If a large number of properties are involved, data processing may be required		
Other Considerations	A questionnaire or data form may aid in obtaining uniform quality of response from all locations		

Table III.
Elements of Phase 2, Classification and Identification of Potential Problem Properties

Objective	Identify those properties where present or historic activity gives cause to suspect possible site contamination		
Assignment of Responsibility	Corporate Level Coordinator and support staff	Division Level Coordinator and support staff	Plant or Facility Level Plant or Facility Mgr and and support staff
Info. and Data Req'd., Action to be Taken	All Phase 1 data is reviewed by corporate and divisional coordinators. All properties are classified: (1) known site contamination; (2) site contamination likely or suspect; (3) data for site not complete; and (4) site contamination unlikely. •Obtain missing data for Category 3 sites		
Info. and Data Sources	All data should be in hand as a result of Phae 1. Responsible individuals provide missing data for Category 3 sites		
Equip. and Services Needed	If a large number of properties are involved, data processing may be required		
Other Considerations	A rating or scoring system may aid in the categorization of properties. All individuals involved should be counselled as to the importance of the project		

Table IV.
Elements of Phase 3, Preliminary Field Screening

Objective	Using simple and inexpensive field investigation techniques, confirm and qualify site contamination problems	
Assignment of Responsibility	Corporate and division coordinators assign a site investigation team to work directly with plant or facility personnel. The team should consist of a Hydrogeologist, Environmental Scientist and an Environmental Engineer. The team is responsible for the design of each site screening program and for assuring that the program is properly carried out. At least one team member should be on-site during any field work	
Site Screening Tasks	*Research*—Prior to field work the following data should be obtained and reviewed: •Phase 1 and Phase 2 file •Published and unpublished geologic-hydrogeologic reports and maps •Expanded present and historic site activities report from plant or facility personnel •Copies of any RCRA notifications or permit applications •Copies of any Superfund notifications •Available site maps and surveys •Present and historic aerial photographs of the site area •Waste generation and disposition inventory from plant or facility personnel (present and historic) •Obtain any available environmental monitoring data *Field Program Design*—Based on a review of the above data, a one or two day site specific field "prospecting" program is designed. The following activities might typically be included: •Conduct structured interview of facility personnel followed by detailed picture taking tour of site •Water quality survey of standing water bodies, streams, drainage ditches, seeps, monitor wells (if present) and surface impoundments •Shallow soil sampling survey noting evidence of contamination (odor, discoloration, etc.) •Vegetation survey noting species present and evidence of death or stress •Site access survey noting accessibility to general public (particularly children) and means taken to control access	
Info. and Data Sources	The responsible plant or facility personnel should be able to provide or obtain all of the research data required. Telephone assistance and advice can be provided by the site investigation team	
Equipment Needed	hand anger post hole digger shovel surface water samplers well bailers or pumps sample containers 100 ft steel tape	35 mm camera pH meter and probe conductivity meter and probe portable contaminant test kits (HACH type) reagents distilled water
Other Considerations	Enlisting the aid of responsible individuals most knowledgeable concerning the site is strongly advised	

program is flexible and can be adopted in whole or in part as the needs in given situation demand.

Depending upon the goals of a particular audit, corporate officials may require a simple problem potential screening inventory of the properties under their control and any planned acquisitions or a full scale site investigation of the type, source and extent of contamination, definition of possible remedial measures and costs, plan for implementing remedial work, environmental performance monitoring and liability control strategy.

Phases of the audit process which begins with general property inventory steps and progresses through detailed site specific investigation and remedial action decision making are shown in Tables I to XI. The elements of each phase are described in detail, with attention to objectives, assignment of responsibilities, information sources and data needs, equipment needs, outside services required and other considerations.

CASE HISTORIES—UNINVESTIGATED LAND ACQUISITION

Asbestos Contamination

This case history clearly illustrates the need to conduct careful screening audits of properties before purchase.

Late in 1978, a developer purchased an abandoned Connecticut gasket factory and surrounding acreage intending to develop a shopping center on the parcel (see Figures 1 and 2). During the early stages of construction it was discovered that the site was dotted with asbestos sludge pits and asbestos gasket waste piles.

Concerned for the health of workers and area residents, local health officials contacted State and Federal officials. Teams of inspectors from the Connecticut Department of Environmental Protection (DEP), U.S. Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) descended on the site. Construction was immediately halted.

After several days of negotiation, the developer signed a DEP consent order. THe twenty compliance conditions specified in the order involved everything from informing workers of the hazards associated with asbestos, to the consolidation and proper on-site disposal of all asbestos wastes. Construction delays and compliance costs added $900,000 to development costs. If a simple and inexpensive site contamination screening audit had been conducted, the developer would have avoided the property and its problems.

Coal Tar Contamination

A Pennsylvania utility was notified by the U.S. EPA that an oily discharge from one of its properties was entering an important trout stream. The utility contracted with TRC to investigate the source and nature of the material and to delineate the extent of contamination.

A review of the land use in the site area showed that coal gas had been manufactured on the site by the previous owner and that the oily substance seeping into the stream was coal tar. Aerial photographs dating back to 1939 were used to identify suspect areas and help design the drilling and sampling program. The boundaries of the contaminated area have been identified and the feasibility of various containment and removal alternatives is being studied.

Table V.
Elements of Phase 4, Prioritization of Problem Properties

Objective	From field screening data develop preliminary estimate of the magnitude of potential contamination and risk presented by each site and rate properties accordingly. Priority for site specific investigation and remedial action is established
Assignment of Responsibility	Corporate and divisional coordinators, site investigation team, and corporate or outside counsel
Rating and Prioritization Tasks	*Rating Potential for Health and Environmental Damage* Site rating methodologies have been developed by: 1) LeGrand;(1) 2) JRB Associates;(2) and 3) the Mitre Corporation.(3) The methods consider potential receptors, pathways for contaminant migration, contaminant characteristics, and site engineering characteristics. These methods vary in specific data requirements and emphasis. Preference should be given to the development of a rating methodology synthesized from these approaches that is simple to apply and requires only that data already in hand as a result of Phase 1 through 3 efforts. Using the method developed, each site is evaluated and given a numerical rating. *Rating Liability/Risk Potential* Close approximations of the financial liabilities presented by a site cannot be made until detailed site investigation work is completed and remedial action option costing developed. However, a qualitative assessment of liability risk potential can be made by answering the following questions: •Is the property presently a source of off-site contamination? •Has off-site environmental or property damage been documented? •Are environmental regulatory enforcement or legal actions in progress or pending? •Has a "Superfund" notification been filed for the site? •Does the site contain poorly maintained discrete accumulations of hazardous wastes (i.e., drums, waste piles, sludge, etc.)? •Is the property accessible to the general public? •Are any private legal actions in progress or pending? •Has environmental impairment liability insurance for the site ever been denied?
Rating and Prioritization	Based on the answers to these questions, the potential financial liability is rated *High Risk, Moderate Risk* or *Low Risk*. Three or more yes answers should place a site in the high risk category. *Prioritization for Further Action* Sites with high health and environmental damage scores and a high risk liability rating would obviously be priority candidates for immediate emergency stop action response and detailed site investigation
Info. and Data Sources	Phase 1 through 3, should have provided all the information and data needed for Phase 4 prioritization. Follow up telephone conferences may be required for clarifying data and answering liability risk questions
Other Considerations	The value of legal counsel at this stage is of critical importance. The corporate legal staff should be immediately briefed concerning all high score/high risk sites

Table VI.
Elements of Phase 5, Immediate Emergency Stop Action Response

Objective	Prior to the start of and during the detailed field investigation problems may be uncovered that require immediate emergency remedial action. Rapidly conceived and implemented remedial action is taken to mitigate imminent public endangerment or potential catastrophic environmental release.
Assignment of Responsibility	Corporate and divisional coordinators, site investigation team, facility personnel, corporate legal staff and outside contractors develop and implement emergency remedial measures
Typical Stop Action Remedial Measures	Actions taken will be site specific, responding to the special problems presented at each site. Typically, these measures might include: *General Response* •Immediately notify and brief all local emergency response officials •Immediately provide site security—fencing, warning signs and 24-hour security personnel *Drums and Tanks* •Identify contents and quantity, determine structural integrity, transfer contents if necessary, label, number and properly stage •As soon as practical, remove all containerized material for proper disposal *Pits, Ponds, Lagoons, Surface Impoundments and Waste Piles* •Identify contents and stored volumes, determine engineering specifics and structural integrity of any liners or containment structures •Take measures as necessary to eliminate or control contaminant release and improve integrity of containment, such as: 1. cease discharge of waste to facility 2. remove waste for proper disposal 3. transfer material to secure temporary storage 4. install top liner 5. increase dike or berm elevation and 6. stabilize waste physically and chemically *in situ* by fixation and/or solidification *Ground and Surface Water Contamination* Before any effective long-term program to eliminate or control ground and surface water contamination can be designed and implemented, extensive site investigations must be performed. However, the following stop gap measures can be instituted to provide some degree of temporary control. •Identify obvious pathways of contamination such as drainage ditches, seeps, outflow pipes, etc. and seal them off •Divert surface drainage away from contaminated areas •Install combinations of cutoff walls, collection ditches and trenches to concentrate and collect strong leachates for treatment and proper disposal
Equipment and Services Needed	To be determined on case specific basis
Other Considerations	All emergency remedial work should be conducted by trained, experienced and properly equipped personnel or outside contractors. Work must be planned in detail and contracts carefully drafted. Contract provisions should include proper insurance, attention to regulatory detail and adequate emergency procedures and contingencies

Table VII.
Elements of Phase 6, Detailed Site Field Investigation

Objective

A complete field investigation is designed and implemented to include sampling and analysis of wastes and monitoring, sampling and analysis of area soils, surface waters and groundwaters. The nature and extent of contamination, present impacts and potential future impacts are determined.

Assignment of Responsibility

This investigation will need to be conducted by outside contractors selected by the corporate, divisional and plant coordinators, together with the appropriate legal staff

Detailed Field Investigation Tasks

Preparation Tasks

- Assemble and review all data collected through previous phases
- The importance of site historical data cannot be overstressed. Prior to conducting expensive field work, the record must be clear concerning property chain of custody, hazardous materials use, and hazardous waste generation and disposition. Techniques for obtaining missing information include: searching land records; obtaining historic air photos and maps; reviewing old industrial directories and commerce reports; interviewing local historians; and interviewing employees of long standing, former employees and employees of past operations
- Prepare request for proposals for detailed site investigation
- Review proposals, interview finalists and select environmental consulting contractor

Typical Field Tasks

- Complete a photogrammetric survey of the site area. Maps of a scale 1" = 20' or 1" = 50' with a 1' or 2' contour interval are usually required
- Using the site maps and aerial photographs, prepare a detailed surface and subsurface exploratory program plan. The plan considers what data is already known and provides for the stepwise collection of the remaining data needed to meet the Phase 6 objective. The program would typically consist of the following:
  1. Sampling and analysis of discrete waste accumulations, for which chemical analyses do not already exist
  2. Based on waste characteristics and analyses, select contaminant parameters, contamination indicator parameters, and ground and surface water quality parameters for subsequent monitoring, sampling and analysis work
  3. Conduct surface water sampling and analysis program for any standing or flowing water bodies immediately upgradient, on, or immediately downgradient of the site
  4. Complete test pit and shallow soil boring program, logging and sampling materials encountered
  5. Install piezometers and/or groundwater monitoring equipment in selected shallow borings and test pits which intersect the water table
  6. Conduct deep drilling and boring program, collecting split spoon samples at 5' intervals or change in lithology
  7. Install piezometers and/or groundwater monitoring equipment in selected borings and drill holes
  8. Perform pump tests on selected well installations to aid in defining site hydrogeologic characteristics
  9. Conduct geophysical survey (eletrical resistivity and/or seismic) to confirm and augment subsurface data and
  10. Define surrounding property use, present natural resource use and potential future nature resource use

Data Reporting and Evaluation

- Even if a field investigation program is well designed and carried out, surprise discoveries will require modification of the plan as work proceeds. This is the norm rather than the exception
- At the conclusion of the investigation sufficient data will be in hand to determine the extent and nature of contamination, present impacts and potential future impacts. Typical outputs might include:
  1. Results of waste, soil, surface water and groundwater sample analyses
  2. Maps showing discrete waste accumulations, types and volumes
  3. Maps presenting surface water quality data and flow information
  4. Soil contamination maps and cross sections
  5. Geologic (bedrock and surficial geology) maps and cross sections
  6. Results from field and laboratory permeability tests, transmissivity calculations
  7. Hydrogeologic maps, cross sections and flow nets and
  8. Groundwater contamination maps, cross sections and flow nets

Equipment and Services Needed

To be determined on case specific basis

Other Considerations

The contractor should be a full service environmental consulting firm with site contamination investigation experience and staff expertise in the fields of Geology, Hydrogeology, Chemistry, Environmental Engineering, Industrial Engineering, Chemical Engineering, Hydrology and Environmental Science

Table VIII.
Elements of Phase 7, Definition of Remedial Strategies, Risk and Financial Liability Assessment and Remedial Cost Effectiveness

Objective

Several removal, containment and combination scenarios are developed to remedy the environmental and related health problems presented by the site. The costs of implementing each scenario are calculated. Relative cost effectiveness is then determined for each case in terms of implementation dollars paid out versus estimated financial liability risks remaining after implementation.

Assignment of Responsibility

It is recommended that the contractor on board for Phase 6 be retained for the Phase 7 efforts, working closely with the corporate, divisional and facility coordinators and assigned legal staff.

Remedial Scenario Development

Removal Scenario

- In cases where discrete waste accumulations of known type and volume are the sources or potential sources of significant environmental and/or health damage, removal and proper disposal at permitted treatment and disposal facilities is highly recommended
- Costs of removal and proper disposal are easily determined by obtaining quotes from reputable disposal contractors
- This scenario assumes that any residual contamination left after removal is insignificant and of no future consequence

Containment Scenarios

- Containment strategies seek to control the release of hazardous contaminants to the environment. Control is achieved by isolation, partial isolation, contaminant collection, physical and chemical stabilization and alteration of ground and surface water flow to prevent off site contaminant discharge
- In a given situation one or any combination of containment strategies might be used
- Unit costs are determined using conceptual designs and standard engineering costing procedures
- Containment scenarios assume that long-term maintenance and monitoring will be required to assure continued performance of the containment goals
- Monitoring and maintenance costs for an assumed period (usually 20-30 years) are computed, adjusting for inflation, and added to scenario implementation costs

Combination Scenarios

- In a given situation removal and any combination of containment strategies might be used

Cost Effectiveness

Costs

- Costs, as computed above, are taken as given for each particular remedial scenario
- Cost effectiveness is determined by employing an event/consequences analysis

Event/Consequence Analysis

- The event/consequence analysis is a semi-quantitative cost effectiveness assessment of the degree of risk control provided by implementing a remedial scenario of known cost
- Each remedial scenario is evaluated in relation to the answers to the following questions:
  1. How might the strategy fail?
  2. What is the probability of failure?
  3. Are obvious or planned fall back strategies available to detect and correct failure situations?
  4. What financial risk is exposed as a result of failure in terms of resource restitution, replacement, awards for health and property damage, and enforcement penalties?
  5. Is the financial risk manageable; or should a remedial scenario requiring larger initial investment, but posing substantially lower long-term financial risk be employed?

Other Considerations

It is recommended that an insurance consultant who is expert in environmental liabilitiy matters be retained to review cost effectiveness issues related to financial liability risks

Table IX.
Elements of Phase 8, Selection of Preferred Remedial Strategy

Objective	After careful examination of the pros and cons attending each remedial scenario developed through Phase 7 efforts, a preferred strategy is selected for implementation. The alternatives considered and the rationale for selection of the preferred strategy are presented to the appropriate regulatory agencies for review, comment, negotiation and final concurrence or approval
Assignment of Responsibility	Corporate, divisional and facility coordinators working with assigned legal staff and outside consultants
Info. Req'd.	The data needed for presentation of the strategy selection process should be in Data on hand as a result of Phase 6 and 7 tasks. This information will include: detailed field investigation reports and maps; remedial scenario conceptual designs and costing data; and cost effectiveness and financial liability risk evaluations A statutory and regulatory compliance brief should be prepared by the legal staff to determine compliance issues and status related to implementation of the preferred remedial strategy. Details concerning the need for any regulatory permits and steps to be taken to maintain compliance throughout remedial action implementation should be addressed
Other Considerations	The importance of regulatory agency concurrence and approval of the remedial strategy cannot be overstressed. While in certain cases approvals are not required, obtaining consent is still recommended. This reduces the potential for costly regulatory agency second guessing during and after remedial work. The legal staff must be convinced that any instrument (letter of approval, consent agreement, compliance order, permit, etc.) issued by the appropriate regulatory agencies is both understandable and conclusive.

Table X.
Elements of Phase 9, Implementation of Remedial Action

Objective	The engineering, schedule, logistics and all contractual arrangements are finalized. Any required permits are obtained. Remedial work is initiated and completed.
Assignment of Responsibility	Corporate, divisional and facility coordinators work with assigned legal staff, *outside consultants, clean up contractors, construction contractors and* disposal contractors.
Contract Considerations	Most corporations have standard construction and service contract formats. These formats often do not consider contract conditions needed for work related to the handling, transport and disposal of hazardous substances. Topic areas to be considered when drafting site remedial work contracts are listed below.

1. Definitions
2. Overall Project Management
3. Cleanup Operations Management
4. Construction Management
5. Security
6. Emergency Procedures
7. Contingency Plans
8. Personnel Safety and Training
9. Safety Equipment
10. Utilities
11. Materials Handling
12. Transportation and Permits
13. Treatment and Disposal Methods
14. Treatment and Disposal Permits
15. Record Keeping and Reporting
16. Insurance
17. Performance Bonds
18. Indemnification
19. Subcontracting Authority
20. Inspection of Work
21. Sampling and Analysis Protocol
22. Services to be Performed, Responsibilities
23. Facilities to be Provided
24. Materials to be Provided
25. Equipment to be Provided
26. Personnel to be Provided
27. Project Start and Completion Dates
28. Project Milestones
29. Compensation to Contractor
30. Method and Schedule of Payment
31. Rate Schedule
32. Amendment Clause
33. Payment of Taxes
34. Title and Disposition of Equipment
35. Release and Discharge
36. Termination
37. Force Majeure

Figure 1.
Fitzgerald Gasket Plant, Torrington, Connecticut, 1976

Figure 2.
Shopping Mall On Former Fitzgerald Gasket Property, Torrington, Connecticut, 1980

Table XI.
Elements of Phase 10, Certification of Performance and Addressing Future Potential Liability Issues

Objective	Confirm that remedial work has been completed as planned and establish mechanisms to control any future potential site liability
Assignment of Responsibility	Corporate, divisional and facility coordinators work with assigned legal staff, outside consultants and regulatory agencies
Certification of Performance	•A licensed professional engineer certification of as-built plans and specifications for the remedial work is obtained •The certification is reviewed by the appropriate regulatory agencies, inspections conducted and conclusive regulatory sign-off obtained via: 1. Letters of approval 2. Release of bonds 3. Statements of compliance with stipulated agreements 4. Statements of compliance with regulatory compliance order conditions and 5. Statements of compliance with specific regulations
Control of Remaining Liability	•Any required long-term monitoring and maintenance is initiated to detect and control future liability •The availability and economic feasibility of obtaining environmental impairment liability insurance, self insurance, or other forms of indemnification is investigated •Nonsudden environmental impairment insurance is now offered by the following firms: 1. Shand Morahan 2. Alexander and Alexander 3. American Intern'l Group 4. Stewart-Smith 5. Swett and Crawford Management 6. Travelers 7. Aetna 8. U.S. Insurance—Lloyds of London
Property Transfer	•Property transactions involving hazardous substance site contamination must consider the responsibilities of the seller, buyer, lessor and lessee with relations to liability, site maintenance and site monitoring •Responsibilities and liabilities can be shared or assumed by one party •Contracts and sales agreements must be carefully worded by attorneys working closely with technical experts

CASE HISTORY—INVESTIGATION AND CLEANUP BEFORE PROPERTY PURCHASE

PCB Contamination

TRC performed a contamination evaluation for a pharmaceutical manufacturer. The need for the study arose when the potential purchases of the site required that the present owner certify that the site was not contaminated. The TRC program included a number of shallow borings to determine whether soil or unsaturated zone contamination had occurred through spills. A test well was drilled to determine the quality of site groundwater. Because numerous industrial sources existed in the area, routine analyses were keyed to an organic chemical produced by the previous owner. These routine analyses showed that some product spills had occurred but that the level of contamination was not significant.

Analyses for PCBs, however, showed that several spills had occurred around the site. While levels did not exceed "regulated" amounts it was decided to delineate and remove the contaminated soils to avoid future problems.

CONCLUSIONS

In response to a clear public mandate, statutory and regulatory initiatives conceived to seek out, control and assign liability for hazardous substance and hazardous waste site contamination problems are now in place. The site contamination and liability audit process presented herein has outlined methods for locating, investigating and controlling hazardous site contamination problems.

The property screening phases are the most valuable aspect of the audit process. Screening identifies hidden problems before time can make them worse. More importantly, however, is that a low cost investment in property screening prior to purchase can prevent the acquisition of liabilities of vast dimension.

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INSTITUTIONAL LEARNING IN A BUREAUCRACY: THE SUPERFUND COMMUNITY RELATIONS PROGRAM

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INTRODUCTION

With the passage of the Comprehensive Environmental Response, Compensation, and Liability Act in December 1980, the federal government acquired funding and authority to clean up the multitude of abandoned hazardous waste dumps threatening public health and the environment across the nation. Primary responsibility for administering the Act's provisions was assigned to the U.S. Environmental Protection Agency (EPA). EPA had, however, begun planning its program—the "Superfund" program—some six months in advance, recognizing that the widespread publicity given cases like Love Canal made the need for such legislation clear.

In this paper, the authors analyze the planning and development of one component of EPA's Superfund program—community relations—as an illustration of a general model for institutional learning in a bureaucracy. The model is presented first in outline form. Then, in the third section, the development of the Superfund community relations program is described to illustrate the model. In the fourth section of this paper, the authors analyze the structure of the community relations program, in its present form, in order to relate the bureaucratic learning process to organizational aspects of the performance of program functions. The adequacy of the model to the learning process in other kinds of institutions is commented upon in the conclusion.

The distinguishing feature of the development of the Superfund community relations program, as a case of institutional learning, is that it constituted more a revision of an institutional memory than the acquisition of new knowledge. EPA, as a ten-year-old institution, was not only well-acquainted with the kinds of functions that comprise community relations, but in fact, had a significant bias toward their inclusion in programs aimed at the protection and enhancement of the environment. Thus, the learning that took place in the evolution of Superfund community relations did not begin with a *tabula rasa*; rather, it refined and redirected familiar functions. But it did so in a political climate that was becoming unreceptive to the value of those functions.

A Schema for Institutional Learning

The learning process illustrated by the Superfund community relations program can be represented by the following steps:

- The recognition of a *problem* to which the institution must respond.
- *Research* on the nature of the problem and its implications for institutional organization and performance
- Development of *policy* based upon the research conducted
- The development of means for *disseminating* the policy
- The acquisition of programmatic means for *implementing* the policy
- Monitoring and *evaluation* of the program implemented

The learning process must not be equated with the research step. Rather, it should be regarded as all those actions that lead to the incorporation of relatively novel functions in the on-going activities of the institution. The learning that takes place, in other words, is constituted by the alteration of institutional behavior and the actions leading up to that alteration. Data-gathering, subsequent analysis and the broadening understanding of the staff of the institution are only steps in the process. These steps may serve primarily as instruments useful in changing policy rather than being valuable in their own right as the acquisition of knowledge.

The alteration of institutional behavior is the result of changes in three areas as a result of the learning process:

- The institution's self-conception.
- The institution's operations.
- The program in question and its results.

These factors require some explanation.

Corresponding to (or produced by) the institution's memory is a conception of its role and significance that is passed down through the staff. This self-conception may or may not accord with the conception that others—e.g. the public or members of sister institutions—have of the institution. In any event, the self-conception will dictate, to some extent, the manner in which the institution's functions are performed.

On a more formal level, the institution's policy will be codified in certain explicit standard operating procedures. A learning process will alter policy, alter standard operating procedures in turn and, ultimately, alter the activities of the institution.

Finally, the program under whose auspices the learning process begins will be directly affected, even in its structure and operations, by that process. These should be consequences for the results obtained by the program, that is, the success (or failure) in various aspects of program activities.

The development of the Superfund Community Relations program illustrates this learning process, and the factors changed through it, against the backdrop of a prior institutional memory.

COMMUNITY RELATIONS POLICY DEVELOPMENT

In April 1980 EPA established the Office of Analysis and Program Development (OAPD) to provide pre-implementation planning and legislative support for the anticipated Superfund program. By mid-1980, OAPD had established the theoretical parameters of the community relations program. The office conceived of it as a coordinated program of federal government interaction with a local community where that community is the subject of a federal action. Community Relations was considered to include local media and press relations, public participation, local government and local interest group relations and public information/education.

With the degree of public, congressional and media interest in the pending Superfund legislation, OAPD recognized that its planning process had to emphasize effective response. In emergency situations, an effective response was considered one that ends an existent state of emergency and permits a return to substantially pre-emergency conditions. In proposed remedial action, an effective response was considered one that would permit the Agency to maintain its credibility while eliminating the environmental hazard. In either case, the Agency recognized that its response must not only remove the peril to the environment and to human health but also remove the perceived threat to human and ecological well-being as well.

With this understanding as background, OAPD proposed that the primary goal of the community relations program be to facilitate the implementation of cost-effective solutions to hazardous waste problems by ensuring adequate communication between government and local communities during response actions. It was assumed from the beginning that hazardous waste incidents had the potential to generate extremely emotional reactions in local communities. Thus, government actions in this extremely volatile political environment would have to be explained with great thoroughness and care if they were to be fully understood by the community. In order to achieve the goal of ensuring adequate communication, a number of secondary goals were advanced:

- Ensuring the local community a meaningful voice in those implementation decisions that the community considers most important
- Establishing a program of public information and media relations that is appropriate to the degree of interest and concern about the site
- Anticipate potential conflicts and attempt to avoid conflict whenever possible
- Establish standard operating procedures that ensured extensive interaction between local government officials and federal/state officials.

OAPD generated an issue paper which outlined these goals and the resources needed to reach them for a program of the scope envisioned by Congress. It was anticipated that the Agency would be expected to have the organizational and technical capacity to address community concerns. This would only be possible if, from the outset, community relations were declared a major program element in Superfund. OAPD reasoned that waiting until political pressures forced community involvement on EPA would probably result in the loss of the opportunity to manage community relations to facilitate rather than impede cleanup actions.

Although the Superfund program was to have many elements which would be new to EPA implementation, the Agency was not without experience in emergency response to hazardous waste incidents. Much valuable experience had been gained over almost a decade in the implementation of Section 311 of the Clean Water Act. In order to avoid serious blunders in the new program, OAPD would have to do a lot of learning in a hurry. To do so, it let a contract to ICF Incorporated to take a serious look at several hazardous waste emergency operations which had been conducted either under Section 311 or under state auspices in order to analyze the degree to which community relations efforts had been effective. In short, the purpose was to analyze what had been accomplished at these sites, what had been done well, where the Agency had failed to provide for effective community/government interactions and generate the lessons which would be applicable to the greatly expanded scope of the Superfund program.

The analysis was based on the assumption that with knowledge of what had actually taken place in hazardous waste emergencies across the country, a more realistic program could be designed—one that was more understanding of, and responsive to, the needs of the public and the capabilities of government. In addition, by looking at the community relations techniques which had been employed in the past in these situations, and seeing which had worked well and which had not, EPA would learn what techniques to use in the future or to avoid. The result, it was hoped, would be a program which would more effectively—and efficiently—involve citizens in their government's response to these environmental problems and inform them of actions underway in their community.

The methodology employed was to learn as much as possible about the cases through newspaper accounts and interviews with officials in Washington—the staff of local congressmen and EPA personnel—and then to travel to

the site for at least a week of intensive interviewing. Officials in state environmental agencies and Regional EPA offices were consulted at length. Interviews at the site were conducted with citizens who were actively involved in the problem, civic leaders, local government authorities and environmentalists—as well as with people living in the vicinity who had taken no interest or expressed no concern. The completed studies were envisioned as background material for the development of a handbook that would assist EPA personnel responsible for implementing the Superfund program.

By August 1980, it was clear that the researchers were breaking new ground in the understanding of community relations at the four sites under review, but it was equally evident that a more complete picture of community relations around the country was required. These initial studies demonstrated a wide range of citizen concern with and involvement in hazardous waste emergency operations; thus EPA decided to expand the study to include sites in each of the ten Regions. Site selection was based on input from 311 emergency operations personnel throughout the country, with the final selection geared toward sites at which Superfund operations might be initiated. The cases analyzed in this second round brought the total number of cases in the study to 21.

Even as the results of the expanded series of case studies were being analyzed, EPA began moving into the field with draft guidance to the Regions on the probable extent of a community relations program under Superfund. The first draft of a guidance document was sent to the Regions based on a preliminary analysis of the case studies and the Superfund headquarters organization requested that the Regions comment on the effectiveness of the proposed guidelines. The draft manual suffered from the fluidity of planning regarding the shape of the final program. Although the legislation had now been passed, the new Administration was not yet established and the shape of the final program was in some doubt. By the end of February, however, Regional comments had been received and catalogued by headquarters and Michael B. Cook, EPA's Deputy Assistant Administrator for Hazardous Emergency Response, issued interim community relations guidance for site cleanup.

The interim guidance document established the policy by which Superfund implementation would be guided in the community relations area. This policy requested that the Regions adhere to the following principles:

- informing the local community about Agency actions
- empathizing with local concerns, learning about the local community
- avoiding the generation of unrealistic expectations
- being open and forthright with information
- anticipating the formation of *ad hoc* citizen groups
- coordinating actions with local officials
- assigning community relations coordinators whenever possible
- using a variety of participatory techniques
- considering the establishment of citizen advisory committees at sites and spills having a high degree of citizen concern
- providing adequate training for Regional staff.

Operationally, each of these principles had been derived from the 21 case studies which had been undertaken by ICF and each was factored into the newly designed remedial and emergency response activity schedules for the Superfund program.

The guidance document for community relations during remedial response activity was divided into discrete response phases and informed by a determination, on the part of the EPA on-scene coordinator (OSC), of the degree of citizen concern at a site, combined with the extent of environmental damage and the complexity of the proposed technical solution. The determination of the degree of citizen concern was to be based, at least in part, on the results of interviews conducted by the OSC at the site among local officials and concerned citizens.

The methodology which had been employed by ICF in conducting the case studies had been found to be so effective in ferreting out the concerns of the local community that the interim guidance incorporated that methodology into the schema for Superfund response at all remedial actions. In addition, the value to the Agency of the ICF case studies was exemplified in the requirement, placed in the interim guidance, for the development of a Community Relations Plan for each site at which remedial action was to be taken. The plan was to be designed and executed as an integral part of the remedial response, not simply appended to the response as an afterthought.

During emergency response actions, the interim guidance document noted the importance of keeping the community informed of the Agency's actions and the need for the establishment of a close working relationship with local officials. The same principles which mandated the generation of a community relations plan during remedial response prompted the inclusion of a similar plan in those emergency situations which might be followed by remedial action. As a result, the community relations component of the Superfund program had become a significant element of all responses which would be taken by the Agency.

By the summer of 1981, the National Contingency Plan (NCP), first developed for the implementation of the Clean Water Act, was ready for publication in the *Federal Register*. The newly revised NCP, as mandated by CERCLA, was to contain the final guidance for the implementation of the Superfund program. It would outline, in detail, the steps which could be taken at remedial and removal operations under the authority of the Act.

Unlike earlier versions of the NCP, the newly issued guidance fully incorporated the Community Relations function into the operation of a response. Even the format of the NCP points to this incorporation. The text of the new NCP mandates the inclusion of all of the community relations techniques, including the methodology developed for ICF's case studies, the use of the community concern and degree of technical difficulty factors in determining the level of response necessary for an effective community relations program, and the inclusion of Community Relations Plans in all response actions.

Annex XI of the NCP, titled "Community Relations," specifies the mechanisms to be used, the design of the community relations plans, and the nature of the community relations program. The Annex states that:

> "All community relations functions will be fully integrated within the operational units responding under provisions of the Plan, and all aspects of response operations must include provision for the execution of community relations programs."

THE ROLE OF EPA HEADQUARTERS, REGIONS, AND PRIVATE CONTRACTORS IN IMPLEMENTING COMMUNITY RELATIONS PROGRAMS

The basic thrust of all efforts in headquarters, Regions and by contractors was to implement community relations programs in the field. Superfund resources would not be used for a nationwide education campaign, but instead, would be directed to support response actions.

Headquarters

Headquarters' role included the lead on policy formulation, reviewing community relations plans, training, program evaluation and resource analysis. Headquarters provided informational materials on the Superfund program, expert personnel for temporary community relations work at critical sites, overall contract management and other support services in the field.

Regions

Regions would take the lead on implementing community relations programs, developing site-specific public information materials, supervising regional community relations subcontractors and developing community relations plans for headquarters. The community relations load unit was a matter of Regional discretion.

Contractors

Contractors would provide support services to headquarters and regional community relations program activities. At headquarters, this would primarily be analytic work in support of guidance and policy revisions. In the Regions, contractor work would be staff and background work to permit the Regions to stretch their own personnel to allow coverage at as many sites as possible. One essential principle was to be maintained throughout the program: contractors would never represent, or even appear to represent the Agency to the public, other government officials, or the media (i.e., to anyone).

IMPLEMENTING COMMUNITY RELATIONS

Organizational Strategy: Headquarters

One of the four branches in the original design for the Superfund DAA staff office was the "Community Governmental Relations Branch." In the original proposal, the Branch had three sections: (1) Community Relations, (2) Public Information, and (3) Government Relations. Typically, minimal staffing for a section would be three professionals, one clerical person, and a supervisor. When staffed, the Branch would have approximately 15 members. The original organizational proposal stated that:

> "The general functions of this Branch would be to: (1) develop public participation/information policy and guidance, (2) carry out a coordinated program of public education and participation, (3) provide community relations support to on-scene coordinators at critical abandoned waste sites, and (4) coordinate the collection and dissemination of technical information and public education materials."

The proposal was considered by the Superfund National Program Manager. He decided not to establish a distinct organizational unit to carry out this function. Instead, community relations policy development and coordination was lodged in the Policy Analysis Branch of the Deputy Assistant Administrator Staff office in the Superfund headquarters organization and each operating division was held responsible for ensuring the implementation of community relations policy within its own functional area.

The rationale for this decision was that community relations was to be an integral part of the Superfund program: a normal, routine part of doing business. Just as there would be no distinct organizational unit established to monitor the health and safety of staff on-site, there would also be no need to establish a distinct organizational unit to handle community relations.

This approach has certain intrinsic strengths and weaknesses. On the positive side, it helps ensure that community relations could be a fully integrated component of response. Those organizations making technical decisions would also be responsible for ensuring that local communities would be informed of and involved in response actions. This type of organizational structure ensures that community relations programs will not develop a "life of their own," and will be given priority only in connection with central technical functions. A more significant advantage of the integrated organization strategy is that a difficult-to-explain, vulnerable function is given lower visibility and protected from attack from OMB, Congress and others.

In early 1981, when the Reagan Administration submitted the FY '82 budget, almost every public participation organizational unit in EPA was eliminated. It is possible that a distinct organizational unit for Superfund Community Relations would have suffered a similar fate.

Nevertheless, a distinct organizational unit for community relations could bring significant benefits. Such an arrangement allows expertise to be accumulated and then concentrated in a single place. It also ensures that a supervisory-level individual would be held responsible for developing and implementing the community relations pro-

grams. In the Superfund program, community relations was a major responsibility of the headquarters policy analysis branch chief, but was only one responsibility among many.

The Superfund headquarters community relations organization was informal. At the staff level, Steve Cohen was responsible for developing policy and ensuring its overall coordination and implementation. Each operating division in the Office of Emergency and Remedial Response had a single individual responsible for ensuring the implementation of community relations policy in Regional office programs. These individuals met for a short time as an "Informal Working Group," to work with Cohen and develop a program to implement community relations policy. This informal group met several times before its collapse. Cohen found it more efficient to work individually with each division's lead community relations person, rather than convene work group meetings. Decisions reached by the group proved difficult to implement due to the fact that each community relations "coordinator" had to clear all tasks with his or her formal supervisor.

Regions

Regional office Superfund organizations evolved throughout 1980 and 1981. During that time, community relations was not organized according to any single pattern. In mid-1980, headquarters asked each Regional Administrator to name a Regional Superfund coordinator. These coordinators, in most cases, came to head the Region's Superfund organizational unit. In late 1980, headquarters requested that each Superfund coordinator name a Community Relations Coordinator. These community relations coordinators were responsible for developing community relations plans and ensuring the implementation of those plans. In some Regions, plan development and implementation was assigned to the Public Affairs or External Relations Office.

DEVELOPING AND IMPLEMENTING COMMUNITY RELATIONS PLANS

The Interim Community Relations Guidance issued on February 25, 1981, required the submission of community relations plans. Because of the shortage of EPA personnel, the headquarters Superfund office planned to provide contract resources to the regions to assist in plan implementation. Throughout the spring and early summer of 1980, the Hazardous Site Control Division (OERR) requested, received and reviewed 30 community relations plans. Although some of these plans were quite good, overall:

- The majority of the plans did not contain a sufficient quantity of the high quality information needed to make an independent judgment regarding the adequacy of the plans
- Very little attention was given to the technical complexity of sites (as required in the Guidance)
- Most of the plans followed headquarters guidelines for cost estimates, but it was difficult to determine whether or not the level of community relations activity recommended was desirable given the lack of background information

In order to develop consistent community relations plans, it was decided to also provide contractor assistance to the regions for developing these plans.

The specific contractor assistance scheme which began in August 1981, followed early in the Superfund program provided the regions with staff assistance from Architecture and Engineering (A&E) firms during technical work on-site, and from the Technical Assistance Team (TAT) contractor. ICF Incorporated, the firm that developed much of the community relations program guidance material, was contracted to:

- Work with A&E firms to develop community relations capability in these firms
- Develop community relations plans for regional office approval
- Monitor contractor performance in the field

FACILITATING INSTITUTIONAL LEARNING

The entire effort at community relations policy development and program implementation was an effort to facilitate rapid institutional learning. The political difficulties that EPA found itself in at a large number of hazardous waste sites around the country (e.g., Love Canal, New York; Stringfellow, California; Memphis, Tennessee; Valley of the Drums, Kentucky; and Jackson Township, New Jersey) convinced Agency management that new standard operating procedures had to be developed and instituted to forestall some of this opposition. It would be impossible to carry forth the mandate of "cost-effective" remedial actions if citizen protest caused delay and redesign at scores of waste sites.

The first stage in institutional learning is to develop new institutional routines or standard operating procedures. The ambitious research program conducted to develop community relations policy included the case studies at 21 hazardous waste sites, interviews with personnel in every EPA Region, and considerable brainstorming and analysis. Once the regional procedures were developed and communicated to the Regions in the form of the February 25 Guidance and the Community Relations Handbook, it was then necessary to provide a set of incentives to secure program implementation.

The incentives provided fall under three categories: (1) leadership, (2) training expertise and (3) staff-contract resources.

Leadership

In a hierarchy such as EPA, consistent messages from the top, and from headquarters to the Regions, are necessary to facilitate institutional learning and organizational change. At the first headquarters meeting of the Superfund Regional Coordinators and at most subse-

quent meetings, headquarters staff and the Superfund National Program Manager stressed the importance of Community Relations in Superfund. This message was reinforced by a number of memos to the Regions.

Regional Superfund staff members were ready for and in most cases welcomed this message. The field personnel had first-hand knowledge of the nature of Superfund's community relations problem, and were eager to take steps to avoid these problems. Many Regional staff members had already dealt with scared and angry citizens and had been shouted at and harassed at public meetings. The Superfund coordinators were fully aware of the fact that Superfund and hazardous waste issues were unlike anything else the Agency had ever faced. The volatility of the issue was particularly obvious. This meant that the Regions were receptive to this new message and such receptivity made the task of institutional learning considerably easier.

Training/Expertise

A training or "briefing" program was developed in spring of 1980 and fielded in the fall of that year. The purpose of the program was to brief Regional staff on community relations issues and practices. In addition, a HQ Public Affairs Assist Team was proposed to assist the Regions in implementing Community Relations at critical sites and will hopefully be established some day as part of the Emergency Response Team in Edison, New Jersey.

Finally, ICF Incorporated briefed the A&E and TAT contractors on the lessons learned in the case studies. This training program provided a means of disseminating new organizational routines. It is, of course, too early to judge the success of those efforts.

Contract Staff Resources

Even if the Regions had the disposition and the expertise to implement the Superfund community relations without resources, all the good intentions in the world will not result in program implementation. Accordingly, headquarters attempted to provide contractor community relations planning assistance to the field to pay for and plan implementation. It was hoped that provision of these resources would reinforce the importance of community relations and stimulate the Regions to allocate some of their own resources to this function.

CONCLUSION

Change is a viable bureaucratic alternative. The inclusion of an effective Community Relations component within the response capability of the Superfund program demonstrates this viability. The entire program has been affected by this inclusion, such that the knowledge gained during program implementation can be applied to the understanding of community relations effectiveness and bureaucratic operations, as well. Had the community relations function not been integrated into the operating divisions of the program, this institutional learning could not have occurred.

THE COMMUNITY HAZARDOUS WASTE COORDINATOR PROGRAM

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INTRODUCTION

All the resources required to solve the hazardous waste problem cannot be found in any one level of government. No one, not state government, not the federal government, not industry, not any other group in society can solve the hazardous waste problem alone. This premise is the basis for the community hazardous waste coordinator program.

The Massachusetts Department of Environmental Quality Engineering (DEQE) cannot do the whole job. The Department's staff realized that in working toward the resolution of the hazardous waste problem it must rely on the interest and expertise of the people who are potentially affected, that is, all the citizens of Massachusetts. It was the recognition of this that led the Department to asking the chief elected officials in Massachusetts' 351 cities and towns to appoint community hazardous waste coordinators. The problem of past improper waste handling at several locations led to this request.

When the Division of Hazardous Waste was established within the Department in January 1980, it faced two immediate uncontrolled sites problems, a huge list of sites potentially containing hazardous waste, limited staff funds and the legacy of poor communications between state government and communities during several hazardous waste incidents in the past. Having a hazardous waste coordinator in each community was seen as a step toward the resolution of both of these.

The Division asked the community coordinators to assist the Department in gathering the necessary historical information on the potential hazardous waste sites and to coordinate the activities of municipal officials and citizens in this effort, because community officials and citizens know their town better than anyone else and important site-specific information is readily available to them. The Division also asked the coordinators to serve as the community contact persons for the Department in any hazardous waste incident and to be responsible for ensuring that the appropriate municipal agencies and citizens are kept involved and informed.

Beyond the need for assistance with these particular uncontrolled sites problems, the Department was convinced that the coordinators also could provide a service to the Massachusetts hazardous waste management program. The coordinators could become advocates in the communities for responsible waste handling.

When the Department asked for the coordinator appointments, their role was described as coordinating local groups and agencies in responding to hazardous waste problems and serving as a lead community representative in all hazardous waste management activities. A previous knowledge of hazardous waste was not required for the position but a strong interest and the ability to manage people and projects were strongly recommended. This approach led to the large variety in the professional backgrounds of the coordinators.

COORDINATOR RESPONSIBILITIES

The specific responsibilities of a coordinator vary depending on the needs of the community and the interest and expertise of the particular coordinator. The materials sent to the chief elected officials and to the coordinators themselves outlined the range of activities involved in preventing, detecting and responding to hazardous waste problems:

(1) Serving as primary community contact for the Department and developing community contacts so that they can relay important hazardous waste problems or questions to the DEQE regional hazardous waste coordinators.

(2) Learning which citizens/agencies/organizations within the community are responsible for or involved in hazardous waste activities:
- *Fire Department* issues licenses for storage of flammable materials above and below ground and also has primary responsibility for responding to hazardous materials/waste spills
- *Police Department* has the ability to patrol the community around the clock and has the authority to arrest individuals engaged in criminal activities
- *Board of Health* has broad powers to protect public health, as well as specific directives including the approval of sites for hazardous waste treatment/disposal facilities and receiving information from DEQE regarding hazardous waste handled within community boundaries
- *Department of Public Works* or Town Engineer knows the locations of sewers, drain outfalls, etc.

- *Conservation Commission* has knowledge of wetlands and other natural resources in the community
- *Industrial Development Commission, Planning Agency, and/or Chamber of Commerce* know about the types of industry currently in the community and about which industries may be planning to come into town—including hazardous materials users and disposers. These agencies can also be very helpful in encouraging the participation and cooperation of local industries
- *Water Department Superintendent* knows the sources of groundwater in the community, as well as sources of drinking water, recharge zones, etc.
- *Many citizens* are knowledgeable in fields relating to hazardous waste

(3) Organizing local resources:
- Contacting and developing local resources
- Forming a hazardous waste committee or task force to assess the hazardous waste/materials situation in the community and to choose activities to encourage good hazardous waste management in the community
- Working through the established authorities to ensure proper hazardous waste management in the community

(4) Educating citizens about:
- The threat to public health and environment caused by hazardous wastes which are mismanaged
- How hazardous wastes can be sensibly handled by using the available technologies for properly treating, recycling and disposing of hazardous wastes

(5) Preventing and detecting hazardous waste problems:

a. Assessing the hazardous waste/materials situation in the community by identifying:
- *All of the hazardous materials in the community* by categories, classes, volumes, locations and type/age of containment. In addition to industrial users, this survey would include facilities such as hospitals, dry-cleaners, research laboratories and gasoline stations
- *What goes into the community landfill.* Although it is illegal, significant quantities of hazardous waste, particularly that generated by small firms, are deposited in landfills (with or without the operator's approval)
- *Old abandoned dump sites* by checking old maps and photographs and by talking to older community residents
- *Transportation routes for hazardous materials* including truck routes and railroad corridors. To the extent possible, the frequency and timing of hazardous materials shipments, as well as the types of materials shipped, should be identified
- *Where underground gasoline storage tanks are located* and beginning as a program to require owners to test them for leakage

b. Mapping out local water supplies. Becoming familiar with the network of aquifers, surface waters, recharge zones, and wetlands in the community, focusing on those that feed drinking water sources. Determining where water supplies are with respect to potential sources of contamination. Finding maps which already exist.

c. Assisting the Department and the U.S. EPA in investigating suspected hazardous waste dump sites by gathering the necessary historical information:
- A complete site-use history
  - *site uses over the years: industrial; residential; waste disposal
  - *owners of the site (past and present) property maps, deed descriptions and restrictions, etc.
  - *chemicals manufactured or possibly dumped at the site
- Types of waste suspected on site
  - *nature of industrial process that generated the waste
- Evidence of pollution resulting from the site
- Location of nearest surface water, including changes in surface water elevations (presence of dams/diversions, culverting of streams) and changes in direction of flow by natural or man-made causes
- Direction of groundwater flow in relation to the site now and in the past
- Location of nearest dwelling
- Location of nearest drinking water supply
- Type and permeability of the soil

d. If an uncontrolled hazardous waste site is found in the community, participating in DEQE's and the community's decision-making process to determine what kind of action should be taken. The range of choices at some sites includes:
- Removing the material for disposal at a secure chemical landfill or treatment at an environmentally sound facility (this is feasible only in a very limited number of instances)
- Designing and constructing a secure containment for the contamination at the site
- Bringing in an alternative source of water supply or treating a water supply to remove contamination

The Department believes that making these decisions must be a public process. Unless the potentially affected parties and the community understand the options and help decide on a particular solution, the particular situation will be extremely difficult to resolve.

e. Participating in the negotiations between the developer and the community, if a location for an environmentally sound hazardous waste treatment, storage, or disposal facility is sound in the community.

(6) Ensuring that the community is prepared for a hazardous waste/materials emergency:
- Learning about the resources available to respond to hazardous waste/materials emergencies
- Working with the agencies responsible—fire dept., civil defense dept.—to ensure that the appropriate people are prepared to respond effectively and efficiently

TRAINING

At this time, 83 percent or 290 of the 351 cities and towns in Massachusetts have coordinators. A volunteer steering committee of the coordinators has been formed; the Division and the steering committee are currently planning a training program which will assist the coordinators in performing the above activities.

The training program will provide the coordinators with information on: enforcement and legal authorities, emergency response procedures, how to detect and prevent future problems and the siting of treatment, storage, and disposal facilities. The training sessions will provide a forum for the exchange of this information between professionals involved or interested in different aspects of the hazardous waste problem. The coordinators will be able to use the information in their communities to encourage responsible hazardous waste management decisions and avoid repeating past mistakes. Mistakes to be avoided include: building a subdivision down-gradient from the town dump, confusion during a hazardous materials spill and enforcement actions which were not well formulated because municipal officials, including police officers, did not understand their jurisdictions.

PERFORMANCE

A number of communities already have a good understanding of sound hazardous waste management activities. For example, not long ago a developer applied to a Massachusetts city to build a shopping center. The center was to be located above a likely source of future water supplies. The town agreed that the center could be built but stipulated that a system to collect the rain water runoff from the parking lot must be constructed and that no small hazardous waste generators, including hair dressers or dry cleaners, could be located in the center.

One of the most important resources for the coordinators' training program are the coordinators themselves. They are a diverse group of people having many areas of expertise: health officers, conservation commission members, firemen, policemen, lawyers, hydrogeologists and engineers. Many of them are already developing their own emergency contingency plans or are mapping water supplies in relation to potential contamination sources.

One coordinator has given two lectures in the past several months for other coordinators on how to map ground water flow and potential sources of chemical contamination. He has also assisted one of Massachusetts' Watershed Associations in establishing a regional program for community coordinators.

Another coordinator, an environmental engineer, has done extensive emergency response planning for a large chemical company in Massachusetts. He has participated on the coordinators steering committee and has provided valuable emergency response planning information to the rest of the group.

A third coordinator is a self-educated hazardous waste expert. Since he was appointed last fall, he has read as much as possible and attended many seminars and lectures. He has become an important resource for other coordinators and a dedicated advocate for the development of the training program.

During the past several months, many of the coordinators have given the Department their ideas on how they think the coordinator training program should be developed:

- legal authority within the municipality
- the general concepts—still a little confused between "wastes" and materials
- specific suggestions as to organizing the municipal officials and departments in order to get better cooperation
- how to inspire citizen responsibility for hazardous waste management
- how neighboring towns can share information
- how to set up industrial-community seminars
- more about hydrogeology and its relationship to chemical contamination
- possibly a listing of types of generators and the kinds of waste they are likely to produce
- how to anticipate problems and deal with them when they occur
- how to effectively handle emergency incidents—do's and don'ts.

DEPARTMENT'S ROLE

The community hazardous waste coordinator program has provided a number of challenges to the Department. During the past eighteen months when the coordinator program was conceived and organized, the Department was undergoing a number of other major changes. Changes involving organization, the delegation of responsibilities and finding the resources to run the mandated hazardous waste program. This was a difficult time to attempt to develop a new program. Finding the resources required for the training program has been one of the most difficult tasks.

In the time of tightening budgets, it is often difficult to fund the existing work load, let alone a new program. The Department is using in-kind assistance and resources outside the agency to develop the program including local colleges and universities, business and industry, environmental education programs sponsored by civic, professional, and educational organizations and other government groups such as regional planning agencies and federal agencies. Specifically, Tufts University, Boston University, the Monsanto Company, Massachusetts Cooperative Extension Service, Nashua River Watershed Association, Lincoln-Filene Center for Citizen Participation, Metropolitan Area Planning Council are among the organizations that have been actively involved in the program. Essential, however, is the involvement of full time staff members during the program's formative stages. A number of staff people also are providing part time assistance in specific technical areas.

Funding a program using outside resources and in-kind services creates the difficult problem of coordinating all these activities and maintaining the spirit of cooperation

and enthusiasm. Whether this funding approach is viable remains to be seen.

The unconventional nature of the community coordinator program caused a certain amount of confusion within the Department. It is certainly an atypical endeavor for a regulatory agency. Although the program was a logical step for the Department's key decision makers due to their long-standing commitment to involving the public in agency decisions, it was not readily accepted by all the staff members. Nearly a year of discussion and delays ensued before the concept gained acceptance. Some staff members held the traditional view that government officials do their jobs well and that citizens need only be involved minimally, if at all.

If the Department had anticipated the reluctance of the staff to accept the coordinator program, some of the resulting delays might have been avoided. The presentation of the program could have been altered to alleviate some staff concerns; in particular, it was found that a simple, direct statement of the objectives was the most effective vehicle. The reasons were:

(1) To provide a solution to the serious communications problems between DEQE and municipal governments which occurred in several hazardous waste incidents such as those in Acton, Bedford, Lunenburg, Norwood and Woburn.
(2) To let the public and local officials know that DEQE has extremely limited resources and cannot solve the hazardous waste problem alone.
(3) To provide a person in each community who is both concerned and knowledgeable about the problem of hazardous waste to help avoid repeating past mistakes such as:
   - •building a subdivision downgradient from the town dump
   - •siting an industrial park on an aquifer or watershed
   - •panic/confusion during a hazardous materials spill
   - •enforcement actions which were not well formulated because municipal officials, including police officers, did not know the proper procedures
(4) To provide an advocate in each community for educating municipal officials, industry and the public about:
   - •the variety of sound waste management options available
   - •the problem of continued emotional response to hazardous wastes
   - •protecting groundwater resources
   - •promoting responsible waste management practices within the community
   - •procedures for response to a hazardous waste/materials emergency
   - •enforcement activities at the Federal, State and municipal levels
   - •detecting potential uncontrolled hazardous waste sites, especially abandoned municipal dump sites

CONCLUSIONS

After reviewing the reasons why the Department asked for the coordinators to be appointed, the staff agreed with the intent of the program and became much more willing to assist in its development. Perhaps an even more persuasive factor for the staff was the community coordinators' demonstration of their interest and expertise. Through their activities, it became apparent that local citizens do know their communities best and that important community specific information is readily available to them.

In the long term, the benefits of having coordinators should far outweigh the difficulties involved in getting the program started. Today's limited budgets and the general movement toward reducing the size of government make the coordinator's program even more relevant than when it was conceived.

The community coordinators are presently looking into the possibility of forming a non-profit association. Such an association would give the coordinators an independent base outside of the Department and perhaps generate some resources. Given the tenuous political support for environmental issues in government, an association could provide the coordinators with continuity they might otherwise lack.

The coordinator program is a reflection of the axiom that "hazardous waste is everybody's problem." As the coordinators become more and more involved in preventing and resolving specific hazardous waste problems, they will be a group of people actively taking responsibility for problems created by mismanaged hazardous wastes.

The community hazardous waste coordinator program is still in the experimental stage. The Department's staff is learning an immense amount with each step that the program takes and hopes that the coordinators are learning enough from the program to keep them actively involved. The Department's staff encourages other agencies to become involved in similar programs, are eager to learn from the experiences of others, and are optimistic about the benefits of this type of public participation.

CITIZEN/GOVERNMENT INTERACTION AT TOXIC WASTE SITES: LESSONS FROM LOVE CANAL

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INTRODUCTION

It is ironic, at least to environmentalists, that the effort of William T. Love to develop hydroelectric power—a form of energy conversion that is considered environmentally benign—should eventually result in one of the most traumatic environmental tragedies of the 20th century. Love's grand scheme to develop a new industrial city utilizing hydroelectric power projected the construction of a canal to carry water from the upper Niagara River to the generation point. After nearly 1000 cubic yards of the canal had been excavated in 1895, the project was abandoned.

In the 1930's the abandoned trench had become a dumpsite; beginning in the 1940's it was used by the Hooker Chemical Company, the City of Niagara Falls, and according to recent assertions, the U.S. Army. The main user, however, was Hooker Chemical which for over a decade dumped hundreds of tons of toxic chemicals, most of them enclosed in 55-gallon drums, into the unfinished canal. When the canal was full, Hooker claims that it was sealed with a clay cap, an accepted procedure for such dumps at that time.

During the late 1940's and early 1950's the City of Niagara Falls expanded into the Love Canal area. Over 700 homes and a school were built in the vicinity of the canal during the late 1950's.

Beginning in the late 1960's and throughout the '70's, the metal drums that had contained the chemicals developed holes due to corrosion and began to leak. Toxic leachate rose to the surface, especially after heavy rains. During the 1970's it was discovered that leachate had migrated horizontally reaching the basements of nearby homes and, even later, evidence was uncovered that the leachate had traveled several blocks.

Chemicals and drums coming to the surface and the appearance of numerous health symptoms, led a few local residents to press government agencies to investigate the problem and take remedial action. Early citizen requests were ineffectual; local governments were not equipped for the problems that citizens were asking them to deal with.

In late 1976, the N.Y. Department of Environmental Conservation (DEC), the City of Niagara Falls and U.S. Environmental Protection Agency (EPA) began to investigate water quality problems in the area. Meanwhile, the State Department of Health began the examination of possible health effects associated with exposure to toxic wastes. In April 1978, Commissioner of Health, Robert D. Whalen, determined that a health hazard existed in the Love Canal area and ordered the Niagara County Health Department to cover exposed chemicals and install a fence around the area. He also ordered health studies of residents living adjacent to the canal.

In May 1978, EPA announced that air samples it had taken from homes adjacent to the canal contained dangerously high levels of toxic vapors. The State Health Department studies began the following month and found high levels of toluene, chloroform, benzene and chlorotoluene.

On August 2, 1978, Commissioner Whalen issued an order declaring a health emergency, recommending a delay in opening the 99th Street School, and recommending the evacuation of pregnant women and children under two years of age from the immediate canal vicinity.

Governor Carey visited the Love Canal area on August 7, and, at a public meeting, announced that the state would purchase homes affected by the Love Canal chemicals. Two days later it was confirmed that 239 homes in two "rings" around the canal would be purchased. Residents within these first two rings were offered temporary relocation at state expense, pending purchase of their homes. Most of the residents affected by this decision were evacuated to temporary housing.

During August, the State DEC had begun working with the City of Niagara Falls and Conestoga-Rovers, the consulting firm it had retained to review a site cleanup plan. The safety and health of workers and nearby residents became an integral and controversial aspect of the interim construction plan. The scope of the safety plan included:

- Security and communication provisions
- Personal hygiene and workers' safety
- On-site monitoring and sampling
- Emergency evacuation provisions (this provision later became quite controversial).

Also, during August, the State Department of Health took blood samples from over 2,800 Love Canal area residents. With such a large number, there were long waiting lines which led to complaints about the planning and organization of the health study. Following the sampling, the residents eagerly, and later impatiently, awaited the results. By August 1978, Love Canal had become a highly

publicized and politicized case marked by an extraordinarily high degree of citizen/government interaction.

ISSUES

By the end of August 1978, citizen activity in the Love Canal area was directed toward a number of issues:

- How many homes should be purchased by the state and which ones should they be?
- Which residents should be temporarily relocated, at whose expense and on the basis of what criteria?
- What adjustments would be made in the property tax liability of citizens whose homes had become less valuable and which, if any, homeowners would receive the adjustment?
- What provision would be made for the safety of nearby residents during remedial construction; who would approve of those provisions and who would supervise and enforce them?
- What negative health effects were attributable to exposure to toxic wastes at Love Canal; how would the types and levels of toxic substances be determined; how would health effects be determined and how would such information be reported, and to whom?

ACTORS

Virtually all levels and branches of government that might have had some possible connection with the Love Canal case entered the picture at some point. The complexity and frequency of governmental involvement fed a sense of apprehension and urgency to the media, and through them to the public. On the other side, the media attention and the public clamor brought about greater governmental involvement.

Government Agencies

The first agencies involved were the Regional Office of the New York State Department of Environmental Conservation, the U.S. Environmental Protection Agency, and the Engineering and Planning Offices of the City of Niagara Falls. These agencies had become involved prior to 1978 in an investigation of the causes of a water pollution problem noted in the Love Canal region. When the source was traced to the Love Canal dumpsite, connections began to be made with the complaints of local residents of the surfacing of buried chemicals and the onset of unusual health symptoms. At this point the State Department of Health entered the stage.

Local governmental officials were, not surprisingly, reluctant to act in a way that might attract unfavorable attention to the area or to create animosity between the people in the city and the chemical industry. The economy of Niagara Falls relies on two industries: chemicals and tourism—both of which could be injured by what was beginning to transpire at Love Canal. Indeed, during all of the early activity that followed the events of August 1978, the City of Niagara Falls was involved in negotiations with Hooker Chemical Company over the latter's prospective construction of a major office building in the city.

Two days after the Health Commissioner's August 2 order was issued, New York Governor Carey created an Interagency Task Force to deal with the problems associated with the Love Canal waste site. The Task Force functioned at both the state and local level. The state level Task Force, headquartered in Albany, consisted of the heads of the departments of Health (DOH), Environmental Conservation (DEC), Transportation (DOT), Social Services, Insurance, Banking, Housing and Community Renewal, Equalization and Assessment, and Disaster Preparedness (ODP). An on-scene "working task force" had offices located at first in the 99th Street School and later in homes, adjacent to the canal, that had been purchased by the state. This local Task Force consisted primarily of representatives of the Departments of Transportation, Health, Environmental Conservation, and Social Services. The on-site coordinator was Michael Cuddy of the Department of Transportation. Throughout this period most of the governmental activity at the Love Canal was performed by agencies that were members of the Task Force; hence, most citizen interaction was with the Task Force or with the governor and/or his representatives.

The State Department of Transportation was selected as lead agency in the Task Force because of its experience with supervising construction activity and its background in dealing with property purchases and relocation of families. There is a natural tendency for agencies coming into a new situation to define a problem in terms that are within their range of experience and competence; this experience also will shape the way that they envision and pursue solutions to the problem they are confronting. In this case, hardly any agency had experience closely relevant to the problems that had to be tackled at the Love Canal site. Experience with highway construction does not help very much in dealing with an apprehensive public fearful of explosions and toxic gas releases. A background in negotiation with homeowners on the purchase of property via eminent domain to build a highway does not necessarily equip an agency with a working model to deal with the purchase of homes from owners who are all too anxious to leave an area for fear of their health.

The primary federal agencies to become involved were EPA, FDAA (now the Federal Emergency Management Agency, FEMA), and the Center for Disease Control; other agencies also became involved (e.g., HUD and HEW—now HHS). FDAA became an actor early when in August 1978 Governor Carey began seeking federal financial assistance; its successor, FEMA, ultimately was a source of federal aid to both the city and the state. The Center for Disease Control was involved in planning health studies of residents and was responsible for setting up and managing long range health studies.

To a great extent, the politicization of the Love Canal case was as much a product of citizens' perceptions and misperceptions, apprehensions and misapprehensions, as it was of ineffective or inappropriate activity on the part of governmental agencies. Numerous agencies were involved,

each perceiving the problem and their own role differently. Each tended to function in the manner for which its experience had prepared it. Because so much learning had to take place by all parties, it is little wonder that at critical junctures public passions rose because citizen's perceptions of agency performance did not mesh well with their expectations of what agencies should be doing.

Public appreciation of agency performance was highest when citizens perceived agency personnel as being open, straightforward and evenhanded. Agencies received low marks from citizens, and citizen tension and anger grew when agencies appeared to be concealing information, soft-pedaling bad news or treating citizens in a condescending or inequitable fashion.

Citizens seemed particularly sensitive to continuity, or lack of continuity, of agency personnel, often expressing frustration with the removal of officials that they had come to know and learned to work with. Many viewed it as particularly salutory that Michael Cuddy was the coordinator of the local Task Force through nearly all of the period that the state government was involved.

Political Involvement

Governmental activity at that site was stimulated and facilitated by several concerned legislators who attempted, through constituent service and legislation to deal with the various problems at the site. These included U.S. Congressman John LaFalce, who represents that district and State Legislators Senator Daly and Assemblymen Murphy and Pillitera.

Citizen Activity

Much of the citizen activity in response to events at the Love Canal coalesced around the Love Canal Homeowners Association (LCHA). During the summer of 1978, Lois Gibbs became more prominent in homeowners activities, and she was ultimately elected president of the Association. Her leadership was strengthened by being invited to attend a meeting at the White House on August 9, that also included state officials, members of several federal agencies and a representative of the President. Mrs. Gibbs believes that state and federal officials made a deliberate move at this time to recognize her leadership because they felt that she was someone they could work with.

In the first stages, LCHA members tended more to react to governmental action rather than develop a strategy to influence governmental officials. Shouting and reacting emotionally toward officials during public meetings were modes of activity that proved to be effective in gaining attention and sympathy in the short run, but proved to be less productive techniques in the long run. As time went on, the LCHA leadership learned to fit strategies to situations much more effectively.

In addition to the Homeowners Association, several groups emerged with smaller memberships and somewhat different concerns. These included the Concerned Area Residents, the LaSalle Development Renters Association, the "93rd Street Group", and the Ecumenical Task Force. The first two were composed primarily of residents of government-subsidized housing adjacent to the canal. Many of the former were senior citizens; many of the latter were from racial minority groups, primarily black. The Ecumenical Task Force is not really a citizens group; rather it is a local arm of Church World Services, an interdenominational cooperative relief and development agency.

COMMUNICATIONS

Sources of Information

The public agencies used a full range of communication techniques. In many cases, the device was a press release or a press conference; several of the statements from the governor's office and from the state Task Force were of this variety. Public meetings also were utilized, but with uneven success. Unfortunately, these meetings tended to generate more heat than light. Many residents felt that the high emotions that characterized these meetings resulted because such meetings followed the style of press releases which did not afford an opportunity for questions and clarification.

In other instances, communication was more limited in scope and more private. For example, many of the consultations regarding the construction safety plan and the tax abatement legislation appear to have been with only a few members of the LCHA. Also, when the results of a chromosome study were available in May 1980, a serious effort was made (before the study was made public) to communicate the results to the people who were tested.

The Task Force working at the Love Canal site utilized a weekly newsletter, and generally speaking, the meetings of the Task Force included representatives of the homeowners and renters associations and were often attended by other interested citizens as well. The meetings provided a regular source of information about activity taking place on the local level. In addition to the newsletter and word-of-mouth communications, the actions of the Task Force also were reported regularly by the local media.

Types of Information

The information that needed to be communicated to the public could be classified as either: a) progress reports, b) policy statements or c) technical data or reports. Government agencies were most successful in communicating on their progress. While communicating the existence of new policy positions did not prove difficult, conveying the substance of policy did. Questions abounded, for example, regarding the intent of the state in the relocation of persons with health problems. It also was unclear to many what role the FDAA intended to play in early August 1978.

Most troublesome, however, was the communication of information about health and environmental studies. Obtaining results from them seemed agonizingly slow. On the other hand, early release of a study from the State Department of Health elicited citizen complaints about

lack of interpretive material or standards. One of the most frustrating incidents for citizens was an academic and scientific debate that ensued after the release of the chromosome study in May 1980.

ROLES OF CITIZEN GROUPS

The events at Love Canal suggest several important questions regarding the roles of citizen groups in such settings: (1) What role should citizens play in the policy process? (2) How should citizen involvement be timed? (3) How can diverse citizen viewpoints be represented most equitably and effectively? (4) How can damaging conflicts and controversies among groups be avoided or mitigated?

Most citizens are neither toxicologists, nor are they public officials with experience in making or implementing public policies; yet, citizens may become quite sophisticated about both technical and political matters related to toxic waste disposal. However, citizens are resident-experts on their own communities and are best equipped to read their own concerns and preferences. Seeking, or accepting, citizens' suggestions on various aspects of a safety and evacuation plan could be a perfectly reasonable action. On the other hand, citizens should not be expected to interpret complex scientific information couched in sophisticated terminology.

When citizens are given some formal role in public policy making, it raises the question of the extent to which different citizens' views should be represented in that forum. A concern expressed frequently by members of other citizen groups was that the Love Canal Homeowners Association was afforded more attention and exercised greater influence on decisions, than citizens from these other groups felt was appropriate. Yet, most of the influence exerted by the LCHA was through informal channels; the organization did not sit as a voting member of any policy making bodies. Because citizen organizations were not given a formal role in decision making at Love Canal, it avoided some difficult problems that formal representation might engender. The reaction of citizen organizations to the perceived influence of LCHA was more a reaction to what these groups perceived as substantive inequities rather than procedural inequities.

There are two important exceptions to the previous comments on formal representation. First, the LCHA was afforded permanent representation at meetings of the local Task Force very early in the latter's existence. Objections by renters groups that their interests were not adequately being represented by the homeowners led quickly to their inclusion as well.

Second, a Love Canal Revitalization Agency was constituted with the intention of having three representatives of the general community as well as representatives of the Niagara Falls and nearby Wheatfield Municipal governments. Disagreement arose over whether specific citizens groups should be represented on the agency or, as the local government officials felt, the three seats should be occupied by representatives of the "community-at-large." This position was partly based on the view that the revitalization agency would be administering the purchase of the last group of homes, as well as the relocation of renters, placing representatives of those groups (homeowners and renters) in a conflict of interest. The view of the municipal officials finally prevailed on this issue, although one of the citizen members of the revitalization agency, Bill Wagoner, remained associated with several of the citizen groups.

EFFECTIVENESS OF CITIZEN/GOVERNMENT INTERACTION

The effects of citizen/government interaction on policy can be viewed from two perspectives: (1) the effect of that interaction on policy makers and policy processes and (2) the effect on policy decisions. With regard to the former, citizen activity seemed to drive some agencies to defensive, self-protective postures. This may have been partly a function of the experience of the particular officials in dealing with the public. Some of the medical researchers and other scientists involved in the events at Love Canal were very reticent about talking with the public. On the other hand, officials in the State Department of Transportation (especially those active at the local level), and local EPA officials were much more at ease.

The Love Canal case alerted the public to the dangers of improper disposal of toxic waste. Citizen participation in those events was instrumental in bringing out new dimensions of the problem. Through their persistence, citizens at Love Canal interjected themselves into the formal or informal decision making structure of many governmental agencies. Citizens' organizations came to be regarded as parties that had to be consulted before many types of decisions could be taken.

In addition to the general effect of shaping perceptions of the dangers of improper disposal of toxic waste and of general policies that must be pursued to avoid such problems, citizen participation at Love Canal influenced a number of specific policy decisions. The most prominent was the decision by Governor Carey to have the state purchase homes in the Love Canal area; later there was a commitment by the federal government to provide financial aid for the relocation of the balance of the affected residents. It is doubtful that these decisions would have been made this way without the citizens' vigorous and persistent demands for help. The decision to purchase homes in the outer ring is the most important achievement of Love Canal citizen efforts.

State legislation providing property tax relief for Love Canal homeowners, and federal legislation providing a capacity for responding to toxic waste emergencies (e.g., the so-called Superfund) followed hearings in which Love Canal residents participated. The occasions for the hearings were themselves a response to pressure exerted by citizens. In addition to the policies that were initiated, numerous policies were revised or modified as a result of citizen/government interaction. The safety and evacuation plans and temporary relocation policies are illustrations of this.

IMPLICATIONS

Many of the implications of the Love Canal case for governmental response at future hazardous waste sites relate to the style in which agency officials interact with the public. The importance of openness and straightforwardness has already been mentioned. There were, however, several other techniques that had a bearing on the nature of citizen/government interaction and which, therefore, could be expected to influence the effectiveness of hazardous waste response efforts elsewhere.

Citizens are apt to entertain somewhat naive conceptions of the role and capability of government, particularly in the early stages of a critical situation. As citizens gain experience and sophistication they are more likely to differentiate the roles of various levels of government and of agencies within a given level or recognize the constraints within which public officials must operate. Before this sophistication can be acquired, a series of dashed hoped can reduce the credibility of some agencies, and government in general, to the point where effective interaction with the public becomes almost impossible. Such problems might be avoided if officials encourage limited, but realistic, expectations of agency capabilities.

An early problem the Task Force seems to have experienced was the release of information by lower echelon members of the Task Force that contradicted other information being released. Reassignment of some staff members to other duties may have helped alleviate that problem. However, the reassignments contributed to the problem of lack of continuity of personnel, cited previously. Release of inconsistent or contradictory information not only reduces governmental credibility, but can lead to anxiety heightening uncertainty among citizens as well. On the other hand, rigid enforcement of a "party line," or imposition of a "gag rule," on staff members may have the effect of hiding agency activity from legitimate public scrutiny or creating an impression of secretiveness and lack of candor on the part of the agency. This need not be an impossible dilemma; the dual goals of coordination and candor seem attainable.

Promptness and orderliness in providing information is important to agency credibility, to say nothing of its benefits for relieving uncertainty among citizens. Especially when vital issues such as adverse health effects are involved, citizens demand—and deserve—to know where they stand. Information may not be available as soon as the public wants it; therefore, it is important that citizens be helped to understand from the beginning how long it will take for such information to become available. Even the orderly and accurate release of information may lead citizens to feel that they face serious risks; disorderly communication can only exacerbate that problem.

Much of the confusion and anxiety generated by the conflicting statements from government agencies and researchers in May 1980 could have been avoided had EPA officials been able to release chromosome study results in a more orderly fashion—as had been their original intention. The necessity of going to the public with test results in order to pre-empt a press leak, precluded thorough evaluation of the results of the study and created an aura of importance around the study that was inappropriate given its nature and scope.

When citizens are already divided by conflicting goals, the potential for serious intergroup conflict can be increased by a communication practice that appears to show favoritism toward one group. There may be any number of legitimate reasons why an agency may wish to encourage or support a particular group but an appearance of preferential treatment may raise fears that other legitimate interests are going to be overlooked. A tradeoff is involved in that dealing with numerous groups may be more cumbersome—and frustrating—than dealing with one or two; yet, the diversity of interests may be capable of effective expression only through several discrete groups.

Evenhanded treatment of groups may become even more of an issue where, as in the Love Canal area, cleavages of interest regarding government policy toward the toxic waste problem overlap other social cleavages in the community—in this case, race and economic status. The renters tended to be black, older, and of lower income and they did not see their interests as identical to those of the homeowners.

Perceived preferential treatment may also lead to a view that agencies are pursuing a "divide and conquer" strategy. The extent to which this perception was created by malicious intent as opposed to bureaucratic ineptitude is unclear. Perhaps the most frequently cited example of a "divide and conquer" strategy being employed by government in the Love Canal case related to the issue of tax abatement. An official in the state Task Force is reported to have told residents on the west side of 93rd Street that they were, in effect, "sold out" by the Homeowners Association in discussions on the boundary lines for tax abatement.

Although circumstances frequently dictate the use of public meetings, such assemblages have widely recognized drawbacks, especially when potentially emotional or highly technical subjects are on the agenda. People who are under great anxiety and stress will naturally press their case in such public meetings and the meetings may turn into chaos. The emotional concerns of citizens will feed upon each other and almost any response by public officials is likely to be perceived as inadequate.

In addition, such meetings are generally poor forums for the display of technical or scientific virtuosity on one hand and for the unembellished reporting of raw data on the other. Data must be accompanied by interpretation, although this should not be taken to suggest that citizens are dullards. Many of the citizens active at Love Canal became sophisticated in their understanding of the language and concepts of toxic chemical wastes.

In some cases, an effective alternative to the large public meeting is private meetings of agency officials with the leaders of various citizen groups. At such "public consultations," it is possible to provide an indepth presentation of information or explanation of policy, and to share concerns about how the material might be received by the public, in advance of a large meeting.

Another useful method for improving communication between citizens and government is for the citizens to acquire their own experts. In the Love Canal case one expert was funded by the state government and another volunteered her services to the LCHA. Citizen-oriented expert consultations have greater credibility than "government experts" and can significantly improve understanding by citizens.

Because there was no "model" for citizen/government information at toxic waste emergency sites, decisions about informing and involving people in policy making tended to occur on an ad hoc basis at Love Canal. As is typical when clear policies of equity have not been worked out, it was in no small degree a case of the squeaking wheel getting the grease. Unfortunately (from the standpoint of citizen/government relations) the perception by citizens that they needed to be vocal and contentious in order to gain attention led to resentment and frustration in many cases, and helped to create a pattern of adversarial relationships. While adversarial relationships may be unavoidable in such situations, more careful attention to the nature and timing of citizen involvement might help to avoid their more counter-productive aspects.