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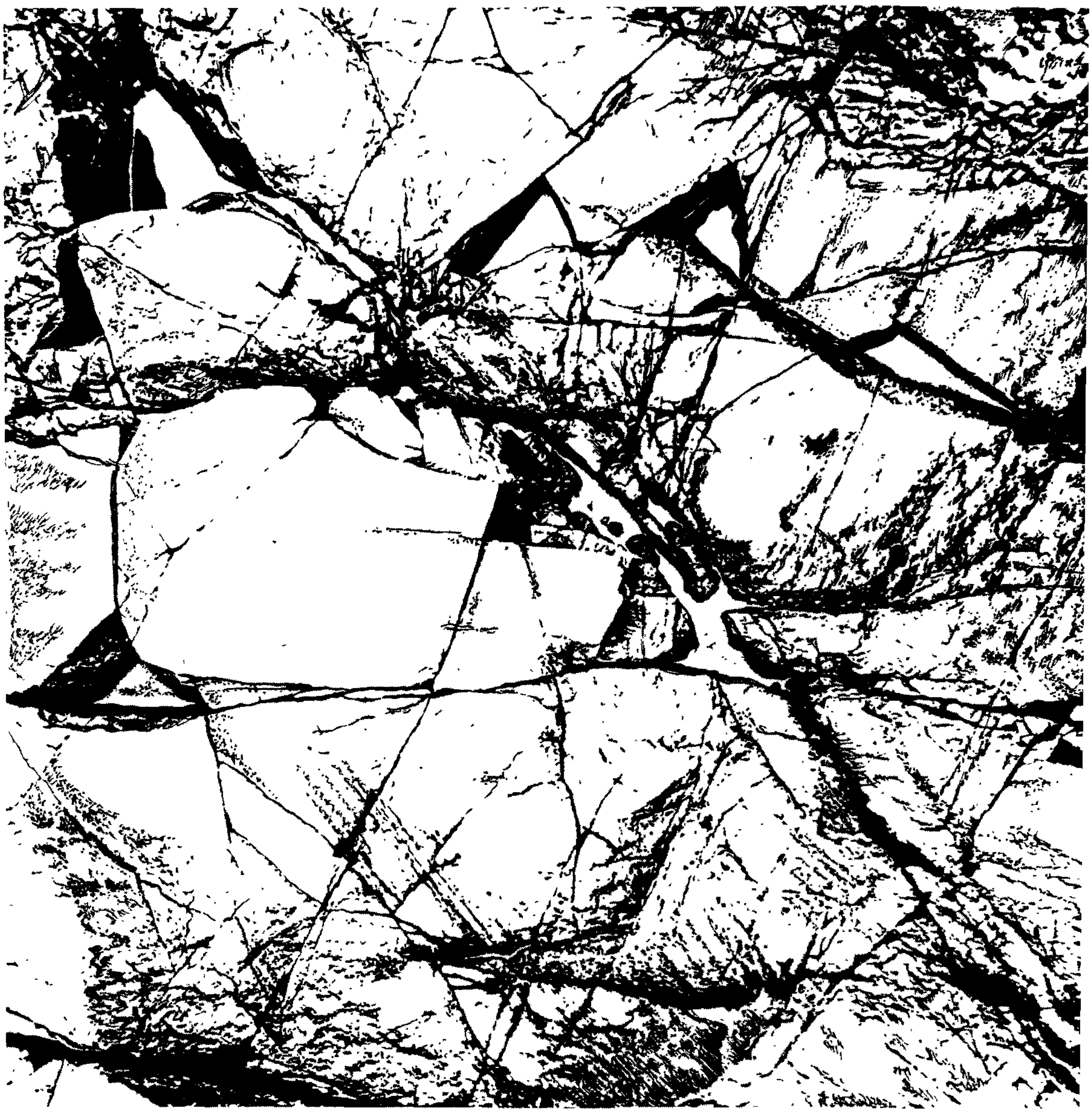
EPA/600/8-86/004 April 1986

EPA Ground-Water Research Programs



EPA/600/8-86/004 April 1986

EPA Ground-Water Research Programs

Program Report—Office of Research and Development

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Washington, DC 20460

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Photographs courtesy of David Balkwill, Robert Landreth, Hugh Masters, James McNabb, Fred Milanovich, Richard Nash, Robert Ryans, Gary Sayler, Kristin Stout, and the U.S. Geological Survey.

Cover: Ground water moves slowly under the earth, filling fractures and fissures as well as saturating microscopic pores in rock and soil. If ground water could be seen, a vertical cross-section of a portion of an aquifer might look like this.

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Contents

1. Introduction

Water, water every where.
Nor any drop to drink.
Samuel Taylor Coleridge
The Rime of the Ancient Mariner

As recently as 10 years ago, ground water was generally considered a pristine resource: pure and ever-available. Like many of the gifts of the subsurface, it was used, and sometimes abused, without being fully understood. The late 1970s brought a rude awakening for the public; synthetic organic chemicals were discovered in ground-water-supplied drinking water sources in several states, including California, Connecticut, Massachusetts, Michigan, New York, and New Jersey. This was only the beginning. Years of improper disposal and unregulated dumping practices resulted in the release of a Pandora's box of toxic contaminants. Currently, 40 states have documented instances of serious ground-water contamination (1). These problems have become a matter of national concern. As surveys and investigations proceed, more instances will undoubtedly be uncovered. Because ground water is both vital and vulnerable, its contamination promises to be a major environmental issue of the '80s and '90s.

This document describes the U.S. Environmental Protection Agency's (EPA's) ground-water research programs. The programs focus on protection of ground-water resources by eliminating or controlling sources of contamination; understanding and predicting the movement and attenuation of contaminants in the subsurface; monitoring for contamination; restoring polluted aquifers; and ensuring that research findings are conveyed to public officials, field managers, and the scientific community. This document describes these activities, highlights recent research accomplishments, and outlines priorities for future investigation. Readers who desire more detailed technical information about the programs or individual projects may contact the research laboratories directly (see page i).

Ground Water: An Overview

Ground water is a vast and important resource. In the United States, approximately 15 quadrillion gallons (56 quadrillion liters) of water are stored within 0.5 miles (0.8 kilometers) of the land surface (1). Ground water supplies about 25 percent of all fresh water used (2). Fifty per cent of U.S. citizens obtain all or part of their drinking water from ground water; 95 per cent of rural households depend totally upon it (1). Commercially, ground water is extensively employed in agricultural practices, particularly for irrigation, and in various industries

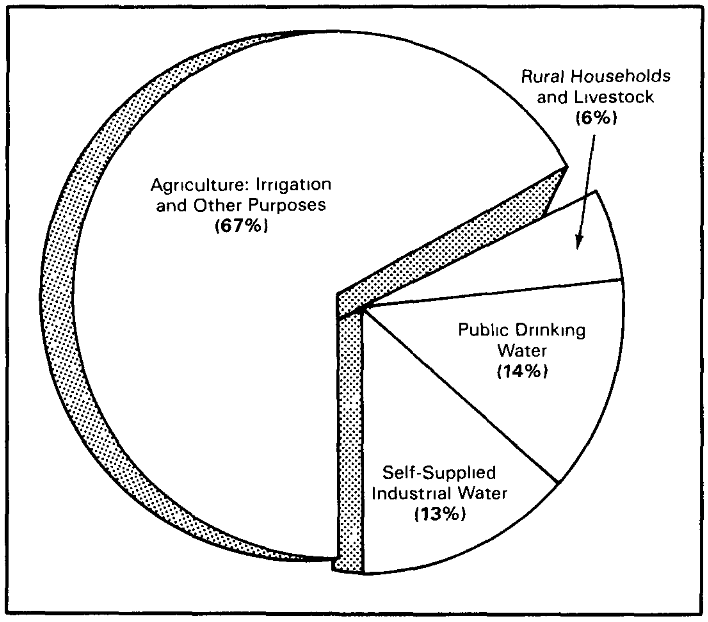

Figure 1. Major Uses of Ground Water in the United States.

(Figure 1). Currently, ground-water withdrawals total about 90 billion gallons (340 billion liters) a day, a threefold increase in usage since 1950 (Figure 2) (1).

Ground water (subsurface water located below the water table) is stored in various rock or soil bodies. While potentially replenishable, it can easily be contaminated. Once polluted, ground water is difficult, sometimes impossible, and always expensive to clean up using currently available methods.

In general, contaminants that are soluble follow the natural path of ground water as it moves in the subsurface portion of the hydrologic cycle (Figure 3). However, insoluble contaminants may move in different directions from ground-water flow (see Section 3, *Prediction* for a discussion of these phenomena). Contamination begins with the source. Ground water may be contaminated by routes such as waste disposal or nondisposal use of chemicals on the land surface. Of these, waste disposal sources present the most serious problem, according to current reports from several states (1). These sources include industrial and municipal landfills and lagoons, underground storage tanks, and chemical spills. Other sources of contamination include well injections, pesticides, fertilizers, septic tanks, and, to a lesser extent, salt or brackish water intrusion, road salts, feedlot wastes, wastewater treatment, land use practices, and mining activities. Among the most troublesome contaminants are organic solvents, gasoline, heavy metals, inorganic

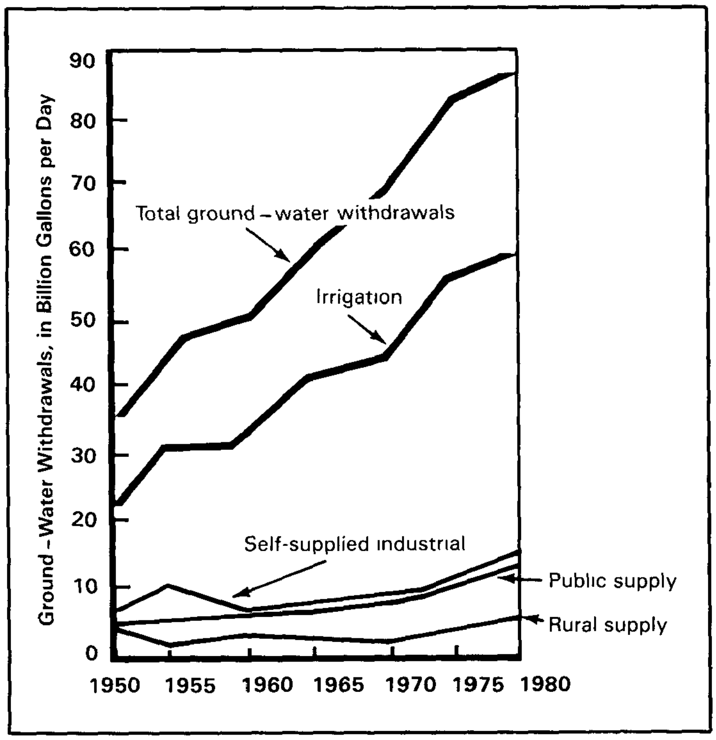

Figure 2. Trends in Ground-Water Withdrawals in the United States, 1950-1980.

chemicals, organic chemicals, pesticides, pathogens, and nitrates.

Contaminants may leak, percolate, or be injected into aquifers. As contaminants travel through the soil, and into and through a ground-water system, they may be slowed down or degraded by processes which are complex and not completely understood. These natural processes are not totally effective for all contaminants. For example, soils were once believed to be capable of binding and holding all chemicals. This is now known not to be true for some important and widely used classes of chemicals, for example, organic solvents such as tri- and tetrachloroethylene, benzenes, and carbon tetrachloride. Other contaminants, such as heavy metals, are not degradable at all, but may be immobilized. Depending on the nature of the discharge and the type of pollutant, contaminants may enter ground water as slugs (isolated masses) or localized plumes.

In general, ground water moves slowly (only a few feet to several hundred feet a year), but because it continues to move, the contaminants it bears eventually discharge to the surface in most cases. Points of discharge can include wells or springs, or surface water bodies such as rivers and lakes. Since the base flow of most streams is supported by ground-water discharge, the usefulness of both surface and ground water may be severely compromised when the quality of ground water is degraded. Rainfall, completing the hydrologic cycle, replenishes ground water, but it may add to the contamination if it moves through overlying soil that contains pollutants.

Although ground-water supplies are generally abundant in the United States, they vary by region in quality, quantity, and accessibility. The contamination of aquifers (geologic formations capable of yielding a significant amount of ground water to wells or springs) is becoming a problem for an increasing number of regions and localities. Public officials, industry managers, and private citizens may be confronted with the issue when contamination is discovered in a heavily populated area or valuable ecosystem.

Not only place, but time enters the equation as well; the long-term nature of ground-water contamination is unarguable. Some contemporary American examples can be traced to disposal activities conducted 30 or 40 years before, but an instance in England, for example, has been traced to pollutant dumping done 135 years previously. In fact, some landfills from the Roman Empire still produce leachate. This huge potential time-span for contamination makes the task of ground-water research particularly complex; not only must current and future concerns, such as protection and prevention, be addressed, but methods of dealing with prior contamination must also be explored.

Current knowledge of the extent and severity of ground-water contamination is limited, and it is likely that the coming years will reveal additional contamination as investigative techniques become increasingly sophisticated and accurate, and more comprehensive data are collected. In developing strategies to deal with the problem, environmental consequences must be balanced against feasibility and costs. The United States, with its plethora of different climates, hydrogeologies, population densities, types and levels of industries, and other variables, requires a number of different strategies and priorities at the state and local level. Solutions may be as diverse as problems. Areas where aquifers lie close to the surface, or in rapid recharge locations, may face a different set of contamination issues from regions where ground water lies deeply buried. In some situations, aquifer cleanup—no matter how expensive—may be the only viable alternative; in others, alternative solutions can be found. Any effective strategy, however, must be supported by a coherent base of scientific knowledge and sound management.

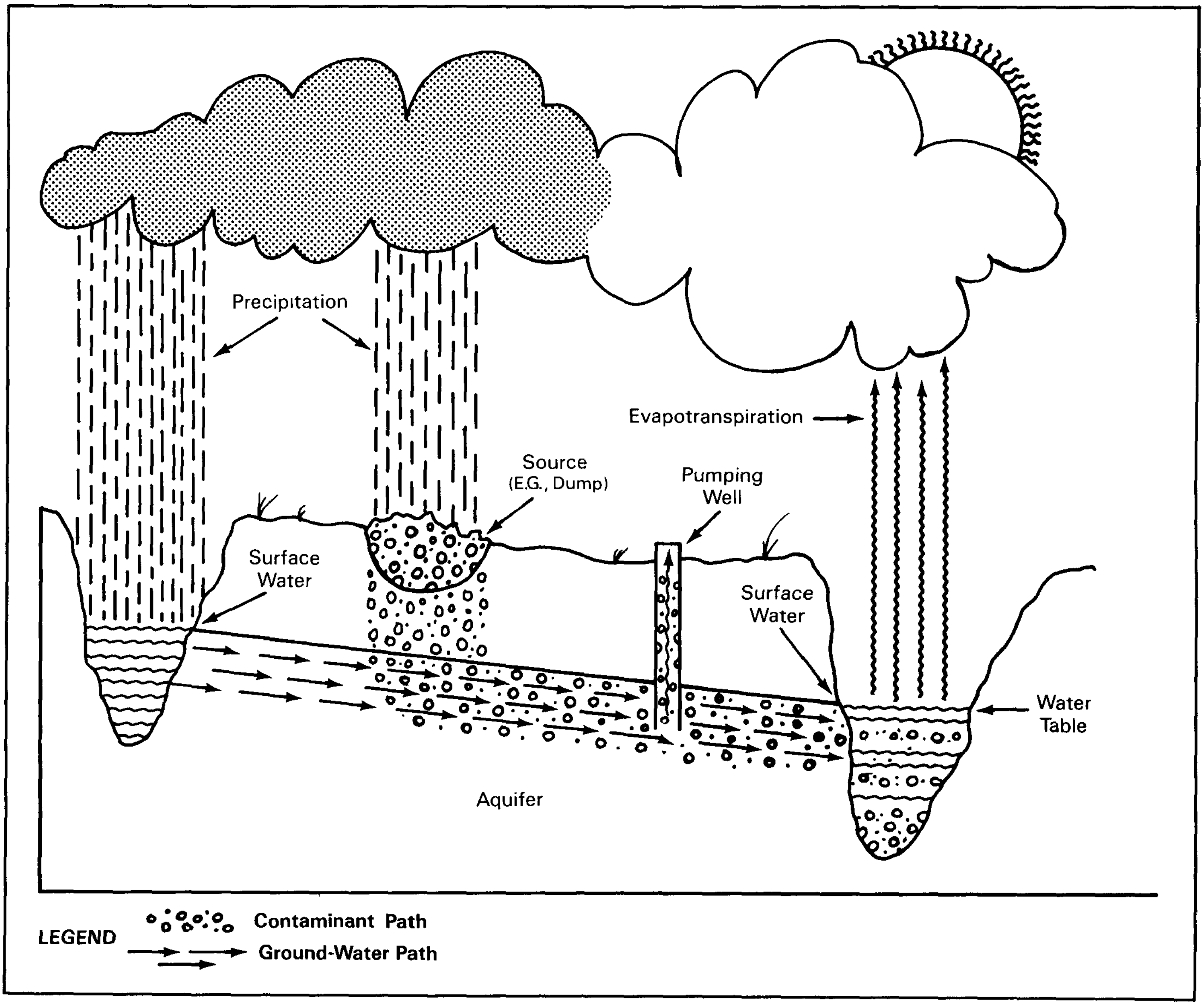

Figure 3. Contaminants in Ground Water: Their Relationship to the Hydrologic Cycle.

EPA and ORD: Ground-Water Roles

EPA derives its statutory authority to protect ground water from the Clean Water Act (CWA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), the Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the Toxic Substances Control Act (TSCA). In addition to these statutory mandates, in August 1984, through the Office of Ground-Water Protection, EPA established a Ground-Water Protection Strategy, featuring four components:

- Short-term build-up of institutions at the state level.
- Assessing the problems that may exist from unaddressed sources of contamination—in particular, leaking storage tanks, surface impoundments, and landfills.
- Issuing guidelines for EPA decisions affecting ground-water protection and cleanup.

- Strengthening EPA's organization for ground-water management at the headquarters and regional levels, and strengthening EPA's cooperation with Federal and state agencies.

While it is important to develop and implement national ground-water policies, protection programs must be area-specific on the operational level because of the complexities of individual situations. For this reason, state and local governments are assuming primary responsibility in assessing and controlling their ground-water problems, and are working in partnership with EPA, which provides national drinking water standards, general program goals, research, information, and technical assistance.

A protection program may focus on a small aquifer that is the sole source of drinking water for a locality, or may be a large, regional project dealing with an aquifer that underlies several states. The EPA and state and local governments require extensive information to develop, implement, and evaluate ground-water protection programs. For each program, managers must be able to:

- Determine the number and types of contamination sources.
- Assess the extent and nature of existing and potential contamination.
- Predict and/or measure concentrations of contaminants in water supplies.
- Ascertain the health implications of these concentrations.
- Compare alternative prevention and/or cleanup measures and assess their costs.
- Evaluate program effectiveness.

To assist in accomplishing these goals, the EPA's Office of Research and Development (ORD) conducts several research efforts. SDWA and RCRA provide the major funding sources for ground-water research. Funding for the programs, in fiscal year (FY)'85 totals $18.1 million (Figure 4); funding is expected to rise to $22.4 million in FY'86. This reflects a growing awareness of the importance of investigating ground-water problems; in particular, the control of hazardous wastes and leaking underground storage tanks. The EPA's ground-water research programs, aimed at protecting the resource, have five major goals:

- To develop and improve methods to control sources of contamination.
- To improve methods for predicting and assessing contaminant transport and fate.
- To develop ground-water monitoring technology.

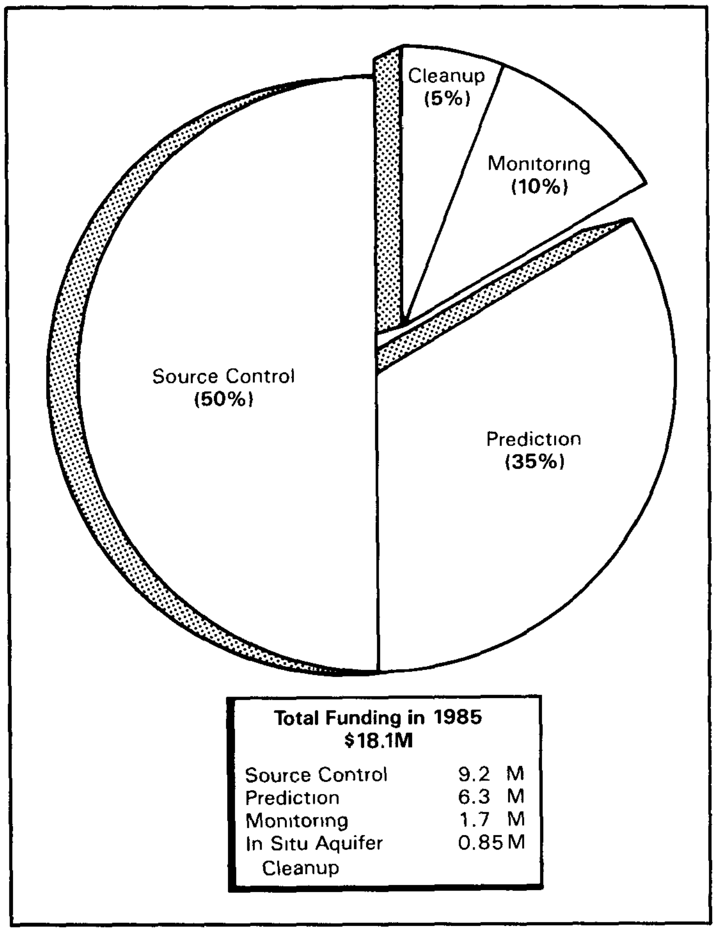

Figure 4. FY'85 Funding Allocations for EPA Ground-Water Research Programs.

- To devise means for aquifer cleanup.
- To provide technical assistance and information transfer for all these subjects.

ORD administers fourteen laboratories throughout the United States, four of which conduct research directly related to protecting ground water (Figure 5). Other ORD labs study drinking water quality, health effects, treatment technologies, analytical methods for water samples, and techniques for quality assurance. These investigations, which often address contaminants occurring in both surface and ground water, also provide valuable informational and control tools.

Because of its complexities, the study of ground water requires cooperative efforts by scientists and technical specialists from many disciplines. Agronomists, biologists, biochemists, chemists, engineers, environmental

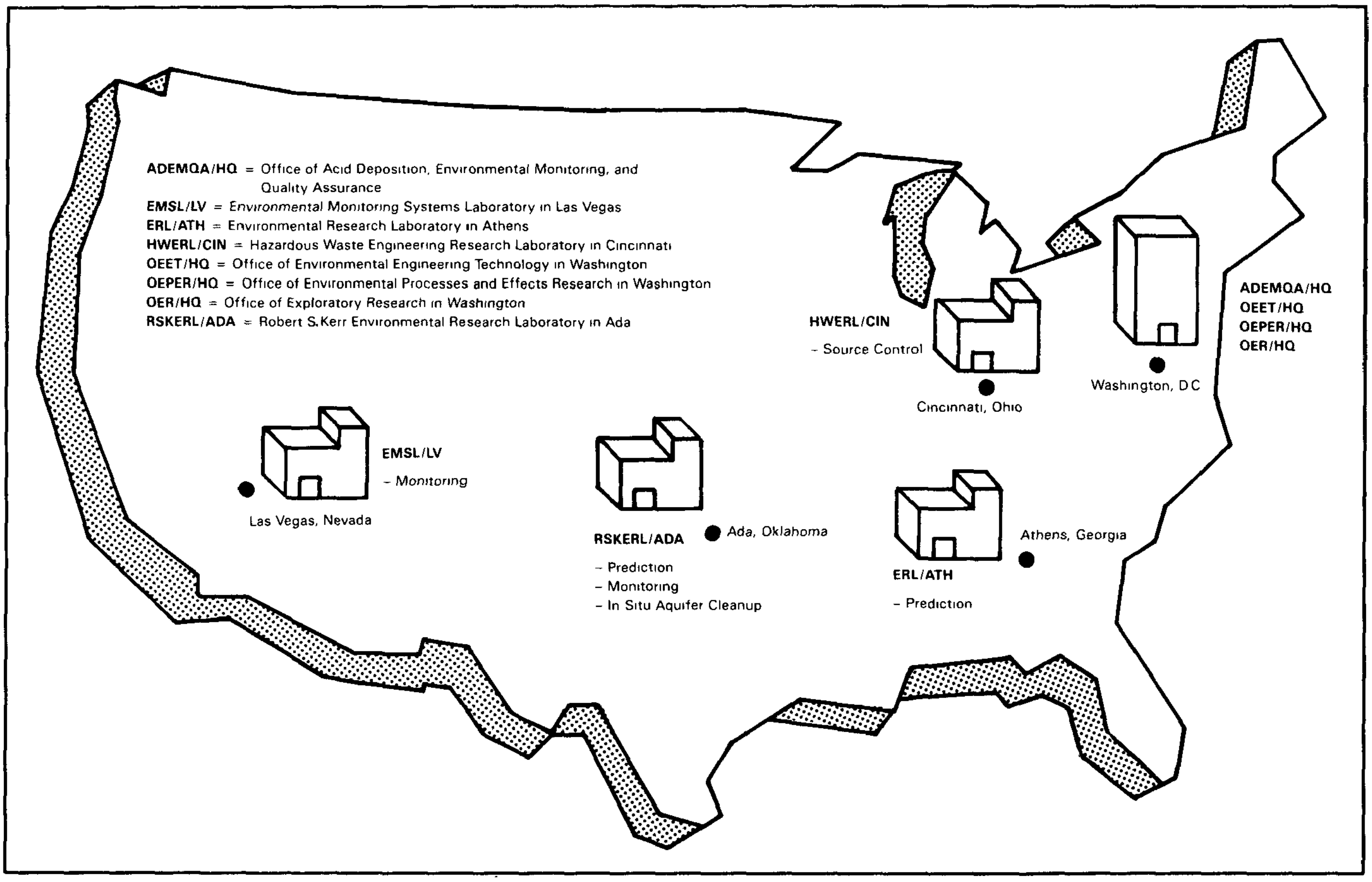

Figure 5. EPA Offices and Laboratories Involved in Ground-Water Research Programs. All offices and laboratories shown here are part of the Office of Research and Development.

scientists, geologists, hydrologists, mathematicians, microbiologists, soil scientists, and physicists all contribute their expertise to various facets of ground-water research. ORD funds or maintains contact with various organizations and members of the scientific community, including universities, information centers, institutes, consultants, and engineering firms. Several other Federal agencies also conduct research on ground water (see Appendix A for further information).

ORD provides research products, information, and assistance to a wide range of clients, including EPA program and regional offices, other Federal agencies, state and local governments, industry representatives, environmental groups, professional associations, foundations, institutes, consultants, and researchers.

A series of mechanisms have been established to ensure that EPA's ground-water research programs continue to meet client needs. ORD has formed the Ground-Water Research Planning Group to advise on overall issues in the areas of prediction, monitoring, and cleanup. This group includes members of all relevant EPA program offices plus several EPA regional representatives. The Planning Group reports to both the Water Research Committee and the Hazardous Waste/Superfund Committee, which advise the Assistant Administrator for Research and Development on research priorities (Figure 6). At the state level, ORD has developed a cooperative agreement with the National Governors' Association to provide a mechanism for interaction on the research needs of specific states.

ORD: Current Research

Research on the quality of ground water is essentially a new discipline: complex, full of unknowns, and still in the process of being mapped out. In recent years, scientific

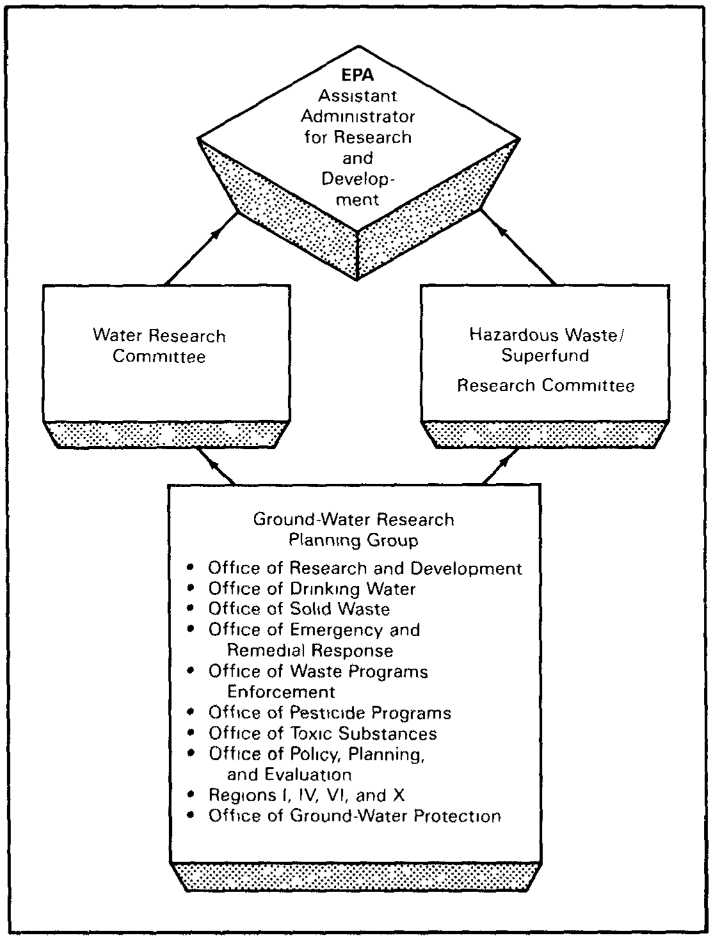

Figure 6. EPA Ground-Water Research Planning Mechanism.

knowledge about ground-water systems has been increasing rapidly. The ability to take uncontaminated samples in the subsurface—previously a major limitation in research—has been greatly improved. At ORD, researchers have developed techniques that allow them to enumerate and characterize subsurface microbes. ORD scientists have also stimulated the aerobic biodegradation of trichloroethylene (TCE) (see Section 5, *In Situ Aquifer Cleanup*). Improvements have been made in technology for assessing the subsurface. Advances have been made in adapting techniques from other disciplines to successfully identify specific contaminants in ground water (see Section 4, *Monitoring*). The behavior of certain chemicals in some geologic materials can be assessed.

Much remains to be learned, however. The technologies for source control need to be reviewed, assessed, and

Cape Cod, Massachusetts. Contaminated ground water, foaming with non-biodegradable detergents, is pumped from a monitoring well into this bucket 30 years after the original contamination had occurred.

refined. Basic research is needed to develop models for prediction of contaminant movement and transformation in complex aquifer systems. Monitoring technology, despite specific advances, in general remains cumbersome, costly, and imprecise. Little information is available on the costs or effectiveness of current methods for cleanup of aquifers in situ. Before ground water can be said to be truly protected as an environmental resource, further research is necessary. The most effective means of protection is prevention—in this case, controlling the sources of contamination.

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2. U.S. EPA. 1984. Facts about ground water. *EPA Journal* 10(6):7.

2. Source Control

Control of contaminant sources on the land surface represents both the beginning and end point of current ground-water research efforts. Until more is known about subsurface processes and their interaction with specific contaminants, source control remains the primary method for preventing ground-water contamination. At the same time, source control techniques are also used where contamination has already occurred, for example, in the cleanup of unregulated dump sites or in emergency response to accidental spills.

A major source of ground-water pollution is the improper disposal of hazardous wastes. Contamination may occur from sources such as landfills, surface impoundments, or injection wells. Research must address all aspects of the technology associated with preventing contamination: improving the design, construction, operation, and maintenance of disposal systems; increasing knowledge about leachates; and improving techniques for emergency and ongoing handling and destruction of wastes at uncontrolled sites.

ORD supports two source control research programs through the Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio (HWERL-CIN) (Figure 7). Both programs develop and evaluate state-of-the-art technology for hazardous waste management, storage, and disposal. The Hazardous Waste Land Disposal Program, in support of RCRA disposal regulations and guidelines, investigates landfills, surface impoundments, and

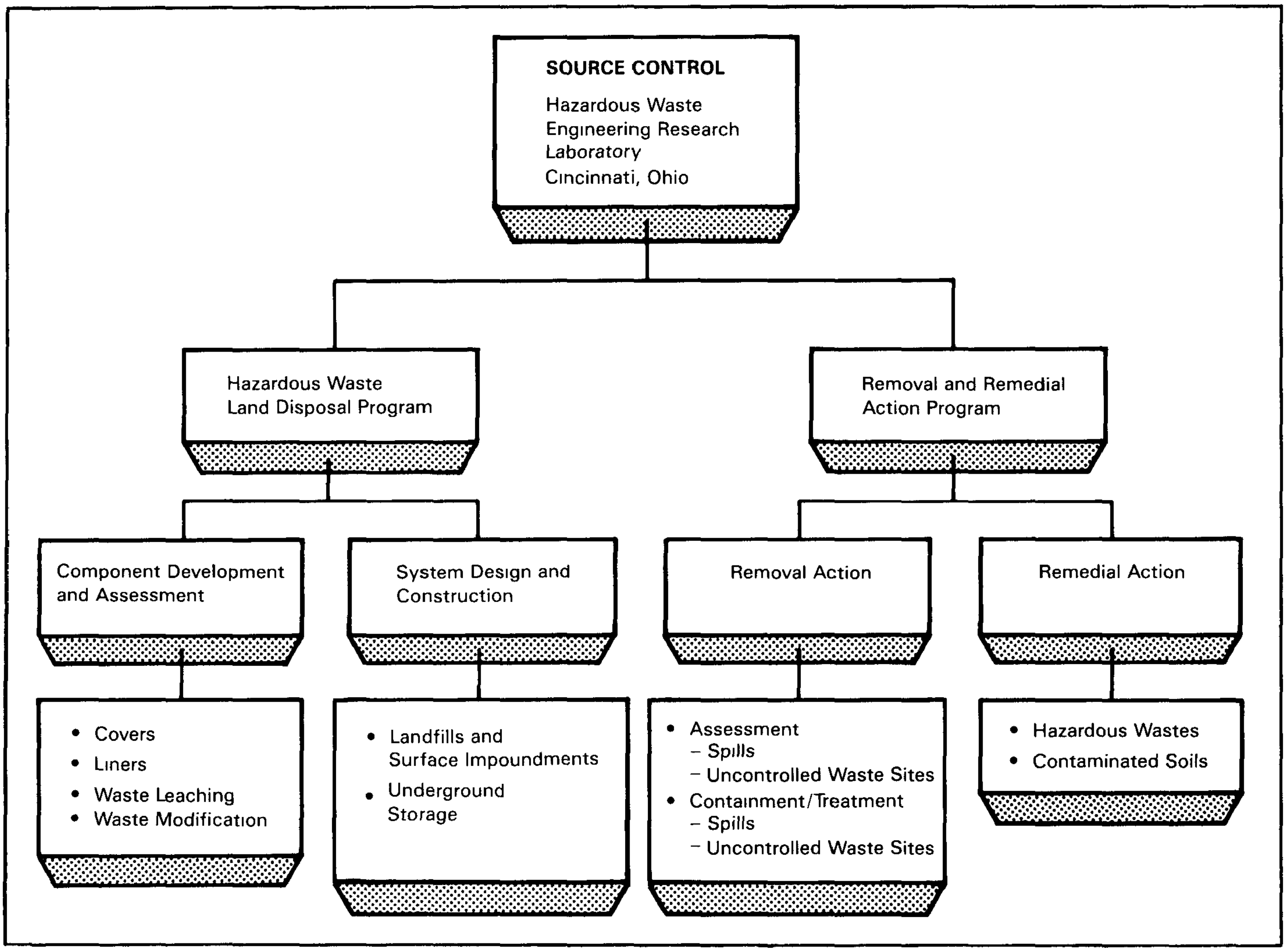


Figure 7. Highlights of EPA Ground-Water Source Control Research.

underground storage facilities. The Removal and Remedial Action Program develops technology for emergency and ongoing hazardous waste site cleanup in support of CERCLA (Superfund). Table 1 lists current source control projects for both programs.

Table 1. Source Control Research
Hazardous Waste Engineering Research Laboratory—Cincinnati, OH

AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Land Disposal	Office of Environmental Engineering and Technology (OEET)—Hazardous Waste—Surface Impoundments	Assess and develop improved design, operation, and closure components for landfills, surface impoundments, and waste piles used for hazardous waste management. Areas covered include gas and VOC (volatile organic chemical) emission control technologies, clay soil and FML (flexible membrane liner) liner performance, cover performance, contaminant/soil interaction, leachates, leak detection techniques, and dike construction criteria.	• Technical Resource Documents (TRDs). • Computer programs to review land disposal permit applications. • "Expert Information" computerized systems on containment technologies. • Technical assistance to RCRA permit writers. • Improved design and technology.
Land Disposal	OEET—Hazardous Waste Technical Resource Documents	Develop and update technical manuals for landfilling and surface impoundment of hazardous wastes, including information such as design, construction, and operating and monitoring procedures. The manuals will address the design and installation of liners, the design of landfill covers to prevent infiltration, and closure procedures for surface impoundments.	• Provide state-of-the-art technical information to field managers and Federal, state, and local officials.
Land Disposal	Support to Land Disposal	Develop design, operation, maintenance, and closure procedures for landfills. Research topics include the effects of subsidence on cover performance, chemical compatibility and service life prediction for synthetic liners, leachate collection and treatment efficiency, cost effectiveness of multi-layer cover systems, assessment of maintenance-free cover systems, and the impact of designing secure landfills in saturated soils.	• Develop and improve the performance of components and the unit operations of secure landfills to comply with RCRA regulations.
Remedial Action	Chemical Treatment Methods for Dioxins and Dibenzofurans	Develop and evaluate methods for the destruction of dioxins and other chemically related wastes in soils, sediments, and contained waste streams. Laboratory and field studies will address the feasibility of UV photolysis and APFEG reagents for treatment of dioxin-contaminated soils, the removal of chlorinated dioxins from contaminated soils, the application of alkali polyethylene glycolate complexes to destroy dioxins in Missouri soils, and the supercritical extraction of chlorinated dioxins from soils.	• Improve chemical and physical contaminant destruction technology.
Remedial Action	Dioxin Assessment and Control Research	Evaluate the feasibility of incineration for on site detoxification of dioxin-contaminated liquid wastes and soils.	• Improve contamination destruction processes.
Remedial Action	Engineering Support for Site and Situation Assessment	Apply engineering expertise to assessments of hazardous waste site situations (e.g., waste characteristics, hydrology, geology, and soil characteristics) to assist in developing corrective measures. Develop criteria for conducting site assessments. Prepare feasibility studies regarding data requirements for remedial action decisions.	• Technical assistance at hazardous waste sites.

Table 1 Cont.

AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Remedial Action	Provide Technical Support to Enforcement Program and Regional Offices	Provide scientific information and analyses in support of litigation on corrective actions at Superfund sites. Support areas include review of designs for remedial actions, review of data submitted by liable parties, expert witness testimony, technology transfer, emergency response assistance at releases and waste sites, supervision of cleanup operations involving ORD equipment, analytical support using mobile and central laboratories, and technical support regarding the designation of hazardous substances and assignment of reportable quantities.	• Technical assistance to EPA regional and state and local officials.
Removal and Remedial Action	Evaluate Technology to Manage Uncontrolled Waste Sites	Evaluate improved and new technologies for emergency and remedial actions for hazardous material spills and newly discovered releases of hazardous substances from uncontrolled waste sites. Topics include field evaluation of prototypical mobile equipment and innovative commercially available equipment, the use of chemicals for mitigation of the effects of hazardous substance releases, fugitive dust control procedures, and the fixation of contaminated soils.	• Provide most effective technology for spill control and release cleanup.
Removal Action	Prevent and Contain Hazardous Material Releases	Develop new and improved technology for the prevention and control of pollution from hazardous material releases by adapting related industrial technologies. Research topics include spill or accidental release prevention, pre-response planning, containment and confinement, separation and concentration, the destruction of collected cleanup residuals, and the selection of chemicals to control releases of floating hazardous substances.	• Improve technology for emergency handling of hazardous releases.
Removal Action	Special Biodegradation Processes for Detoxifying Contaminated Soils	Develop and evaluate biological methods for the destruction or detoxification of chemicals in soils. Genetic engineering and other biological techniques will be used to determine if living organisms such as plants, yeast, and microbes can be employed to successfully transform or degrade such substances as organochlorine compounds, 2,4,5-trichlorophenoxyacetic acid, chlorinated dioxins, and halogenated hydrocarbons.	• Cost-effective decontamination techniques.

The Hazardous Waste Land Disposal Program

Land disposal—the temporary or permanent storage of wastes on or under the land surface—is currently the primary means of hazardous waste containment. Emerging techniques for contaminant destruction and land banning of some wastes suggest a future where land disposal will lose its primacy. However, some wastes will still be land disposed, for example, because of large volume or lack of alternate disposal options. In addition, residues from other disposal methods such as incineration will be land disposed. For these reasons, refinements in land disposal technology will be necessary.

The Hazardous Waste Land Disposal Research Program develops, tests, and assesses the technology of land disposal systems in order to ensure the safe disposal and storage of hazardous wastes. Information from investigations on specific subjects, such as liner selection, system design, and waste modification techniques is compiled into technical resource documents (TRDs) which are used for review and evaluation of land disposal permit applications mandated by the Resource Conservation and Recovery Act (RCRA). To produce TRDs, the program engages in bench and pilot studies, economic assessments, laboratory analyses, and full-scale field verification studies.

Currently, HWERL researchers and contractors:

- Evaluate the design and construction of land disposal systems.
- Develop and assess system components, including cover systems, liners, waste leaching, and waste modification.
- Provide information on these subjects to the user audience through written material, conferences, and computerized systems.

To date, the program has emphasized landfills; although surface impoundments have similarities in design and construction, their unique features require more research attention in the future. The potential use of a third containment option—underground storage—is being explored.

Cover Systems

HWERL engineers are developing, evaluating, and comparing various landfill cover systems for long-term durability and for relative efficiency at preventing infiltration.

- *Cover materials* such as flexible membranes (plastic or rubber sheeting) and waste residue (for example, fly ash and papermill sludge) are being evaluated as alternatives to or combinations with soils and grasses, which are currently the most commonly used cover materials.
- *Cover designs* consist of several materials in alternating layers (Figure 8). One design being field-tested is a three-layered cover system. Researchers are measuring surface runoff, subsurface drainage, leachate formation, and soil moisture distribution under natural and artificial rainfall conditions.
- *Land subsidence* over time may impair the effectiveness of a cover system. Studies are currently evaluating the impact of land subsidence on flexible membrane covers and on three-layered cover systems. Another research tool is the Hydrological Evaluation of Landfill Performance (HELP) model, a representation of subsurface drainage that has been computerized as an aid to evaluating the effect of subsidence on cover performance.

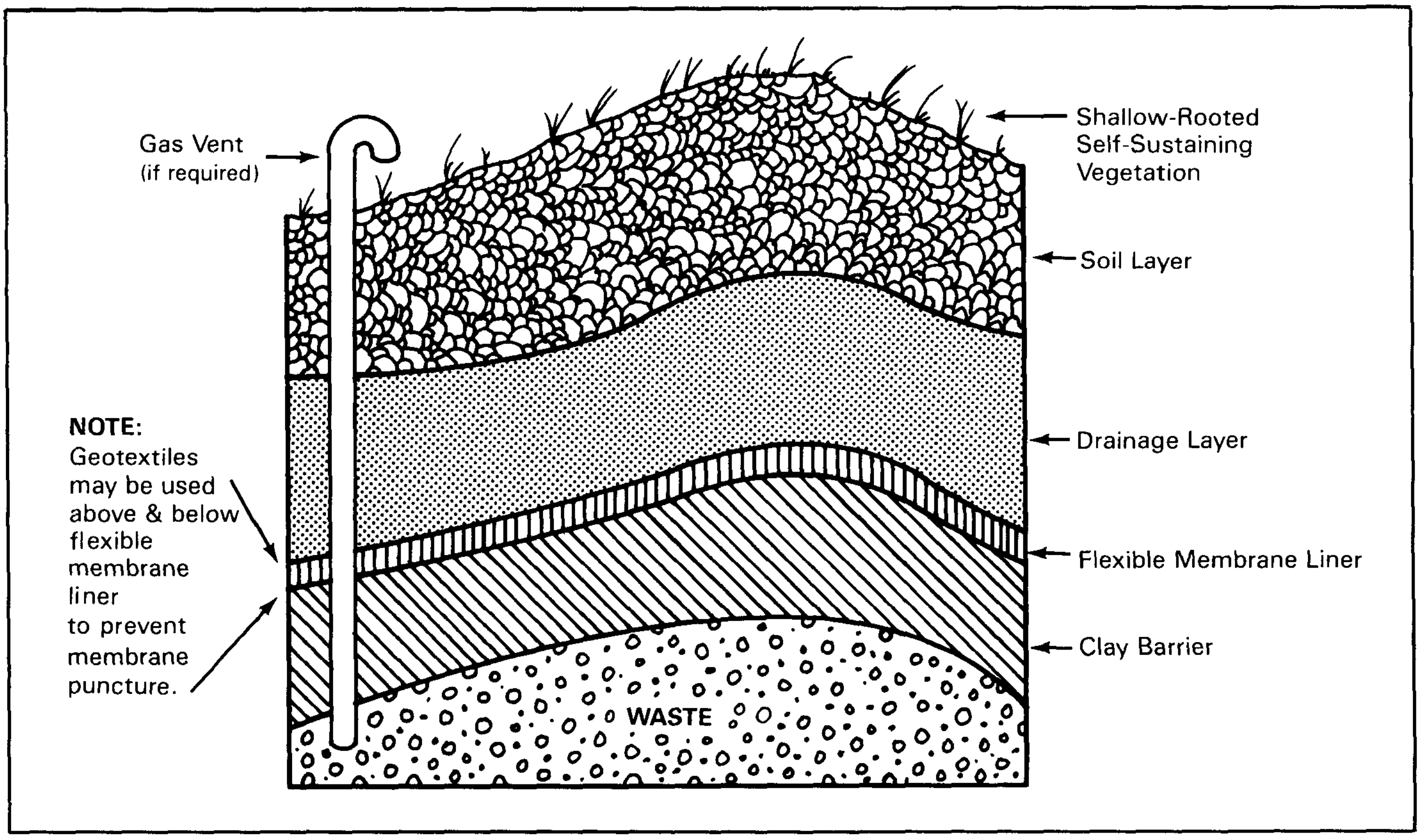


Figure 8. Prototype Four-Layer Cover Design. (Idealized; not drawn to scale.)

This research will be integrated into a technical resource document (TRD) which presents information on methods to improve cover design, and on construction, maintenance, and inspection techniques for clay and flexible membrane cap performance, cap drainage, and maintenance-free vegetation cover systems.

Liners

When choosing the most appropriate liner material for a disposal facility, the designer must consider the advantages and disadvantages of the material based on the nature of the waste, the characteristics of the site, and relative costs. For example, clay soil materials may be less expensive but are more permeable than flexible membrane liners (FMLs); however, FMLs may be damaged by poor installation procedures, or over time by tears, leaks, rodents, or chemical action.

- *Clay soil liners* are being examined for their response to organic and inorganic leachate components. Researchers are assessing the effects of organic solvents on clay soil permeability, developing a matrix to predict soil/waste interaction, and evaluating the adverse impact of soil shrinkage on performance when selected inorganic salt solutions are placed in contact with the liner. Laboratory soil porosity tests are being evaluated for use as performance indicators to predict the retention and rate of movement of pollutants through soil liners. Liners are also being evaluated to determine causes for failures. TRDs are being developed 1) to evaluate clay soils as liners and 2) to describe proper construction, maintenance, and inspection procedures for installation.
- *Synthetic liners* are being tested to determine their long-term life and resistance to chemical (leachate) attack. Methods to assist the designer on FML selection are being developed. Field studies are concentrating on evaluating installation techniques as well as methods for locating and repairing leaks in liners (for example, patching and grouting), and for detecting leaks by means of electrical resistance. Increasing awareness about and use of flexible membrane liners have generated a substantial amount of new information. The latest research findings are being incorporated into a TRD.

Waste Leaching

Methods for predicting leachate composition and flow time, and possible methods for treatment are being investigated at HWERL labs and field sites.

Workers installing a flexible membrane liner in a landfill. Proper installation techniques are important to minimize tears and seam leaks. HWERL is revising its technical resource document (TRD) on liner systems to include minimum technological standards for double liners required by 1984 RCRA amendments.

- The predictive effectiveness of techniques of leachate extraction (for example, batch extraction and column leaching) is being compared using hazardous waste samples with diverse physical and chemical characteristics.
- Models are being developed to evaluate predictive methods for determining liquid flow rates through landfilled wastes. Another model is being developed to predict saturation levels in landfills to assess how effectively a system can control the production of leachate over time. A predictive model for pollutant rate of release is being evaluated through comparison with actual pollutant activity at a field site.
- Laboratory studies have been initiated to develop and evaluate physical, chemical, and biological treatments for hazardous waste disposal sites. These investigations may eventually lead to the use of landfills as in situ reactors to minimize or neutralize toxic waste components.

Waste Modification

As an additional deterrent to leachate formation, waste may be rendered inert or less toxic through processes such as encapsulation (coating waste materials with an impermeable substance), solidification, or chemical stabilization (mixing waste with chemical additives to render it less harmful or harmless). HWERL researchers are evaluating solidification and stabilization technologies to better understand their potential roles in managing hazardous wastes. Studies are attempting to provide tools for predicting the performance of processes and products over time, using such parameters as ease of waste handling, reducing surface area, limiting solubility, and ability to detoxify pollutants.

- Encapsulation studies are currently examining the performance of organic binders (epoxides, polyesters, vinyls) and inorganic binders (cement, calcium, and silicates).
- Researchers are studying several solidification and stabilization processes to determine how interfering organic and inorganic materials affect both the processes and the products (i.e., the stabilized or solidified wastes). Areas being studied include the degree of fixation, durability, and strength; and resistance to leaching.

Systems Evaluation

Landfills and Surface Impoundments. Evaluations of landfill and surface impoundment systems are being made to determine the relationship between design and actual construction, to correlate this with potential failure mechanisms, and to assess whether (and in what ways) sites may be used for other purposes after closure. To assist in evaluation, HWERL scientists are combining a series of computer programs that delineate various aspects of facility design into one large system that will review data and calculations for an entire permit application, note errors or deficiencies, and recommend potential solutions. This system should provide more consistent, rapid turn-around times for these applications.

In addition, surface impoundments are currently being explored in order to provide a comprehensive understanding of their design, operation, and maintenance. Researchers are examining the design of dikes, the correlation of laboratory measurements with construction standards achievable in the field, and the degree to which specification of construction techniques and inspection practices may be able to influence uniformity and performance of finished impoundments.

Underground Storage. Subsurface cavities, particularly salt formations, have been used as storage depositories in the United States and Europe for several years. Using literature review and field demonstrations, HWERL researchers are assessing technology for the use of underground mines as possible long-term hazardous waste storage sites. Factors to be addressed include mine availability, capacity, and location; surrounding geological and hydrological conditions; and operational issues such as transportation, waste handling and placement, and fail-safe back-up systems.

The Removal and Remedial Action Program

HWERL's Removal and Remedial Action Program conducts control development activities in support of CERCLA (Superfund). This program, which was structured to match the requirements of CERCLA legislation, has two components: the Releases Control Branch, which investigates removal actions (for use in emergencies) and the Containment Branch, which investigates remedial actions (longer-term cleanup activities). Because of the frequent necessity for immediate response to cleanup situations, activities at HWERL do not always follow the classic path of concept development, laboratory evaluation, pilot testing, and field demonstration. Rather, the program concentrates on developing and adapting existing technologies, determining their costs and effectiveness, and producing state-of-the-art guidance material for use by designers and planners of uncontrolled hazardous waste site cleanup activities.

Removal Action

Transportation accidents, mishaps at industrial plants, and activities at uncontrolled hazardous waste sites can create emergency situations requiring rapid containment and cleanup. Each year, hundreds of releases involving Clean Water Act-designated and CERCLA-designated hazardous chemicals are reported. Removal action activities at HWERL concentrate on developing and testing equipment and procedures to prevent releases, to protect emergency response personnel, and to assess, contain, dispose of, and destroy contaminants.

Assessment. Because of the many possible permutations involving chemical combinations, size of releases, populations affected, geology, and weather, personnel responding to emergencies involving hazardous substances may face diverse technical problems. For this reason, the development of accurate and rapid assessment techniques has high priority. HWERL scientists and contractors are developing equipment and procedures to determine the extent of contamination, the appropriate extent of cleanup, and priorities within cleanup efforts. For example, nondestructive testing techniques designed to locate subsurface releases and chemical containers are being evaluated, including ground-probing radar, CW (continuous wave) microwaves, sonics/ultrasonics, and magnetometer metal detectors. In another project, dogs are being tested to determine whether their acute sense of smell can be used to pinpoint low levels of chemicals. Models to determine the performance of physical and chemical treatment technologies are being designed. A state-of-the-art manual on removal of hazardous materials which will provide guidance for identifying, treating, and disposing of close to 700 designated hazardous substances is being compiled.

Containment/Treatment. Once an accurate assessment of the situation is made, it is essential to contain, degrade, and detoxify the contaminants as quickly as possible in order to prevent or mitigate pollution damage. At HWERL, alternatives for containing spills are being developed, as well as techniques for reducing the rate of liquid spread into spills. These include rapidly deployable covers to prevent overtopping from rainwater, and stabilization and reinforcement techniques for impoundment walls and dikes. Equipment being tested and refined includes mobile incinerators, modular transportable incinerators, carbon regenerators, and soils washers.

Remedial Action

Hazardous Wastes. Remedial action studies cover the adaptation, evaluation, and recommendation of technologies for the containment, concentration, recycling, and destruction of hazardous wastes. To do this, researchers take existing technologies, (for example, those used in the construction, wastewater treatment, and spill cleanup industries), test their efficacy, and combine them into cost-effective, long-term cleanup actions. Selecting the appropriate technology for a specific site is a complex process. A detailed study of site and waste characteristics must be made, and the feasibility of applying various remedial techniques must be determined.

Contaminated Soils. Contaminated soils are a major problem at hazardous waste sites. Even a low level or volume of pollutants can combine with certain land and weather conditions (for example, high water table, permeable soil or rock, heavy rainfall) to produce ground-water contamination. Removing contaminated soils and immobilizing and burying them at another location has several drawbacks; since landfill and immobilization techniques are only partly successful, the same problem may simply be transferred to a different location. Further, communities are becoming increasingly sensitized to the difficulties associated with transportation and removal and may delay or prevent attempts to do so.

Methods of soil cleanup in situ are a promising answer to these problems. They have not been used extensively at uncontrolled sites because the technologies are either still being developed or have not been field-tested.

Sensor of the future? As part of an EPA pilot project to apply dogs' acute sense of smell to environmental problems, this German shepherd has been trained to detect toluene and trichlorophenols in simulated field situations. Because of dogs' speed and sensitivity (locating as little as 0.2 g of chemical from distances as great as 50 ft. [15.25 m]), they can outperform conventional field instruments. One promising use is detecting leaks from underground storage tanks.

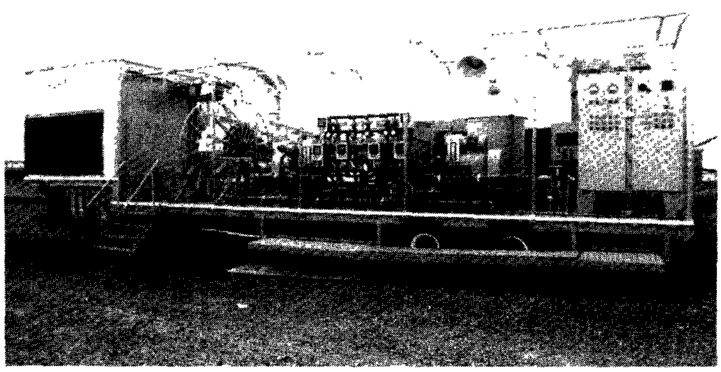
HWERL scientists and contractors are engaged in testing and determining the economic feasibility of several in situ cleanup techniques. Three promising ones are described below.

- *Soils washing* involves washing soils with plain water, solvent, or water plus an additive to remove contaminants, which are then treated in a separate facility. Laboratory tests are being conducted on soils washed with water and water plus surfactants (such as soaps or detergents). Other studies will cover pH-adjusted water and solvents (for example, chelating agent, acid wash).
- *Grouting* (for example, mixing the waste with a cement or polymer grout) is one technique to immobilize contaminants in order to reduce their rate of release from the soil to an acceptable level. HWERL researchers are currently studying grouting techniques and grout-pollutant interactions.
- *Precipitation* of a highly insoluble compound can render heavy metals harmless. HWERL scientists are investigating the development of a process that uses substances such as sulfides, carbonates, and phosphates for this purpose.

A major issue for almost all in situ treatment processes is to develop a means of employing them quickly and efficiently. As one answer, HWERL engineers and contractors are currently field-testing a prototype mobile in situ containment and treatment unit (ISCTU). This is a 45-foot-long (14-meter-long) drop-deck trailer capable of treating approximately 80,000 square feet (7,500 square meters) of contaminated soil approximately 25 feet (8 meters) deep per month. The system has the capacity to treat a variety of contaminants in several different soils. Depending on the needs on site, the ISCTU can:

- Inject a grout curtain into the soil to keep the pollutants from spreading and contaminating ground water, or to prevent uncontaminated ground water from entering the waste site.
- Treat the contaminated soil with a variety of techniques such as washing, neutralization, biostimulation, polymerization, oxidation-reduction, and precipitation.
- Remove contaminated treatment water from recovery wells.
- Air-strip volatile organic contaminants.

The treatment process of choice is continued until a point of diminishing return is reached. The ISCTU's versatility and its capacity to treat soil to a considerable depth are a meaningful step in bringing practical, economical on site treatment closer to reality.



The EPA In Situ Containment/Treatment Unit (ISCTU) houses a range of treatment components for detoxifying contaminated soils. A motor generator set (encased, far left) supplies power to the system. The trailer's open frame allows ease of movement for workers, while a canvas cover (not shown) provides protection in inclement weather. Floodlights attached to the frame make 24 hour operation possible.

3. Prediction

Predicting pollutant behavior in the subsurface is one of the most difficult—but also one of the most important—tasks for ground-water protection programs. Many interacting variables can influence the transport and fate of contaminants: for example, the source of contamination, the type of pollutant(s), climatic conditions, topography, and the geological and biological characteristics of the subsurface. The relative influences of various processes and conditions on the behavior of a contaminant can vary, dramatically affecting the accuracy of predictions. Knowledge of these interactions must be refined in order to develop and improve mathematical models to predict chemical transport and fate. In order to gain this knowledge, continued research is needed to obtain representative samples, to develop more accurate laboratory simulations (microcosms) of environmental systems, to conduct field verification studies, to refine tools and procedures used to measure chemical and physical reactions, and to determine chemistry and biology in situ.

At EPA's Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma (RSKERL-ADA), researchers are investigating the movement of water in the ground (hydrogeology) and the various physical, chemical, and biological attenuation processes that degrade or destroy contaminants (Figure 9). In addition, RSKERL scientists and engineers are investigating methods for determining the mechanical integrity of injection wells, and the interaction of injected fluids with geologic materials. This research has high priority because of the 1984 amendments to the Resource Recovery and Conservation Act (RCRA). RSKERL staff also offer technical assistance to personnel in the field. Information about recent findings, techniques, and technology is disseminated to a broad professional audience through journal articles, symposia, training sessions, reports, and guidance documents. RSKERL also monitors and coordinates the National Center for Ground-Water Research (NCGWR), a consortium of three universities: Rice, Oklahoma State, and the University of Oklahoma, funded through ORD's Office of Exploratory Research.

The Environmental Research Laboratory in Athens, Georgia (ERL-ATH) researches subsurface transport and transformation processes for organic pollutants and heavy metals, develops and tests leaching models for unsaturated zone transport to ground water, and provides technical assistance and methodology to support proposed RCRA regulations (Figure 9).

Table 2 summarizes current prediction research at RSKERL and ERL-ATH. Some key projects are described in this section.

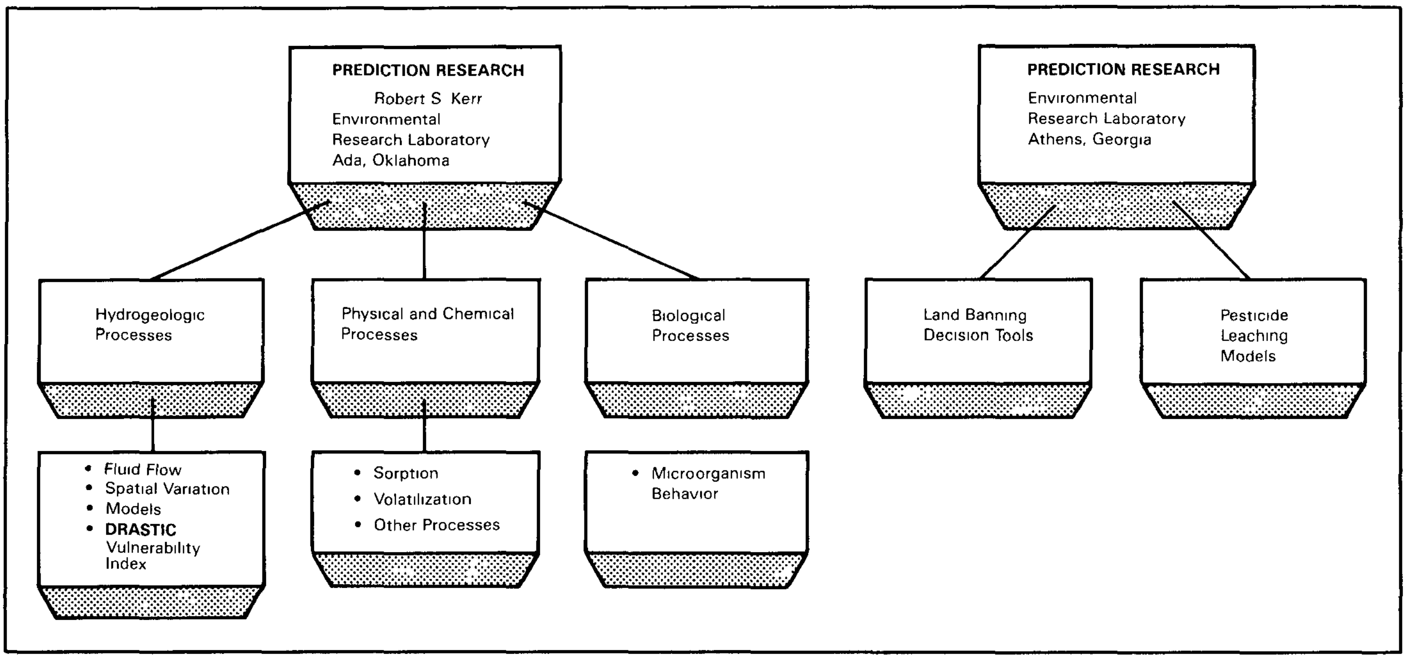


Figure 9. Highlights of EPA Ground-Water Prediction Research.

Table 2. Ground-Water Prediction Research
Robert S. Kerr Environmental Research Laboratory — Ada, OK
Environmental Research Laboratory — Athens, GA

AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Biological Processes	Determination of Subsurface Microbial Activity	Adapt methods such as electron and epifluorescence microscopy and muramic acid assays to determine the abundance and metabolic activities of indigenous microflora in subsurface habitats. Develop methods to estimate the proportion of metabolically active bacteria to determine their nutritional state.	• Develop improved methods for identifying and characterizing subsurface microflora.
Biological Processes	Prediction of Microbial Contaminant Concentrations	Develop and evaluate predictive models describing the movement and survival of viruses and pathogenic bacteria in ground water.	• Provide methods and data for predicting chemical concentrations in ground water at a point of use.
Hydrogeologic Processes	Determination of Dispersion Coefficient Processes	Conduct field investigations to develop an understanding of physical and chemical components of dispersion.	• Determine the physical and chemical components of dispersion as used in solute transport models. • Increase applicability of prediction equations.
Management Aids	Determination of Waste Mobility by the Use of Microcosms	Evaluate soil profile and aquifer microcosms for their capacity to predict hazardous waste movement. Test protocols using selected chemicals from RCRA Section 3001. Compare results with field verification studies.	• Develop screening methods to assess hazardous waste exposure potential.
Management Aids	Enforcement and Other Technical Support	Provide consultation, project supervision, testimony, and analytical support for Superfund activities involving ground-water contamination.	• Provide technical support.
Management Aids	Evaluating Ground-Water Contamination Risks from Hazardous Waste Disposal	Investigate the processes that govern the transport rates, transformation, and fates of hazardous waste constituents in the subsurface. Evaluate mathematical models describing solute transport in the subsurface. Assess validity through field experiments.	• Provide field-evaluated methods and data to predict concentrations of contaminants from the treatment, storage, and disposal of hazardous wastes.
Management Aids	Methods to Determine the Impact of Geology on Ground-Water Quality	Develop techniques for determining the impact of geology, including the impact of surface development and water use, on ground-water quality. Develop methods for detecting geological areas within an aquifer that should not be developed for public water use because of naturally occurring contaminants such as chromium, selenium, uranium, and arsenic.	• Develop methods for determining impact of naturally occurring geological materials and conditions on ground-water quality.
Management Aids	Standard System for Evaluating Ground-Water Pollution Potential Using Hydrogeologic Settings	Develop a protocol to determine the pollution potential of any United States aquifer or area within an aquifer based on hydrogeologic criteria. Provide training and guidance in the use of the protocol.	• Provide technical basis for planning the location of land disposal sites. Preliminary system has been published; current field evaluations will lead to the development of the protocol.
Management Aids	Support for the Land Disposal Banning Decision Rule	Assess hydrolytic reactivity and the applicability of a sorption estimation procedure for selected chemicals.	• Support the Office of Solid Waste's (OSW) land disposal banning decision rule required in the 1984 RCRA reauthorization.

Table 2 Cont.

AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Management Aids	Validation of Predictive Techniques for Environmental Exposure	Develop an extensive field data base to establish parameters to test exposure assessment models. These models are designed to assess pesticide migration through the saturated and unsaturated zones.	• Validate pesticide exposure assessment models, including PRZM, PESTANS, SESOIL, and SWAG.
Physical and Chemical Processes	Mathematical Models for Subsurface Transport and Fate	Create or modify a range of models for predicting concentrations of toxic chemicals in the subsurface.	• Provide a choice of mathematical models of contaminant transport and fate, suitable for a variety of computers, to aid in estimating exposure of humans, animals, and plant life.
Physical and Chemical Processes	Movement and Persistence of Dioxins in Soils and Ground Water	Determine batch sorption isotherms using labeled dioxins. Evaluate successive additions and extractions of dioxins to determine desorption characteristics and sorption kinetics in the subsurface. Validate transport potential using unsaturated microcosms.	• Provide capability to predict the rate of movement and transformation of dioxins in soils and ground water. • Assess potential for human exposure to dioxin.
Physical, Chemical, and Biological Processes	Prediction of Chemical Contaminant Concentrations	Examine sorption/retardation of organic contaminants in the subsurface in terms of subsurface characteristics and organic chemical properties. Define the subsurface microbial population and investigate capability to transform organic pollutants. Study abiotic transformations of organics and concentration effects on sorption and transport.	• Provide methods and data to predict concentrations of microbial contamination in ground water.

Hydrogeologic Processes

Exploring the Complexities of Ground-Water Contaminant Flow

Contaminant dispersion is a more complex process than had previously been thought. Until recently, most dispersion studies were done in relatively uniform rock or soil formations, i.e., consisting of one type of material with few or no changes or discontinuities. Similarly, most predictive models have been developed for chemicals that mix readily with water. However, many hazardous contaminants are not miscible (for example, gasoline, TCE). They may be either heavier or lighter than water, and may flow at the same rate as water or less rapidly. These qualities, alone or combined with geologic discontinuities (for example, fractures, formation changes, porosity changes) can lead to faster ground-water recharge and can cause a chemical plume to flow counter to the mass of water (see Figure 10).

RSKERL scientists are trying to analyze how immiscible fluids move through porous rock and soil formations, and how these fluids may physically change a formation's characteristics, such as permeability, structure, and sorption capacity. Mathematical tools have been developed to simulate and predict contaminant transport in plumes that contain a number of immiscible components, as is often the case with sources such as hazardous waste disposal sites, leaking underground storage tanks, and accidental spills. Another process being investigated is fractured flow, i.e., the flow of water through fractures or other discontinuities (caverns, fissures, limestone cavities) in rock.

The Effect of Spatial Variability on Transport Processes

Another pressing research task is to assess the importance of the spatial variability of the subsurface on the transport process. Water and contaminants move in the subsurface in three dimensions. Movement is influenced by many physical, chemical, and biological factors that may change even in a small geographic area. To investigate spatial variability, researchers must answer such questions as: How many samples are necessary to describe a hydrologic system, and how can unaltered samples of subsurface materials be taken? To date, progress has been slow because of the complexity of the subsurface and difficulties in obtaining representative

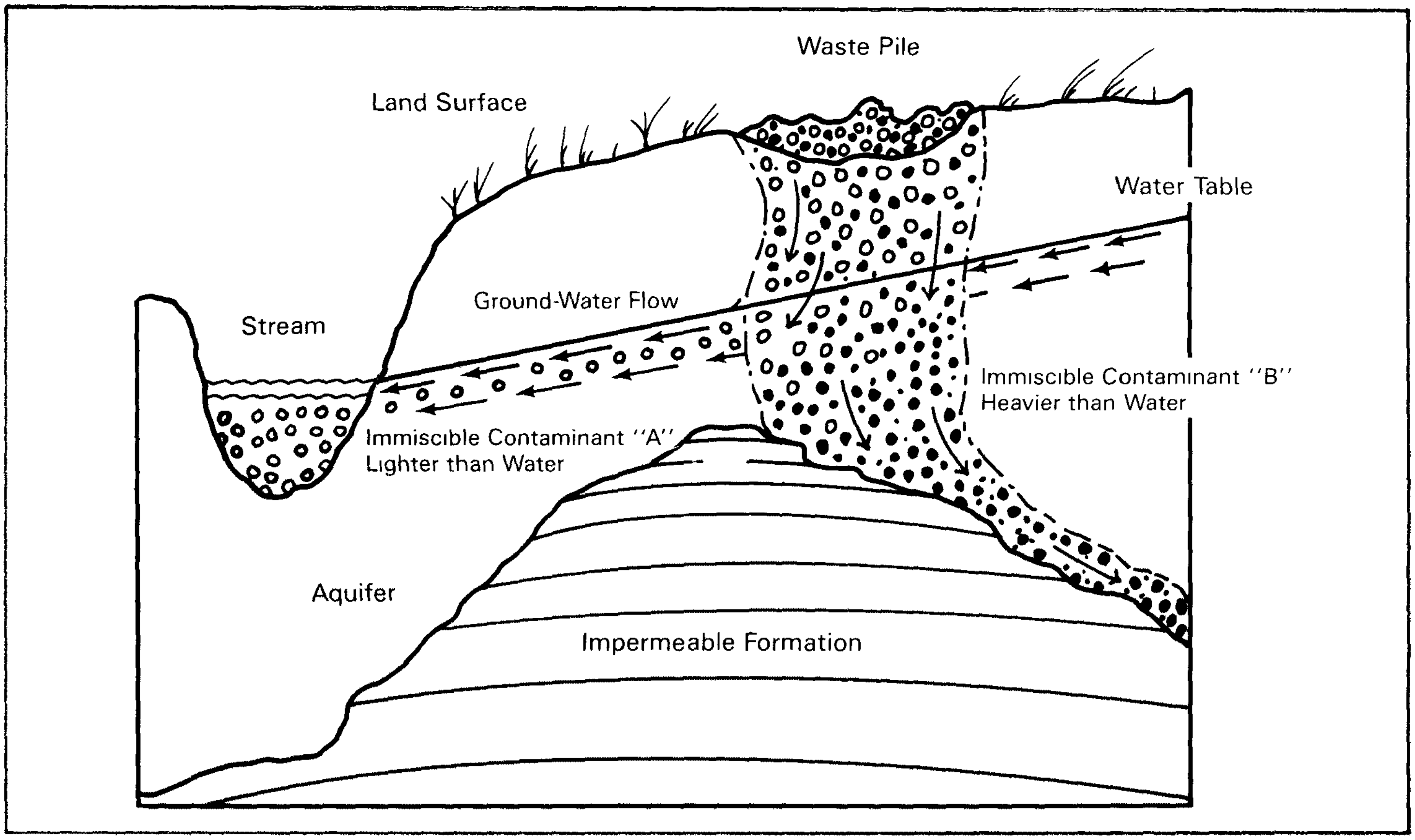


Figure 10. Movement Flow of Immiscible Fluids. This idealized drawing illustrates the possible complexities of ground-water investigation. Immiscible contaminant "A," leaching into an aquifer from a waste pile, is lighter than water and therefore follows the ground-water flow. Immiscible contaminant "B," entering the aquifer at the same point, is heavier than water and flows downward until halted by an impermeable formation. At this point contaminant "B" follows the downward slope of the formation and flows counter to the direction of the ground water.

samples. This is an area that requires additional research in sampling and analysis techniques. A project is planned to characterize the probability distributions of subsurface parameters.

Improving Existing Models

Over 400 models now exist to describe the movement of fluids in the subsurface. These range from simple models capable of being used with a hand calculator to highly complex ones requiring a mainframe computer. Each has its advantages and disadvantages. RSKERL, together with the International Ground-Water Modeling Center (IGWMC), maintains a data base on these models, and works at refining and validating them. Many of these models are more appropriate for research than for practical application at this stage. Most transport models are too general to be helpful in answering site-specific questions. To rely on these models for developing regulatory decisions is also problematic, because many are theoretical and have not been validated. IGWMC scientists are attempting to improve the reliability of these tools, and to develop simple, user-friendly models suitable for managers in field situations.

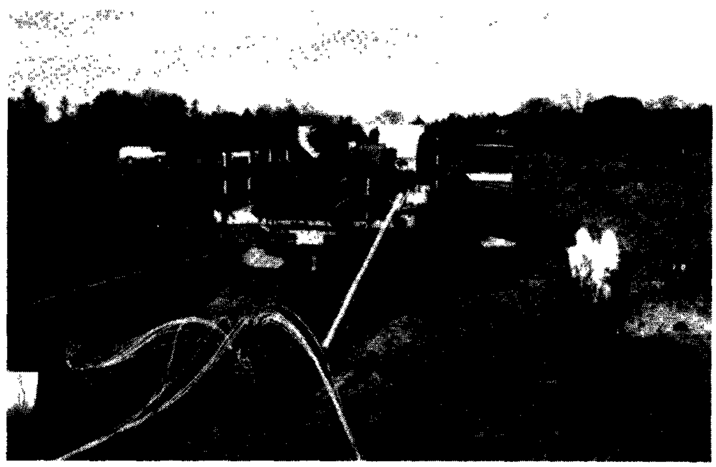
Assessing Vulnerability to Contamination

Researchers at the National Water Well Association, under a RSKERL cooperative agreement, have developed the DRASTIC Index, a tool for evaluating any hydrogeologic setting in the United States for its potential vulnerability to ground-water contamination. A hydrogeologic setting is defined as a mappable geographic area with common geologic and hydrologic characteristics. DRASTIC produces a vulnerability rating by ranking the seven most important factors in any setting: 1) depth to water table, 2) recharge, 3) aquifer media, 4) soil media, 5) topography (slope), 6) impact of vadose (unsaturated) zone, and 7) hydraulic conductivity of the aquifer. Because the evaluation is relative rather than absolute, DRASTIC is designed to be used for planning or screening. However, the DRASTIC concepts are key to the development of EPA Ground-Water Protection Strategy vulnerability guidelines and subsequent regulations. DRASTIC is now being applied to index ten areas of the United States in order to ensure its applicability in a wide variety of hydrogeologic settings.

Pesticide Leaching Models

Pesticide contamination of ground water is a growing concern, particularly because of its possible connection to agricultural practices such as conservation tillage. Because conservation tillage is considered the best soil protection method and possibly the best management practice to improve surface water quality, estimates indicate that it will be used for 95 percent of row crop acreage by the year 2000. However, the increased pesticide application rate, increased infiltration rates of water, and the use of soluble, persistent pesticides associated with conservation tillage pose considerable potential danger to ground-water supplies.

Scientists at the Environmental Research Laboratory in Athens, Georgia (ERL-ATH), and at RSKERL have developed two leaching models to screen pesticides for their potential to contaminate ground water: Pesticide Analytical Solution (PESTANS) and Pesticide Root Zone Model (PRZM). A methodology for screening pesticides for their potential to migrate in various geographic areas, called Leaching Evaluation of Agricultural Chemicals (LEACH), has been produced by running PRZM through a spectrum of possible soil/crop/weather agricultural scenarios in the United States. Early efforts to validate PESTANS and PRZM were retrospective performance tests associated with specific applications for regulatory purposes, rather than actual scientific validation. Current validation efforts include the Dougherty Plains project, in which the actual migration of two pesticides, Temik and Dual, through sandy, layered soil growing a peanut crop, is compared to the projections of PESTANS, PRZM, and other first-generation leaching models. The project is designed to provide rigorous evaluation of these models over the next several years.



At the Dougherty Plains Project, several vacuum-pressure lysimeters (projecting teflon tubes shown in left foreground) are being installed. The lysimeters will be buried in this field and then unearthed after crop planting and pesticide application so that soil-water samples can be tested for levels of contamination.

Research to Support Proposed RCRA Land Banning Regulations

The newly reauthorized RCRA requires EPA to develop criteria to determine whether land disposal of hazardous wastes adequately protects human health and the environment, and to determine if certain wastes should be banned from land disposal. In EPA's proposed regulations, the rule for evaluation of ground-water contamination and potential human exposure requires certain contaminant-specific and environmental characterization data. Implementing this rule for the approximately 450 contaminants now on the RCRA list requires the following information:

- For chemicals:
  - hydrolysis rate constants (sorbed and dissolved)
  - partition coefficients
- For metals:
  - thermodynamic and sorption data bases sufficient for speciation calculations
- For all contaminants:
  - appropriate environmental characterization
  - appropriate assessment methods

For each contaminant, data will be incorporated into a ground-water/surface water model developed for this purpose. In each case, using this model/data combination requires a thorough uncertainty analysis to better defend the specific parameter choices, and to better understand the range of possible outcomes. The ERL-ATH laboratory is providing the EPA's Office of Solid Waste (OSW) with contaminant-specific data, as well as giving technical assistance in the development, technical defense, and application of the proposed rule.

Physical and Chemical Processes

Sorption

Adapting Surface Models to Describe Subsurface Phenomena. Once a contaminant has entered the subsurface, it is subject to various physical and chemical attenuation processes such as sorption, hydrolysis, reduction, substitution, and volatilization. Investigation at RSKERL and at extramural projects has concentrated on sorption (chemical or physical processes of adherence or assimilation). Sorption processes may be complex. Many existing theories and models of sorption processes were developed for surface soils and do not take into account the special nature of ground-water scenarios. For example, several theories have been based on surface soils that contain a relatively large carbon content; thus, they do not address subsurface geologic conditions, where the carbon content is often low, or where the ratio of clay soil to carbon is high, altering potential sorption capabilities. RSKERL scientists are studying surface sorption models of hydrophobic organic pollutants to adapt them to ground-water conditions.

Developing New Models for Subsurface Phenomena. Scientists must also assess how well current sorption theory predicts how the subsurface might change the characteristics of contaminants or how contaminants change the characteristics of the subsurface. For example, certain organic solvents will change the chemistry of some clays that line lagoons and will then leach through these clays. This kind of scenario might be found in the subsurface, where, for example, a contaminant might interact with a clay stratum that covers a confined aquifer, and then migrate through to contaminate the aquifer. RSKERL scientists and extramural researchers are quantifying the various interactions possible in the subsurface in complex but realistic simulations of environmental systems in order to develop theories and predictive models to describe sorption.

Investigating the Rate of Sorption. Another important aspect of sorption research is the rate at which sorption occurs. Most models assume the process is instantaneous. Laboratory and field experiments have shown this to be largely untrue, but current theories devised to explain the dynamics of slower sorption rates do not adequately describe the behavior of many environmentally significant chemicals. RSKERL and contract scientists are refining these theories and developing others to more accurately explain sorption rate.

Two RSKERL staff members use a hollow stem auger to obtain a soil core sample for laboratory study. Researchers may examine a soil to determine its physical constituents, its hydraulic properties, the extent and activities of its microbial populations, and other information that may aid in understanding contaminant behavior in ground water.

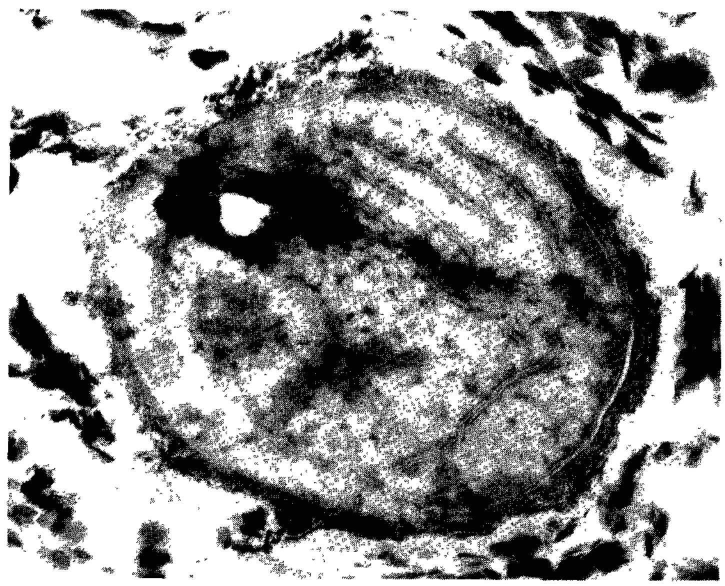
Volatilization

Another process that needs to be studied is volatilization. How much of a contaminant is volatilized and lost through the unsaturated zone? How important is this process in the eventual fate of a contaminant? In an attempt to answer these questions, RSKERL scientists and extramural researchers are studying volatilization in a closed system.

Future Directions

Almost no field information exists on transformation processes such as hydrolysis, reduction, complexation, and substitution in organic chemicals and heavy metals in ground water. Because ground water moves slowly, processes such as these, which can take several years to occur, may turn out to be the most significant in pollutant attenuation. The greatest impediment to the study of physical and chemical processes in the subsurface is the lack of techniques and equipment for measuring chemistry in situ. Tools and procedures must be developed to determine the potential for reactions and to measure their extent.

The particular species of a metal has a dominant influence on the metal's transport and transformation in ground water. Metals may exist in different oxidation states or in complexes with various organic chemicals. Determining the influence of speciation on metal movement is a new area of research at the RSKERL and ERL-ATH laboratories.



By examining bacterial populations in the subsurface, scientists learn more about biological influences on contaminant behavior. This bacterial cell, from a soil core taken at 18 feet (5.6 m) by RSKERL researchers at Fort Polk, Louisiana, is unusual for the sample population because of its small size and particular structure. The dark area with the white hole is a storage granule—bacteria use mechanisms like this to store material needed for survival or growth. Long periods of scarce nutrient supplies in the subsurface may have caused the development of such adaptive mechanisms.

Biological Processes

RSKERL researchers and extramural contractors are studying the transport and fate of organic solvents and pathogens in ground water. In surface soils and waters, microorganisms play the primary role in transforming organic compounds. Their role in the subsurface, however, is largely unknown, although some promising discoveries have been made. Initial findings by the scientific community have shown that there are microorganisms in both the shallow and deep subsurface; that these microorganisms may vary considerably in both type and number; and that some are capable of degrading certain chemicals of interest. In fact, while it was previously assumed that the subsurface held no life, scientists now think that the total biomass in regions below the root zone in North America is probably much higher than the bacterial biomass in rivers and lakes.

Now that these general questions have been partially answered, researchers must continue to examine subsurface microbes and their degradation ability by asking more specific questions such as: What do they do? When? Where? How much? How fast? Under what conditions? What are the by-products? How can their behavior be predicted? For example, it is now known that organisms in the subsurface can transform many important organic pollutants. The rate of transformation is limited by the number and activity of the microorganisms, while the extent of transformation is most frequently limited by requirements for metabolism such as oxygen or mineral nutrients. However, these conclusions are based on a limited number of studies.

RSKERL scientists are furthering this knowledge by investigating the relationship between organisms and their particular environment (for example, depth, geology, mineralogy). They are also studying other factors, such as the processes and conditions that encourage or limit biodegradation. For example, extramural researchers are investigating the activities of hepatitis A virus (HAV), a major pathogen that causes severe gastroenteritis and intestinal infections. Until a few years ago, scientists were unable to identify and isolate HAV in the laboratory. The recently developed ability to assay for HAV has enabled researchers to initiate studies to determine how long the virus retains its infective capacity in a variety of soils and water samples. This is a first step toward assessing what physical, chemical, and biological changes HAV and other viruses may undergo in ground water.

4. Monitoring

Monitoring provides information on potential or known contamination. Many types of monitoring may be performed for a variety of reasons; for example, monitoring may be used to determine probable contaminant pathways, to map actual contaminant flow, to locate sources of contamination, to identify contaminant plumes, and to detect leaching, percolation, or leaks. Monitoring research, conducted at the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV), with assistance from the Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma (RSKERL-ADA), focuses on developing ground-water monitoring and sampling techniques and geophysical monitoring techniques, and refining methods for interpretive analysis of data (Figure 11). These techniques and methods are used to define the nature, location, and movement of subsur-

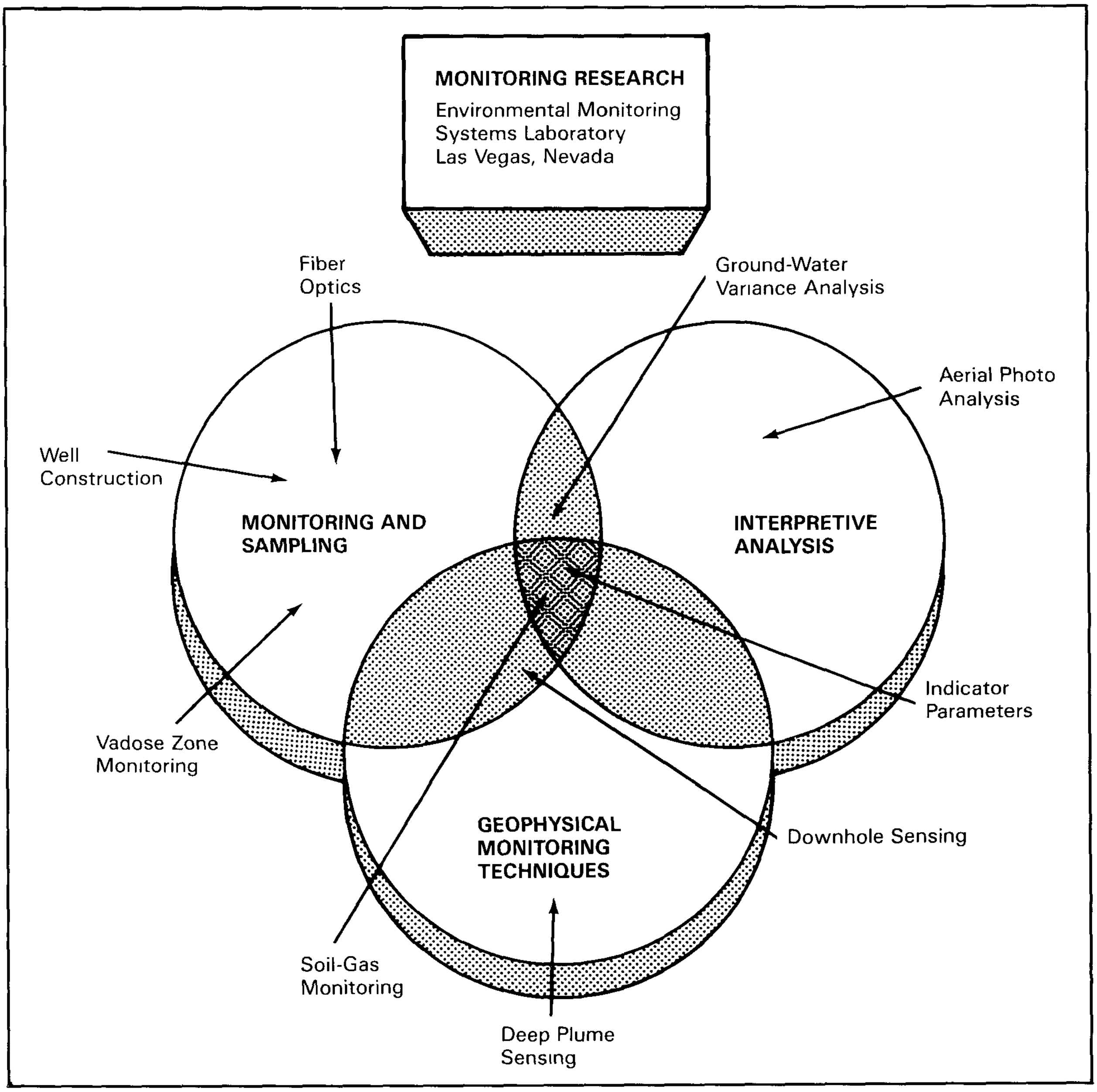


Figure 11. Highlights of EPA Ground-Water Monitoring Research.

face contamination. Table 3 lists current monitoring projects. The laboratories also provide operational guidance and technical support to EPA program and regional offices, and to state and local agencies.

Research findings are communicated to the user audience through guidance documents, journal articles, workshops, and training courses.

Table 3. Ground-Water Monitoring Research
Environmental Monitoring Systems Laboratory—Las Vegas, NV
Robert S. Kerr Environmental Research Laboratory—Ada, OK

AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Monitoring and Sampling	Geophysical Surveys of Hazardous Waste Sites	Provide geophysical and geochemical monitoring support to EPA regional offices and EPA's Emergency Response Team for assessment of CERCLA hazardous waste sites.	• Meet RCRA land disposal regulations for ground-water detection and compliance monitoring for contaminants leaking from permitted facilities. • Provide cost-effective monitoring techniques. • Support remedial and removal actions at CERCLA sites. • Establish standard procedures for the application of geophysical and geochemical techniques. • Conduct geophysical surveys on request.
Monitoring and Sampling	Ground-Water Quality Protection from Injection Wells	Test the mechanical integrity of injection wells. Develop an overview of contamination cases associated with Class II and V injection wells.	• Provide technical support in the implementation of Underground Injection Control (UIC) regulations.
Monitoring and Sampling	Methods for Monitoring Well Construction	Assess alternative methods for constructing monitoring wells to determine problems with surface and subsurface contamination; select and field-test recommended monitoring options.	• Determine and recommend preferred well drilling and sealing techniques to derive accurate ground-water samples.
Monitoring and Sampling	Monitoring Ground Water with Fiber Optics Technology	Evaluate the feasibility of performing contaminant-specific ground-water monitoring using fiber optics technology combined with laser fluorescence spectroscopy.	• Develop methodology and hardware to monitor organic and inorganic chloride concentrations. • Conduct field demonstration to identify weaknesses in the methodology. • Improve response time and lower cost of monitoring technology.
Monitoring and Sampling	Unsaturated Zone Monitoring for Hazardous Waste Sites	Evaluate agricultural equipment and methods for monitoring in the vadose zone to detect leaching and percolation of pollutants from hazardous wastes. Determine the relative effectiveness of suction and gravity lysimeters.	• Adapt existing technology to meet RCRA regulations for monitoring at permitted land treatment or land farming disposal areas. • Provide guidance for lysimeter performance for permit writers. • Develop technical resource document on unsaturated zone monitoring at hazardous waste land treatment units.
Monitoring and Sampling	Well Construction and Sampling for Ground-water Quality Analyses	Develop methods for constructing, completing, and sampling ground-water monitoring wells to obtain representative physical, chemical, and biological data.	• Update manual for sampling ground-water quality parameters.

Table 3 Cont.

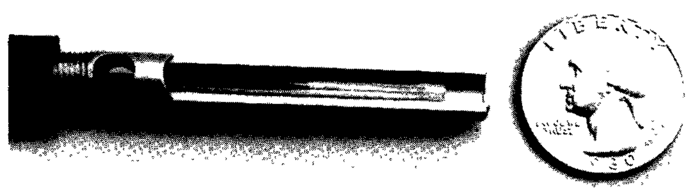
AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Geophysics	Detection of Leachate Plumes in Ground Water with Geophysics	Evaluate geophysical and geochemical methods to detect and map organic and inorganic leachate plumes at hazardous waste sites, emphasizing soil-gas sampling techniques for mapping organic plumes.	• Establish guidelines for the number of sample points required to map a plume. • Develop quality assurance guidelines for the calibration of equipment and procedures for mapping hazardous waste sites. • Provide guidance on the application of geophysical and geochemical techniques to hazardous waste sites. • Recommend procedures for hazardous waste site investigations.
Geophysics	Downhole Sensing for Hazardous Waste Site Monitoring	Design, build, modify, and evaluate sensing devices and methods used to obtain geohydrologic data from monitoring wells.	• Develop new technology or modify existing technology for typical small-diameter, shallow-depth, plastic-cased monitoring wells. • Develop procedural manual for use by site operators and regulatory personnel. • Make conference presentations on project efforts.
Geophysics	Geophysical Sensing of Fluid Movement from Injection Wells	Map the migration of wastes from injection wells at depths of 1,000+ feet at several field sites, using the time-domain electromagnetic method.	• Assess the applicability of time-domain EM technology to meet Underground Injection Control (UIC) regulation requirements. • Develop a technical transfer report.
Interpretive Analysis	Locating Abandoned Wells with Historical Photographs	Identify abandoned oil and gas wells through historical aerial photographs and verify by comparison with conventional records.	• Assist EPA regional officials in examining large areas for abandoned gas and oil wells to comply with UIC regulations. • Provide reports with area maps indicating photo-identified oil and gas well locations.
Interpretive Analysis	Indicator Methods for Ground-Water Detection Monitoring	Determine parameters that indicate the presence of hazardous constituents in ground water at land disposal sites, using existing data from Consent Decree, Superfund, and RCRA site monitoring files.	• Evaluate performance of selected indicator parameters. • Meet RCRA requirements for detection and compliance monitoring as part of land disposal ground-water monitoring programs. • Identify "missed classes" of hazardous constituents. • Develop a short list of parameters that are (1) reliable indicators of leakage, and (2) inexpensive to measure
Interpretive Analysis	Variance Analysis for Ground-Water Quality Monitoring	Determine the variability over time of ground-water monitoring data, using several statistical techniques.	• Develop a reliable, statistically sound, technical basis for the design and implementation of monitoring networks.

Monitoring and Sampling

Monitoring and sampling research involves developing innovative techniques and equipment, refining existing techniques, and adapting those from allied industries. Fiber optics, well-drilling techniques, and soil sampling devices are currently being investigated by EMSL and its contractors.

Fiber Optics

Fiber optics is one of the most promising areas being investigated for contaminant monitoring. A major breakthrough in this research has been the development of a spectrometer (Figure 12) for remote analysis of contaminants through the integration of fiber optics, lasers, chemistry, optrodes, and spectroscopy. The key element is the optrode. This tiny sensor, placed at the end of an optical fiber, can measure concentrations of certain chemicals and transmit this information back to the spectroscope in the form of fluorescent light. The use of a single fiber to send and return light is an important design advantage, since it allows the optrode size to be reduced and minimizes optical alignment and focusing problems at the sampling end.



The organic chloride optrode, which consists of an optical fiber immersed in chloride-reactive chemicals, is housed in a narrow glass tube sealed with a membrane that keeps the chemicals in, water and dirt out, and allows volatile organic chlorides to pass through. This sensor, encased in its protective metal shield, could be dropped down a monitoring hole smaller in diameter than a quarter.

The optrode that is currently being tested monitors volatile organic chloride compounds in ground water and in the unsaturated zone. Research to date indicates sensitivity to concentrations of less than 50 parts per billion at remote distances of up to 656 feet (200 meters)

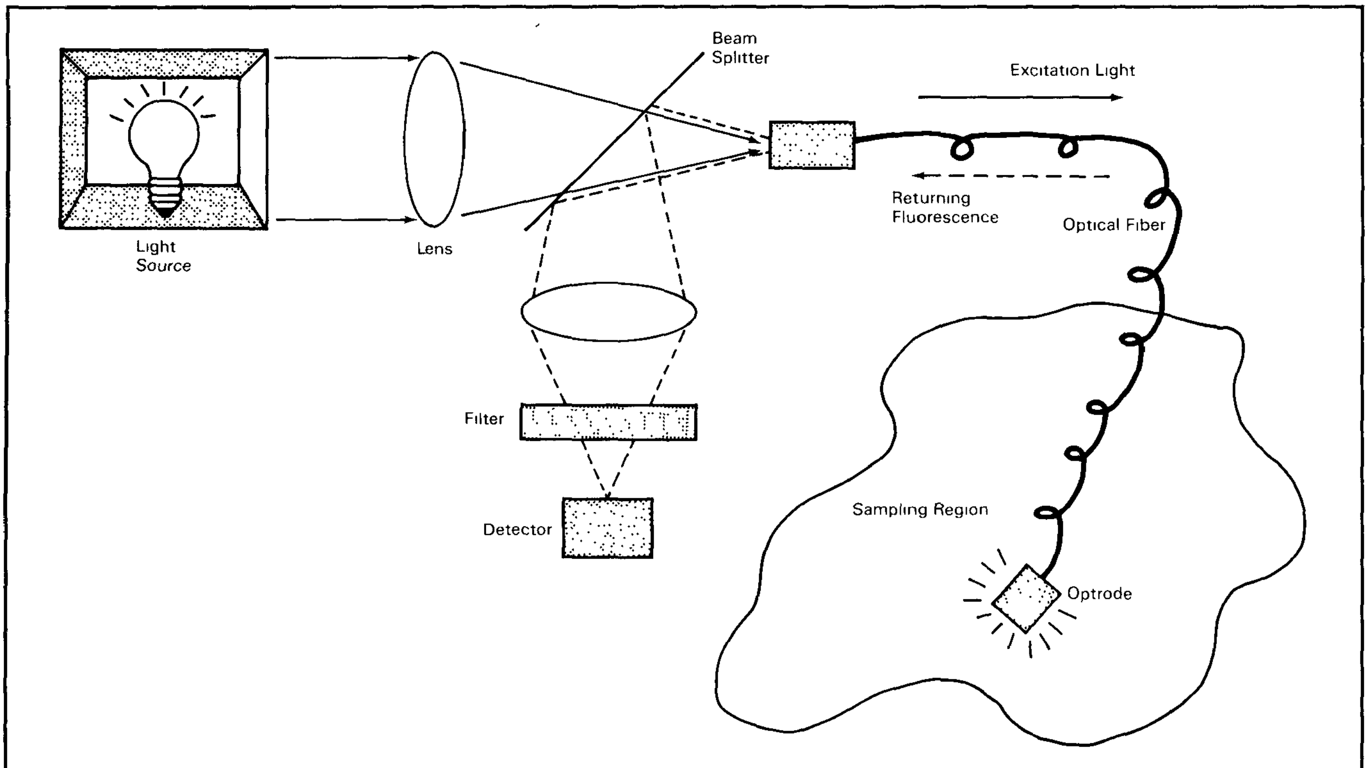


Figure 12. A Schematic Representation of Remote Fiber Spectroscopy.

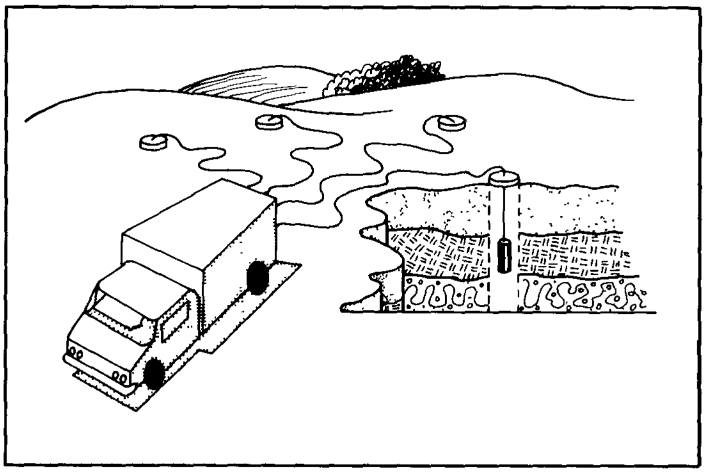


Figure 13. Remote Fiber Fluorimetry Can Be Used to Measure Chlorinated Hydrocarbons in Ground Water.

(Figure 13). The instrument has several advantages over conventional monitoring devices; not only is it simpler and more economical, it is also extremely versatile. It can be used to sample at sites (generally wells) that are hot, cold, radioactive, dangerous, and/or hard to reach. Its flexibility, small size, and ruggedness make it extremely useful for situations that require multiple probes that can read continuously for long periods of time, and are unaffected by other chemicals or equipment. For example, optrodes could be used as part of an "early warning" system to monitor a hazardous waste site for incipient signs of contamination. Since the optrode may be left in place and remain effective for as long as 12 months, it is particularly suitable for long-term monitoring.

The optrode's primary limitation at this time is the number of chemicals it can measure. Although in theory the number is limitless, in practice the optrode can detect only a few chemicals with sufficient accuracy. Selection, adaptation, or development of suitable chemical systems designed for optrodes will be the next major goal for researchers.

Improved Well Construction

In another project, EMSL researchers and contractors are investigating the extent to which drilling techniques and sealing materials commonly used for both domestic water well and monitoring well construction contribute to contaminant dissemination. As a first step, they are examining and testing conventional drilling methods—particularly the hollow stem auger and mud and air rotaries—so that problems in use can be categorized and more effective drilling and sealing techniques recommended.

Vadose Zone Monitoring

At permitted land treatment or land farming disposal areas, RCRA regulations require monitoring of the vadose (unsaturated) zone to detect leaching and percolation of pollutants before they reach the water table. Standard sample collection devices used in agriculture (for example, lysimeters) are being examined for modification for use at land treatment or disposal sites. Lysimeters collect water from soils; the water is then analyzed for soluble constituents. Two lysimeters—the suction cup, which collects liquid through a permeable ceramic cup, and the gravity lysimeter, which collects water that flows downward as a result of gravity—are being compared for performance and effectiveness in various different types of soils in laboratory and field studies.

Geophysical Monitoring Techniques

Geophysical and geochemical techniques for detecting and mapping subsurface contamination, such as ground-penetrating radar, electromagnetic induction, resistivity, magnetometry, and seismic surveys are currently being investigated by EMSL researchers and support contractors. One or a combination of techniques may be used for monitoring, depending on such factors as the nature, depth, and location of the contaminant.

Soil-Gas Sampling and Deep Plume Sensing

Specific investigations include the use of soil-gas sampling (a technique useful for organic contaminants) to locate a gasoline-spill plume in Stove Pipe Wells, California. Also being evaluated is time-domain electromagnetometry, which shows potential for mapping of deep plumes (2,000 to 4,000 feet [610 to 1,220 meters]) at test sites where salt water has migrated from injection wells.

Downhole Sensing

In another area of investigation, devices designed for industrial monitoring are being modified for ground-water monitoring. For example, EMSL and contract engineers are adapting and redesigning downhole sensing devices used in the deep, wide, uncased wells drilled for petroleum exploration, to be useful in ground-water monitoring wells, which are typically narrow, shallow, and encased in plastic. One of these devices—a meter to measure water flow and direction—is being evaluated in both laboratory and field tests.

Interpretive Analysis

Because monitoring investigations typically involve considerable effort and expense, one important aspect of monitoring investigation is the synthesis of existing information on contamination and, where applicable, the analysis of correlative data.

Aerial Photography Analysis

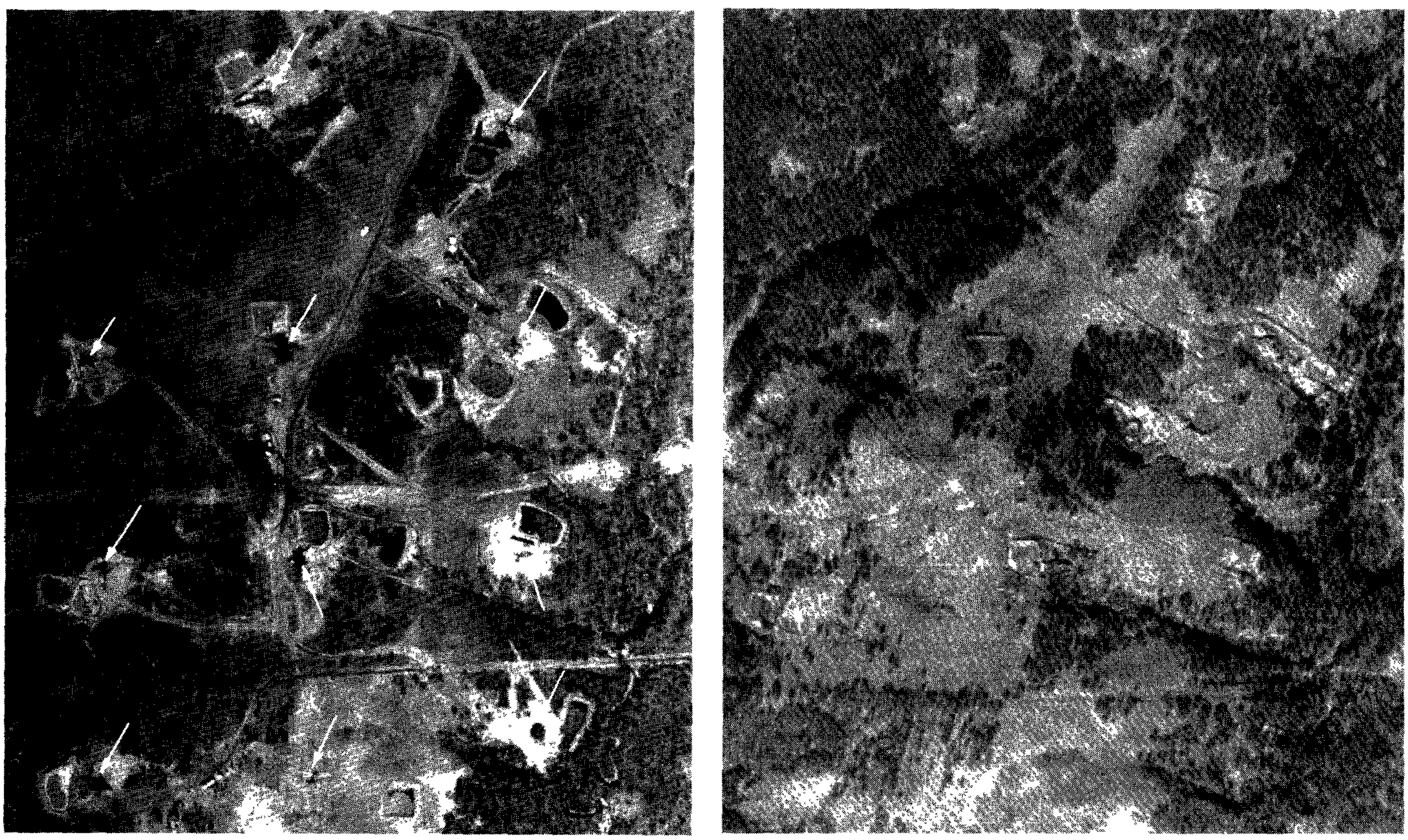
Historic aerial photographs have proved useful in locating abandoned oil and gas wells in Oklahoma. Since Underground Injection Control (UIC) regulations require identification of abandoned wells around proposed injection sites, scientists at EMSL are available to examine photographs of possible abandoned well sites upon request from EPA regional offices. "Signatures" of abandoned wells, composed of artifacts such as building foundations, scars of access roads, and mud pits are developed from the photographs. Identification is then checked against old records to determine accuracy.

Indicator Parameters

Using existing RCRA and CERCLA monitoring data, researchers are developing and testing indicator parameters (such as temperature, pH, specific conductance, and total organic carbon [TOC]) to assess the occurrence of contaminant leakage from land disposal facilities into ground water.

Variance Analysis

Another technique being evaluated is variance analysis, which will be used to assess the variability of groundwater monitoring data over time to assist in the design of large-scale monitoring networks.



Aerial photographs of the same well sites in Arcadia, Oklahoma, over a span of 24 years. The photo on the left, taken in 1951, shows several active wells (indicated by arrows) located near surface impoundments. In the photo on the right, taken in 1975, remnants of the impoundments remain, but the abandoned well locations have become indiscernible as roads and well sites have become covered with vegetation.

5. In Situ Aquifer Cleanup

Restoring a polluted aquifer is generally an extremely expensive enterprise. Nevertheless, in some instances, restoration is the option of choice; for example, when there is no other local drinking water source, when the cost of transporting water from an alternative source equals or surpasses the cost of restoration, or when the damage to the aquifer has serious human health or ecological implications. The decision to attempt restoration of a polluted aquifer is rarely simple or clear-cut. Technical feasibility is only one aspect to consider, and is often not the most pressing one. Economic, health, social, political, and other factors must be weighed against one another.

Until a range of inexpensive, effective cleanup methods is developed, managers who must decide whether to restore an aquifer face a series of difficult decisions. Serious thought, good management skills, and a solid information base are required. To meet these needs, researchers at RSKERL are concentrating on two approaches to improve existing cleanup methods: they are examining ways of making restoration techniques less expensive and more easily applicable, and they are examining case histories of restoration efforts to identify factors that influenced their success or failure (Figure 14). From this base, they will develop guidelines for decision-making. Table 4 summarizes current research projects at RSKERL. Some key projects are described below.

Case Histories and Cost-Benefit Analyses

RSKERL researchers and contractors are using literature searches, information from regulatory officials, and case studies to explore the issues involved in aquifer cleanup. One study reviews case histories of contaminated aquifers, identifies the technology used for restoration in effective cases and, where cleanup was not effective, devises successful alternative scenarios. Issues that influence cleanup decisions, such as cost and feasibility, plus social, political, and institutional problems are being examined.

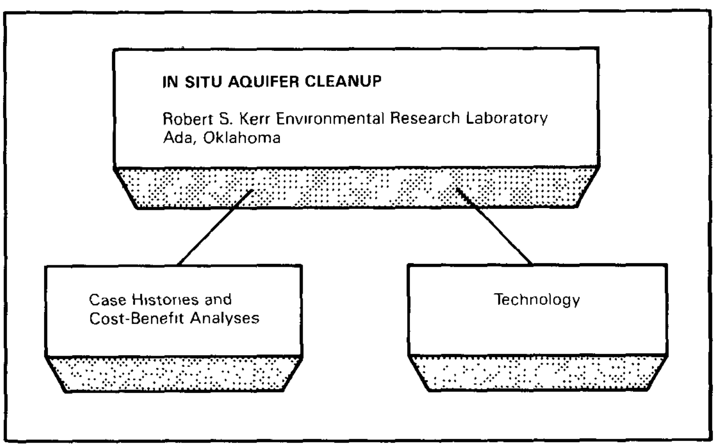


Figure 14. Highlights of EPA In Situ Aquifer Cleanup Research.

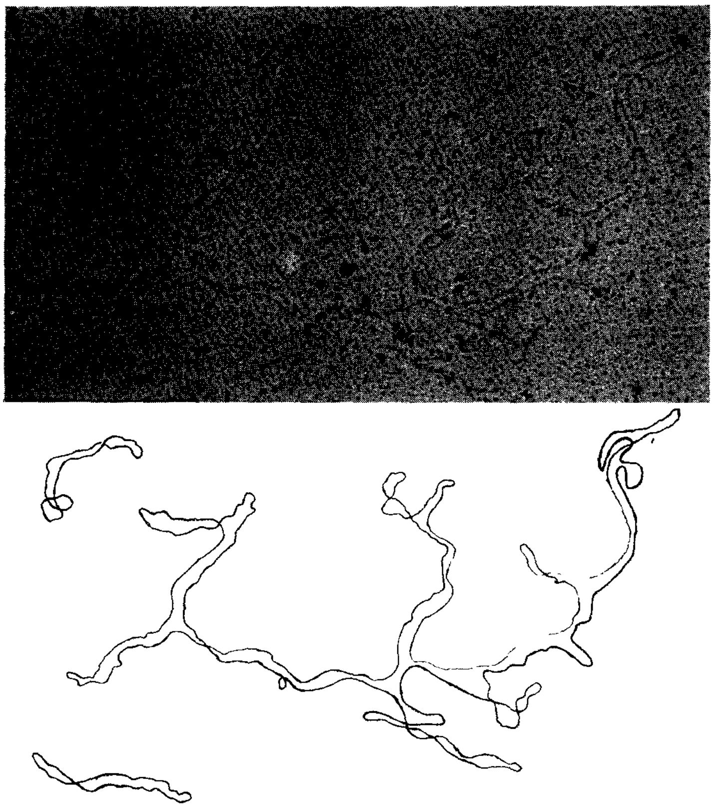
Another study compares the incremental costs and benefits of cleaning up waste sites. In addition to using historical information, researchers are assessing cleanup activities at two active Superfund sites by studying the options for remedial actions and the factors that influence choices. For decision makers at the policy level, management experts are designing systems to address general issues; for example, a hierarchical decision-making set is being developed to answer the question "How clean is clean?" For operational managers, a handbook is being prepared which will provide guidelines on decisions about aquifer cleanup, such as how to assess whether cleanup is the preferred option, what cleanup methods to use in various circumstances, and how to estimate costs.

Technology

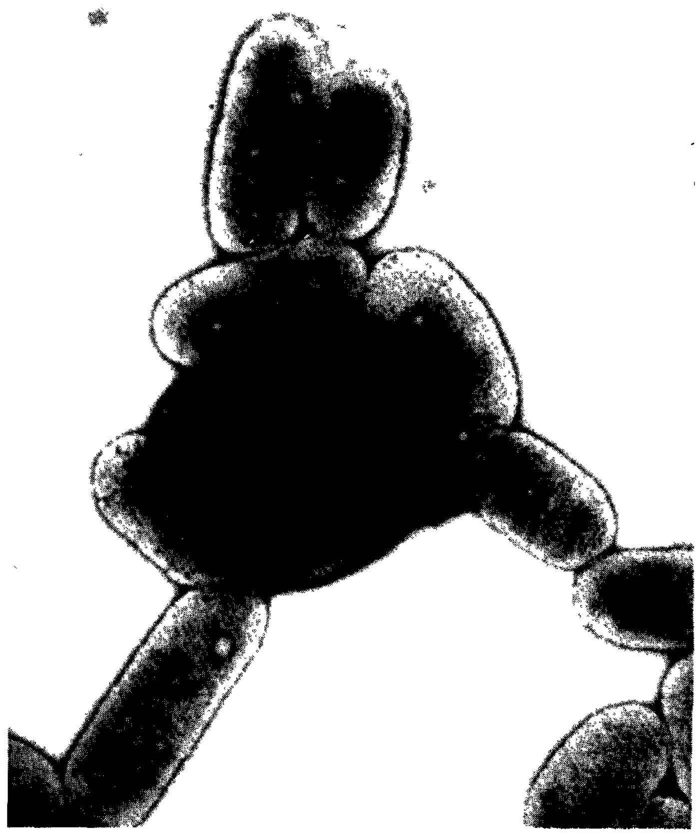
Biodegradation of contaminants is one of the most promising techniques for aquifer cleanup. RSKERL is sponsoring several studies that investigate the biological processes leading to contaminant degradation, and is examining ways to enhance these processes, with the aim of creating economical in situ treatment techniques.

Bacteria as Plasmid Hosts

RSKERL and contract scientists are exploring the possibilities of stimulating degradation in populations of ground-water bacteria. One extramural study is attempting to devise reliable methods to enable ground-water bacteria to "host" plasmid DNA, a key factor in biodegradation. Plasmid DNA, or plasmid, is genetic material that carries information not required for life processes. Because certain plasmids carry instructions on how to destroy contaminants, they are important in all environmental research. Some plasmids contain codes that instruct on how to destroy specific contaminants, such as toluene, PCBs, DDT, and ethyl benzene. Others, sometimes called "superplasmids", contain information on the destruction of several contaminants. While some bacteria can destroy contaminants without plasmids, others must incorporate, or "host" plasmids, and receive their instructions before they can be effective. Hosting can only occur when certain conditions exist, such as a minimum bacteria population size and sufficient nutrients.



A photomicrographed section of DNA containing the curvilinear-shaped plasmid pSS 50 (magnified 27,000 times), isolated from an Alcaligenes *bacterium, and a sketch of pSS 50 taken from the photograph. This plasmid contains instructions for the biodegradation of some polychlorinated biphenyls (PCBs).*



Bacteria of the Arthrobacter species *(a microcolony is shown here, magnified 38,000 times by electron microscopy) are naturally able to degrade styrene, an industrial contaminant. University scientists under contract to EPA are using genetic manipulation in attempts to enable the bacteria to degrade other contaminants.*

Extensive investigations of the bacteria/plasmid relationship have been made in soil and surface water, but ground water raises unique issues. Like the mysterious aquatic life that exists at great oceanic depths, ground-water bacteria are largely unknown phenomena. Scientists must ask basic questions about their behavior and environment, such as: Are there plasmids in ground-water bacteria? Can bacteria host plasmids? Can plasmids be inserted successfully into the ground-water environment? If so, will the bacteria accept them?

To determine answers, scientists are studying bacteria from an actual aquifer in a pure culture medium in the laboratory and in a simulated aquifer environment, and then introducing toluene plasmids to see whether hosting will take place. The development of a technique to detect specific plasmids in populations of bacteria is an important general research contribution that will prove useful in this study. However, some new techniques must be developed, for example, methods to detect plasmids in ground water. Scientists hope that this type of research will ultimately lead to a formula, or recipe, to create effective bacterial "armies" to fight contaminants.

TCE Biodegradation

The organic contaminants most commonly detected in ground water are chlorinated aliphatic hydrocarbons such as trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1,1-trichloroethane, carbon tetrachloride, and chloroform. This class of compounds has been resistant to biodegradation in aerated subsurface environments. Current technology for removing these pollutants involves pumping the water to the surface and air-stripping the compounds in aeration towers or removing the pollutant on a sorbent. An in situ process that would degrade the con-

Table 4. In Situ Aquifer Cleanup Research
Robert S. Kerr Environmental Research Laboratory — Ada, OK

AREA OF CONCERN	PROJECT TITLE	PURPOSE	GOALS AND PRODUCTS
Case History/Cost-Benefit Analysis	Methods for Protecting Public Water Supplies from Existing Ground-Water Contamination	Determine cost-effectiveness and feasibility of alternate aquifer cleanup methods by examining social, political, institutional, and technical issues in case studies.	• Provide states and localities with methods of assessing technology to protect public water supplies.
Case History/Cost-Benefit Analysis	Analysis of Cost-Effectiveness of Aquifer Restoration Techniques	Evaluate incremental benefits versus incremental costs of cleaning up a range of waste sites, considering political, social, economic, and medical issues, as well as cleanup effectiveness.	• Determine the effectiveness of various aquifer restoration techniques. • Develop hierarchical decision-making set to determine "how clean is clean?"
Technology	Feasibility of Enhancing the In Situ Biodegradation of Contaminants in Ground Water	Detect the presence of plasmid DNA in ground-water bacteria and evaluate the ability of ground-water bacteria to act as hosts for specific plasmid DNA associated with biodegradation. Evaluate the behavior of the plasmids in subsurface material.	• Evaluate the feasibility of enhancing in situ biological degradation of ground-water contaminants
Technology	Laboratory and Field Evaluation of Methodology for In Situ Aquifer Restoration	Evaluate selected cleanup methods, including physical removal, chemical treatment, and enhanced biodegradation for feasibility and cost-effectiveness.	• Develop cleanup protocols using the results of the project. • Develop the process for aerobic degradation of TCE (trichloroethylene) for use in the field.
Technology	Simulated Aquifer Restoration	Test aquifer restoration methods under simulated conditions by creating an artifical aquifer that can be mathematically represented	• Use artificial aquifer systems to develop aquifer restoration methods.
Technology	Monitoring the Development of Active Subsurface Organisms During Bioreclamation of Polluted Aquifers	Evaluate existing methods for determining the population sizes of bacterial groups that may be used to biodegrade contaminants in aquifers.	• Increase scientific information that will lead to effective bioreclamation techniques.

taminants rather than transferring the problem to another location would be a more effective and economical treatment. One area being studied is the use of microorganisms to degrade specific contaminants. To investigate this possibility, RSKERL scientists, in a laboratory experiment, enriched soil from the unsaturated zone with natural gas to stimulate microbial activity, and then added water containing TCE. TCE was degraded to carbon dioxide, and the concentration of TCE was reduced significantly—by one order of magnitude in a two-day period—an adequate rate for reclamation in situ. Researchers are now working on identifying other chlorinated aliphatic hydrocarbons responsive to the process, determining other end products, and adapting the process for use in aquifers.

Contamination issues and techniques may be examined in the laboratory or in the field. Field studies have the advantage of allowing scientists to observe techniques and activities under actual, variable, "real-life" conditions. One such study will locate a contaminated aquifer amenable to rehabilitation, and assess the effectiveness of a variety of methods, such as physical removal, chemical treatment, and enhanced biodegradation for cleanup. Cleanup protocols will also be developed. One of the techniques used will be the aerobic degradation of TCE described above.

6. Information Transfer and Technical Assistance

Activities

Transmitting information about current research to decision makers, field managers, and the scientific community is an important part of EPA's ground-water research programs. New research findings are communicated directly to the scientific, technical, and management community via information transfer mechanisms such as articles, documents, symposia, conferences, and training programs. In addition, ORD staff offer technical assistance to a variety of sources (for example, EPA regional and program offices, other Federal agencies, state agencies) to solve specific environmental problems.

The Robert S. Kerr Environmental Research Laboratory (RSKERL) conducts many information transfer activities and, in recent years, has provided technical assistance at field investigations at over a dozen hazardous waste sites in nine states. At the Environmental Monitoring Systems Laboratory (EMSL), technical support investigations and training in geophysics are an important part of laboratory activities. Hazardous Waste Engineering Research Laboratory (HWERL) researchers provide scientific information and analysis in support of corrective actions at Superfund sites, as well as producing a series of technical handbooks on source control technology in support of CERCLA, and technical resource documents (TRDs) on specific areas of landfill design. HWERL has also recently established the Technical Information Exchange (TIX), a specialized reference center that provides state-of-the-art information on hazardous waste cleanup and emergency response technology. The Environmental Research Laboratory in Athens, Georgia (ERL-ATH), in addition to its technical support for the 1984 RCRA amendment land disposal banning rule, maintains the Center for Water Quality Modeling. This center provides and distributes models, maintains data bases on soils, chemicals, and other information, and develops manuals and offers training courses to support model use. Tables 5 and 6 list selected current research-related publications and meetings for these four laboratories.

Table 5. Information Transfer and Technical Assistance
Selected Recent Publications[1]

AREA	SPONSOR	TITLE
Source Control	HWERL/CIN	Batch Soil Procedure to Design Clay Liners for Pollutant Removal (TRD)[2]
	HWERL/CIN	Design, Construction, Maintenance, and Evaluation of Clay Liners for Hazardous Waste Facilities (TRD)
	HWERL/CIN	Hydrologic Evaluation of Landfill Performance (HELP) Model (TRD)
	HWERL/CIN	Methods for the Prediction of Leachate Plume Migration and Mixing (TRD)
	HWERL/CIN	Soil Properties, Classification, and Hydraulic Conductivity Testing (TRD)
	HWERL/CIN	Solid Waste Leaching Procedures Manual (TRD)
Prediction	ERL/ATH	Leaching Evaluation of Agricultural Chemicals (LEACH) Handbook
	ERL/ATH	Users Manual for the Pesticide Root Zone Model (PRZM)
	ERL/ATH HWERL/CIN	Modeling Remedial Actions at Uncontrolled Hazardous Sites (Guidance Manual)
	RSKERL/ADA	DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings (Report)
	RSKERL/ADA	Evaluation of Septic Tank System Effects on Ground-Water Quality (Report)
	RSKERL/ADA	Ground-Water Transport: Handbook of Mathematical Models (Report)
	RSKERL/ADA	Methods for Protecting Public Water Supplies from Existing Ground-Water Contamination (Report)
Monitoring	EMSL/LV	Geophysical Techniques for Sensing Buried Wastes and Waste Migration Manual
	EMSL/LV	Guidance Manual for Vadose Zone Monitoring at Land Treatment Facilities (Manual)
	EMSL/LV RSKERL/ADA	A Guide to the Selection of Materials for Monitoring Well Construction and Ground-Water Sampling (Report)
	EMSL/LV RSKERL/ADA	Methods for Determining the Location of Abandoned Wells (Report)
	RSKERL/ADA	Methods for Determining the Mechanical Integrity of Class II Injection Wells (Report)
In Situ Aquifer Cleanup	RSKERL/ADA	State-of-the-Art Aquifer Restoration Methods (Report)

[1]Published in 1985. For information on other publications, contact individual laboratories or the EPA Center for Environmental Research Information (CERI), Cincinnati, OH.

[2]TRD = Technical Resource Document.

Table 6. Information Transfer and Technical Assistance
Symposia, Conferences, and Training Programs — 1985[1]

AREA	SPONSOR	TITLE
Source Control	CERI[2]	Protection of Public Water Supplies from Ground-Water Contamination (EPA Technology Transfer Seminars)
	HWERL/CIN	Annual Oil Spills Conference
	HWERL/CIN	Eleventh Annual Conference on the HWERL Research Program
	HWERL/CIN	First International Conference on New Frontiers in Hazardous Waste Management
	HWERL/CIN	Superfund Technical Handbooks (Regional Training)
	HWERL/CIN	Source Control Technology for EPA Regions, EPA Contractors, and States (Workshops)
Prediction	RSKERL/ADA	Modeling Subsurface Flow and Contaminant Transport (Training Courses)
	RSKERL/ADA	Second International Conference on Ground-Water Research
	RSKERL/ADA	Seventh National Ground-Water Quality Symposium: "Developing and Implementing Innovative Means of Dealing with Potential Sources of Ground-Water Contamination"
Monitoring	EMSL/LV	Conference on Characterization and Monitoring of the Vadose Zone
	EMSL/LV	Conference on Surface and Borehole Geophysics in Ground-Water Investigations
	EMSL/LV RSKERL/ADA	Conference on Methods for Determining the Location of Abandoned Wells
In Situ Aquifer Cleanup/ Monitoring	EMSL/LV	Fourth National Symposium and Exposition on Aquifer Restoration and Ground-Water Monitoring

[1]This is a representative sample of ground-water-related conferences and training programs held in 1985 For additional information, contact individual laboratories

[2]CERI = EPA Center for Environmental Research Information, Cincinnati, OH

Centers

In addition to activities and documents produced directly by the laboratories, ORD supports two centers that specialize in ground-water information transfer.

The National Ground-Water Information Center (NGWIC) in Worthington, Ohio, houses the world's largest catalogued and retrievable collection of ground-water literature, concentrating on hydrogeology and water-well technology. It contains more than 10,000 volumes, including state publications, technical reports, government documents, maps, reference books, and related literature, plus over 120 periodical subscriptions. The NGWIC maintains its own computerized data base, and has the ability to search two international retrieval systems with access to over 150 additional data bases.

The International Ground Water Modeling Center (IGWMC) serving North, Central, and South America, is located in Indianapolis, Indiana. The Center, supported largely by the EPA and in part by the Holcomb Research Institute at Butler University, operates a clearinghouse for ground-water modeling software, organizes and conducts short courses and seminars, and conducts a research program on ground-water modeling. A second IGWMC office in Delft, the Netherlands, not directly supported by EPA, serves Europe, Asia, Africa, and Australia.

As part of its activities, the IGWMC monitors and disseminates information on new developments in modeling and related fields such as computer hardware, software for data handling, and graphics. Its training program stresses principles, concepts, theories, and applications of ground-water models. In addition, the Center provides assistance to Federal and state agencies and private groups in organizing and conducting specially designed training programs. The Center's publications include the *Ground-Water Modeling Newsletter*, which contains information about new publications, computer models, conferences, seminars, and announcements of related services.

7. Synergism in Research: The Stanford/Waterloo Project

Of necessity, ground-water researchers often examine discrete subject areas (for instance, dispersion in certain immiscible fluids), and study them on a small scale (for instance, in a laboratory microcosm). Because ground water is a complex subject, this is often the best way to gain a clearer comprehension of individual processes. However, researchers must consider whether the results of short-term, discrete, small-scale studies will validly translate to the long-term realities of contaminant movement in ground water. The question arises: How to take the small pieces of the puzzle and fit them into a larger, coherent whole?

In one effort to address this question, ORD has sponsored the Stanford/Waterloo project, an attempt to provide new understanding of the long-term behavior of contaminants in ground water. This project is an extramural effort monitored by the RSKERL laboratory and conducted jointly by Stanford University and the University of Waterloo, Ontario, Canada. It has two components: a large-scale study of organic contaminant transport, and an investigation of leachate from municipal sanitary landfills.

Study of Organic Contaminant Transport

The study of organic contaminant transport attempts to provide a holistic approach to the study of ground water. It combines many of the components of ground-water research, such as laboratory studies and mathematical models, and integrates them with an exceptionally large-scale field investigation which is comparable in spatial size to an actual ground-water contamination site. Equally important, the study has been made over a two-year period—a time span that reflects conditions representative of actual ground-water flow. The study has been a multidisciplinary effort combining the skills and points of view of theoretical, practical, and computational scientists.

The study used a large-scale controlled field site to determine transport characteristics of selected hazardous contaminants in ground water, and to test the applicability of theories and mathematical models to laboratory and field findings. The project site was a section of a Canadian sand aquifer system, whose surface dimensions (10 x 100 m) are approximately the size of a football field. The site was chosen for several reasons. Sand aquifers are widely used as drinking water sources in the United States (for instance, New Jersey's water supply is largely based on sand aquifers). Therefore, the research findings have potentially broad practical applicability. Because the water table was quite close to the surface for the aquifer, monitoring was made simpler. In addition, the aquifer had already been closely studied, and had been well characterized by hydrogeologists and geochemists.

To study the behavior of contaminants in ground water (particularly halogenated organic compounds selected from EPA's priority pollutant list), scientists injected two inorganic tracers (chloride and bromide), and five organic solvents in a known and constant flow in water down nine injection wells. An extremely closely spaced monitoring network was installed so that detailed spatial analyses of the contaminants over time could be made. The network included 276 multilevel sampling devices containing over 4,000 individual sampling points. More than 18,000 samples were taken over the two-year project period. Specific quantitative measures of the rate and kind of solute motion and the amount of solute were obtained.

Researchers determined that total mass was conserved for the inorganic tracers and two of the organic solutes (carbon tetrachloride and tetrachloroethylene), while for three other solutes (bromoform, 1,2-dichlorobenzene, and hexachloroethane) mass decreased in a manner suggesting that degradation had occurred. The speed and pathways of the inorganic tracers remained nearly constant. The organic solutes followed the tracer pathways at reduced speeds; the rate depended on the specific solute (Figure 15).

Sorption and degradation phenomena were investigated in the laboratory to elucidate the solute behavior observed in the field. The reductions in speed were attributed to the solutes' sorptive interactions with the aquifer solids. Another finding was that sorption equilibrium (i.e., the state where the sorption capacity of the aquifer solids is saturated) was achieved much more slowly than previously believed. These findings contradict prior expectations that the rate of sorption, as well as mobility, should be constant.

In a companion effort in the laboratory, studies showed that hexachloroethane can be degraded by microorganisms under simulated ground-water conditions. This is a promising finding, because prior studies suggested that chlorinated compounds, particularly those that contained several chlorine atoms (such as hexachloroethane), were resistant to biodegradation.

This study of organic contaminant transport is a landmark effort in ground-water research because of a combination of factors: the physical size of the project; its

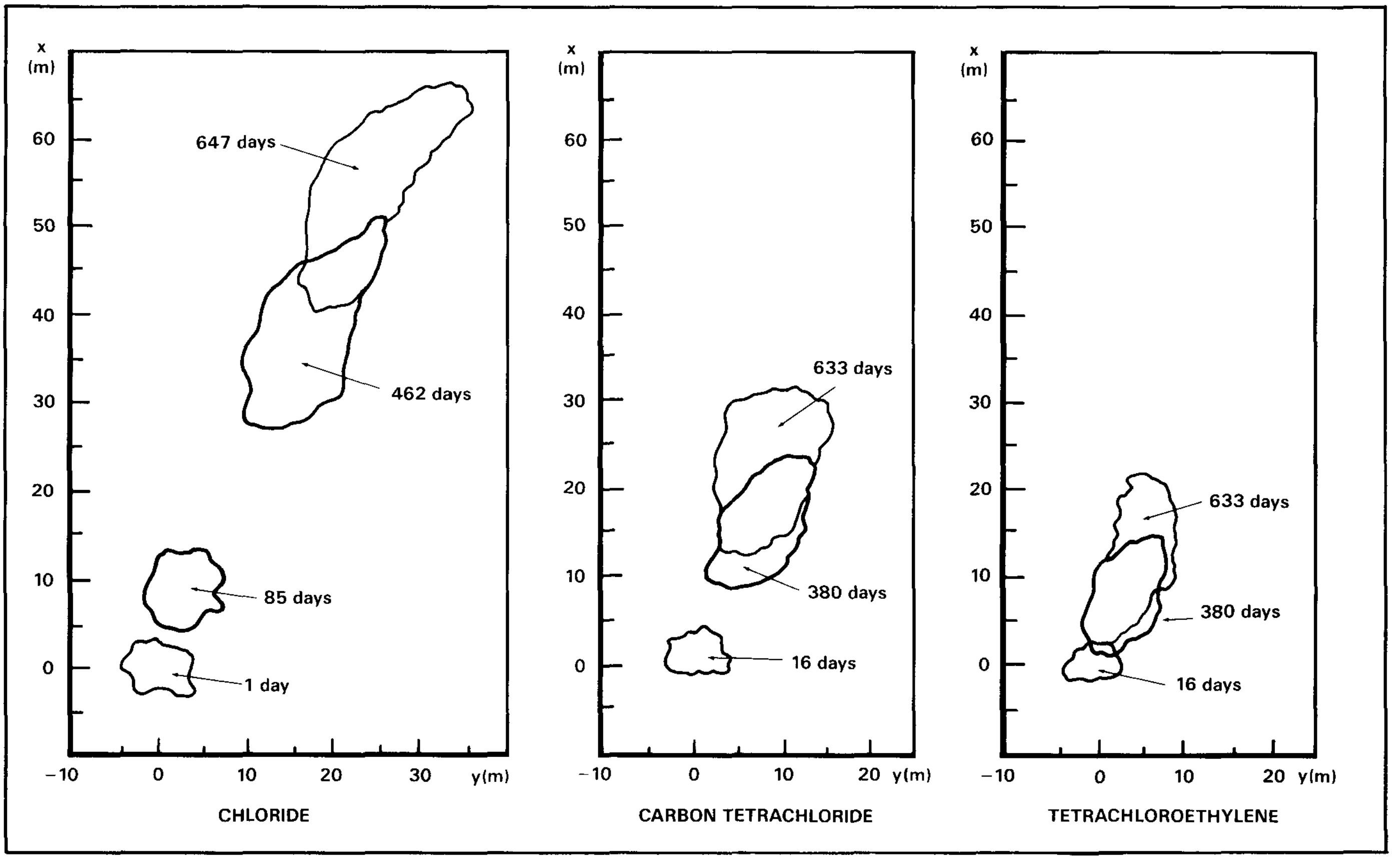


Figure 15. The Stanford/Waterloo Project. Location of Three Chemical Plumes at Selected Time Intervals. (The time contours shown are depth-averaged.)

long duration; the level of detail of the monitoring and background information-gathering; the close cooperation among a wide variety of theoretical and practical scientists, technical experts, and managers; and the synergism among the components, (i.e., the laboratory investigations, theoretical research, mathematical modeling, and field investigations).

Landfill Leachate Studies

In three separate studies, researchers investigated multiple leachate plumes of trace organic contaminants emanating from two municipal sanitary landfills in Ontario, Canada. These unlined landfills, located in areas with high water tables over sandy aquifers, are similar in construction and hydrogeologic setting to many municipal landfills in the northeastern United States. Contaminants investigated were largely industrial and commercial toxicants, including chlorinated and nonchlorinated hydrocarbons, nitrogen-containing compounds, and chemicals produced by detergent degradation. Contaminants such as 1,1,1-trichloroethylene and tetrachlorethylene were found to be present in concentrations of between 1 to 100 μg per liter, typical of concentrations of contaminants in ground water that have caused public concern. Sampling well sites were located up to several hundred meters beyond the landfills.

Monitoring verified that the distribution of trace organic contaminants was complex, and that these contaminants followed a diverse set of pathways because of their varying densities and their immiscibility. For example, researchers found that chlorinated solvents traveled below the leachate plumes, and plunged toward the bottom of the aquifers. Findings such as these mean that inorganic tracers which have been used to monitor leachate plumes through "matching" (moving along with the plume) will not simulate the path of some organic contaminants. Therefore, direct monitoring should be extended to include organic contaminants. Understanding the complex pathways of various organic contaminants is also important for refining techniques for pumping water to clean polluted aquifers.

8. Future Directions

Ground-water research is still in its formative period. Because ground water was considered for so long to be an ever-available, self-supplying, and self-purifying resource, little impetus existed for scientific research. In some respects, only a few years ago, as little was known about organic contaminants in ground water as about the planet Mars. In many ways the subsurface, its structure, and its inhabitants are still alien territory. However, our knowledge is steadily increasing. Perhaps ten times as much is known about contaminants in ground water today as was known ten years ago. Advances are being made—some of them extremely promising—but technical and scientific problems still abound.

Ground water presents a series of complex issues for study. Our industrial society, with its plethora of chemicals and by-products, combined with our diverse topography, geohydrology, and climate, create an intricate matrix for contamination scenarios. Physical and chemical theories must be modified to apply to variable, and often inaccessible conditions in the subsurface. The relative newness of ground-water investigation, combined with its complexity, point to several basic research priorities:

- Identify and study major existing and potential contamination sources and agents. Efforts have been initiated with sources such as leaking underground storage tanks and agents such as Hepatitis A virus, but must be pursued further.
- Invent and/or refine effective, inexpensive technology for monitoring and sampling, source control, and basic predictive research. Ground-water research can only be as accurate and specific as its tools; many advances depend largely on the development of appropriate technology. The fiber optic spectrometer is one step in this direction.
- Standardize data. Protection efforts (for instance, the design of monitoring networks) and planning decisions currently rely on data that is often inconsistent, making conclusions subject to error. Establishing standards for data would reduce this problem in the future.
- Develop reliable mathematical models to predict the movement and transformation of contaminants in ground water.
- Conduct more field studies and studies over time (such as the Stanford/Waterloo project, described in Section 7) to test the validity and reliability of models and laboratory investigations.
- Provide ground-water training for EPA, state, and local officials. Increased training and increased transmission of technical information are vital in this rapidly growing field.
- Transmit information quickly. The time lag between the verification of research findings and practical application should be made as narrow as possible.

Future research advances will require considerable cooperative effort at all levels: within EPA; among other Federal, state, and local agencies; in the scientific and industrial communities; and with scientists abroad who are addressing similar issues. Like other environmental problems, the contamination of ground water underscores a basic lesson of nature: there are no "quick fixes." What we now know about ground water makes its protection imperative, and a great deal more research is needed before we can say that ground water is truly protected.

Appendix A. Principal Findings and Recommendations from the Report on the Review of the Environmental Protection Agency's Ground-Water Research Program, Submitted by the Ground-Water Research Review Committee, Science Advisory Board, U.S. EPA, July 1985

The Science Advisory Board was asked by the Deputy Administrator, Al Alm, on July 10, 1984, to review the Agency's ground-water research program, particularly as it supports the EPA Ground-Water Strategy (EPA, 1984), including the transport, fate, and effects of contaminants, abatement and control technologies, modeling, monitoring and analytical methods, and quality assurance. The Executive Committee of the Science Advisory Board (SAB) established a Ground-Water Research Review Committee to conduct this review, which has now been completed.

The Environmental Protection Agency has no single authority under which it is charged with the protection of ground-water quality. Rather, there are a number of different legislative authorities (with varying requirements) under which the Agency operates. These have all been enacted within the last ten years, and include the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), the Safe Drinking Water Act (SDWA), the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the Toxic Substances Control Act (TSCA), and the Clean Water Act (CWA). Much of this fragmentation is mirrored in the research program.

EPA conducts considerable research in ground water. EPA laboratories with major responsibilities are the Environmental Monitoring Systems Laboratory-Las Vegas (EMSL-LV), the Robert S. Kerr Environmental Research Laboratory (RSKERL) at Ada, Oklahoma, and the Hazardous Waste Engineering Research Laboratory (HWERL) in Cincinnati. Resources in the President's 1985 budget dedicated to research in these laboratories are as follows:

Research Area	Total Dollars (in 1,000s)	Man Years
Monitoring	1,763.0	9.4
Prediction	6,307.1	31.0
Aquifer Cleanup or Restoration	853.6	6.7
Hazardous Waste Engineering	9,272.0	46.2
TOTALS	18,195.7	93.3

Even though there are substantial resources committed to ground-water research, there is no clearly identifiable ground-water research "program." While the research that is carried out is, in general, sound and responsive to the Agency's current regulatory needs, it is inadequate to support the Ground-Water Strategy or future regulatory and policy needs.

The Committee's principal recommendations and the supporting rationale are highlighted in the following summary.

General

A. ***The Committee recommends that the Office of Research and Development establish a strong central direction for its ground-water research program, with appropriate authority for the program director.***

Even though there is a "Ground-Water Research Manager" in the Office of Environmental Processes and Effects Research, the position is not officially established, it has no authority across ORD lines, and only deals with a part of the ground-water-related research programs. Centralized program direction will also improve interlaboratory coordination and the establishment of linkages to other Federal agencies.

A major responsibility of this manager would be the development of an integrated comprehensive ground-water research plan. There are presently many diverse research projects, primarily associatd with hazardous wastes, which have a significant ground-water component. The EPA Ground-Water Strategy is aimed specifically at the protection of ground water from any and all sources of contamination. To support the Strategy, the ground-water components of research programs directed at meeting regulatory and enforcement needs must be identified and coordinated within a broader framework. In recognition of the rapidly advancing development in ground-water science and technology in the private sector and in other agencies, as well as rapidly proliferating and increasingly complex regulatory requirements, the ground-water research plan should be amended annually or as needed. The plan should provide for a feedback process to Headquarters offices, regions, and states when the planning process is complete each year, so that they may have some idea how their needs are being met, and their influence on the process.

B. ***The Committee recommends that CERCLA (Superfund) be amended to authorize research and that a portion of the Superfund budget be made available to support ground-water research.***

Funding for research throughout the ground-water program is inadequate. If one considers the enormous expenditures projected for the Superfund program, the benefits to be gained from having a comprehensive data base to support future remedial action decisions are substantial. In particular, projects could be designed to allow the evaluation of the effectiveness of remedial actions and of monitoring systems. Superfund, unlike other statutes, does not authorize research. Research at individual sites should be authorized and encouraged. 1.5% of annual Superfund expenditures should be made available for ground-water research to support Superfund activities.

C. *The Committee recommends that EPA develop and implement a plan to identify information required for sound policy decisions arising under the statutory programs for which it is responsible, and that it devote substantial resources to the collection and dissemination of such information.*

This plan should incorporate an itemized list of major policy decisions affecting all aspects of ground-water protection which are now pending before the Agency or which will arise in the foreseeable future. It should specify in a comprehensive manner the types of information relevant to such policy decisions, evaluate the adequacy of available information in each category, and define the necessary studies to address deficiencies.

D. *The Committee recommends that EPA initiate research on contamination sources that are not addressed by specific Congressional mandates.*

There is a critical need for research that would allow conclusions to be drawn concerning the relative magnitude and importance of ground-water contamination from sources other than "hazardous" wastes. While the potential ground-water impact of land disposal of wastes defined as hazardous under RCRA are being studied, other sources may be very important contributors to ground-water contamination. These include septic tanks, sanitary landfills, municipal wastewater treatment operations, accidental releases, chemicals applied to the land such as agricultural chemicals and road salt, and salt water intrusion.

E. *The Committee recommends that the Office of Research and Development establish a formal and thorough coordination with other Federal agencies, to take maximum advantage of work being done by others, to expand the level of expertise available to the research program, and to prevent unnecessary duplication.*

The Committee finds that there is inadequate research coordination among Federal agencies, even though researchers themselves are often aware of their peers' activities. This situation results in a lack of effective utilization of results, confusion, and unnecessary duplication.

The Research Program

F. *The Committee recommends that EPA accelerate research to determine the applicability of land treatment as a source control option.*

While the reauthorization of RCRA may eliminate land disposal of certain hazardous wastes, the land will continue to be used for the degradation and immobilization of many wastes. A major effort should be established to determine the land treatability of all classes of hazardous and non-hazardous wastes.

G. *The Committee finds that the funding for research on monitoring is inadequate, and should be increased.*

Funding for monitoring research is now at about 10 percent of the entire ground-water research program, and yet monitoring is crucial to results in programs such as RCRA and Superfund. The monitoring share of the research funding should be increased, but not at the expense of other components.

H. *The Agency should emphasize and expedite the development of ground-water sampling and analytical methods which have proper performance and validation data and proper QA/QC procedures.*

The Agency's current sampling and analytical methods for ground water are often deficient in their lack of data on accuracy and precision, proper validation, and adequate QA/QC, including the lack of reliable QA samples and standards.

I. *The Committee recommends that EPA increase its program of field evaluation of prediction techniques.*

While the USGS has a modest program of field investigations underway, the EPA has specific needs for field-evaluating processes, models, and assumptions used by its regulatory programs. To increase the confidence of the state-of-the-art in prediction, EPA should accelerate its field evaluation program. In addition, statistical tools should be developed that provide a means of assessing the heterogeneity, range, and uncertainty in basic data and in predicted impact on ground-water contamination, particularly where local data for deterministic model use may be poor or nonexistent.

J. ***The Committee recommends that EPA increase research in the basic processes that govern the transport and fate of contaminants in ground water, including the necessary data bases for field application.***

Data are needed for the application of prediction techniques to specific chemicals or combinations of chemicals within the hydrogeologic environment. The understanding of basic processes in ground-water transport remains one of the top priority items in any fate and transport research program.

K. ***The Committee recommends that EPA continue to assess field application of available containment techniques (i.e., caps, liners, barriers, and hydrodynamic controls) for containment of polluted ground water.***

A wide variety of containment techniques, including such things as caps, liners, walls, and hydrodynamic controls are being utilized at disposal facilities and Superfund sites. Controlled test data relating to their effectiveness is lacking. A controlled study program should be instituted at RCRA and Superfund sites, which will serve as excellent field laboratories.

L. ***The Committee recommends that EPA develop methods for remedial action in geologic regions characterized by fractured formations or karst topography.***

Monitoring procedures and remedial activities commonly assume that the ground-water system or aquifer is made up of homogeneous, isotropic materials. This assumption is frequently incorrect, rendering useless the conventional techniques utilized in monitoring and remediation.

M. ***The Committee recommends that EPA initiate research to identify suitable geologic environments for isolating hazardous wastes by means of injection wells, including methodologies for monitoring the integrity of the containing layer.***

Injection wells are already receiving a significant portion of difficult-to-treat industrial wastewater effluent. Therefore, efforts to help choose favorable geologic environments for injection wells and to solve problems of monitoring the integrity of the geologic containment should be expanded.

Technology Transfer and Training

N. ***The Committee finds that a greatly expanded ground-water technology transfer and training program is a critical Agency need.***

This need was expressed by virtually all of the individuals and organizations interviewed by the Committee, and applies both to the large in-house staff working on ground-water-related issues without adequate experience or training, and to state and local governments on whom EPA ultimately depends for proper ground-water management. This includes the transfer of information generated by and within EPA, as well as that generated by other Federal agencies, the states, consultants, and other countries.

O. ***The Committee recommends that EPA establish an in-house training center in ground-water science for the technical training of EPA staff, as well as state and local officials.***

A critical shortage of trained ground-water personnel exists within EPA and state governments. The problem is particularly acute for EPA, since the Agency has a large pool of undertrained professionals who are forced by current operational requirements to make ground-water decisions on a daily basis. An in-house training center could provide training tailored to regulatory program requirements, which would greatly ameliorate the training program. This training should be directed not only at Headquarters and Regional staff, but also could assist in improving skills of state and local personnel upon whom EPA will depend when the Ground-Water Strategy is implemented.

P. ***The Committee recommends increased technology transfer among EPA laboratories, Regional offices, and state regulatory agencies.***

First, the Committee recommends an annual combined presentation at each Regional office by laboratory personnel from each ground-water research facility. The audience should include those involved in such ground-water-related programs as Underground Injection Control (UIC), Superfund, RCRA, Leaking Underground Storage Tanks (LUST), and the implementation of the Ground-Water Strategy. State and local personnel should also be encouraged to attend. This series of presentations would not only provide a means for updating Federal and state field personnel on advances in ground-water research, but would also be the basis for input to the research laboratories. The Committee also recommends expanding the program of making existing scientific information, such as computerized data at the National Ground Water Information Center (NGWIC), readily available to the states and to EPA Regional offices.

Appendix B. Ground-Water Research in Other Federal Agencies

Several Federal agencies sponsor research programs that examine ground-water-related issues. The descriptions of their research given below are not intended to be comprehensive, but rather to provide a general context in which to place EPA's research programs. For more detailed information, the reader should contact the specific agencies mentioned.

The ground-water research of other Federal agencies is summarized in Table 7. EPA integrates its research efforts with these other agencies through joint projects, work groups, committee participation, and informal information exchange. The United States Geological Survey (USGS) is the major Federal agency doing ground-water research, and receives the bulk of Federal funding. Since 1981, EPA has operated under a general memorandum of understanding (MOU) with the USGS. As a result of EPA's Ground-Water Protection Strategy (of which the research programs are a part), an MOU specifically on ground water was signed in June 1985. It addresses data collection and technical assistance as well as research coordination.

U.S. Geological Survey

The overall research goal of the Geological Survey (USGS) is to be able to quantitatively predict the response of hydrologic systems to natural or man-made stress.

Table 7. Ground-Water Research in Other Federal Agencies

	RESEARCH CATEGORY				
AGENCY	SOURCE CONTROL	PREDICTION	MONITORING	CLEANUP	OBJECTIVE
U.S. Air Force	•	•	•	•	Develop methods for predicting the impact of Air Force activities on ground water.
U.S. Army Corps of Engineers	•			•	Develop cost-effective ground-water pollution control and monitoring systems; provide environmental and health effects data on Army-unique pollutants; develop environmental management systems and data bases.
U.S. Department of Agriculture	•	•	•		Provide basis for evaluating effects of changes in agricultural techniques on ground-water quality.
U.S. Department of Energy	•	•	•		Provide information on mechanisms contributing to transport and long-term fate of energy-related contaminants in ground water.
U.S. Geological Survey		•	•		Provide research to describe, assess, and develop ground-water resources.
National Science Foundation[1]	•	•	•	•	Perform basic research.
U.S. Navy[2]					
Tennessee Valley Authority	•	•	•		Provide data needed for assessing the significance of potential Tennessee Valley ground-water contamination sources and for preventing and isolating contamination.

[1]Fundamental research will contribute to all areas, although it is not necessarily specifically directed toward ground-water projection

[2]Program just beginning to be defined.

In FY '84, the USGS collected ground-water measurements at over 35,000 observation wells and sampled approximately 7,500 wells for subsequent water-quality analysis. Data-collecting activities are expected to continue at approximately the same level through FY '86.

Under the Federal-state cooperative program, the USGS conducted 570 multidisciplinary projects concerning water quality, waste disposal and pollution, land use, and problems related to ground-water availability. Almost half these projects focused on ground water. Typical USGS projects use model simulation and statistical analysis to improve the understanding of aquifer systems within a state and to enable managers to protect and develop resources based on this information. Future efforts will attempt to determine the types and extent of contamination in places with the highest priority problems according to the EPA's Ground-Water Protection Strategy.

The USGS Water Resources Division offers technical assistance to other Federal agency programs. For example, it gathers hydrogeologic and geochemical information about petitioned aquifer systems to help EPA to decide whether the systems should be declared sole-source aquifers.

USGS Ground-Water Research Programs

The USGS maintains four research programs on ground water, as described below.

The Regional Aquifer Systems Analysis (RASA) Program. This program, started in 1978, has instituted 19 studies to investigate ground water in various hydrologic regions. Five of these studies have been completed. Three new studies will be started in 1986 to investigate the central Texas Aquifer, the Appalachian Valley and Piedmont Aquifer, and the Carbonate and Glacial Aquifer of Ohio and Indiana. Because of the complex hydrogeology of regional aquifer systems, all RASA studies use model simulation to synthesize ground-water flow systems and to evaluate the impact of stresses on aquifer systems.

The Toxic Waste/Ground-Water Contamination Program. This program improves understanding of the various processes controlling the movement, fate, and alteration of toxic substances in ground water. The program currently sponsors research in three areas: 1) basic hydrologic, physical, chemical, and biological processes—including hydrodynamic dispersion, statistical properties of hydraulic conductivity, multiphase flow, fractured flow, chemical reactions, microbiological reactions, adsorption in the subsurface, and the use of surface geophysical methods to define the flow medium and the extent of leachate plumes; 2) detailed field studies of ground-water contamination at six sites: the oil spill at Bimidji, Minnesota; sewage treatment effluent at Cape Cod, Massachusetts; creosote contamination at Pensacola, Florida; heavy metals from mining at Tar Creek, Oklahoma; and two additional sites (to be selected) contaminated with gasoline and chlorinated hydrocarbons; and 3) large-scale water quality studies in six to eight areas with contrasting geohydrologic and climatic characteristics, which will document the kind, distribution, and concentration of contaminants in ground water, and relate the origin of this contamination to overlying land use practices.

The Nuclear Waste Hydrology Program. This program addresses both low-level and high-level nuclear waste issues related to ground water. For low-level wastes, areas of study include understanding the hydrologic and chemical principles that relate to how radionuclides migrate in ground water, and the chemical mechanisms that control their leaching and migration. Modeling, sampling, and measurement techniques will also be developed. High-level waste investigations will provide hydrologic and geologic information to support the selection of waste repositories, and to develop criteria for their licensure and supervision.

The National Research Program (NRP). This program is organized into six discipline areas. Three of these areas—ground-water hydrology, geochemistry, and water chemistry—touch on ground-water research activity. The primary emphasis is on understanding ground-water-related processes and on creating numerical simulation techniques to allow those processes to be incorporated into predictive models.

U.S. Department of Agriculture

The U.S. Department of Agriculture Agricultural Research Service Ground-Water Program investigates and models the fate and transport of nutrients and pesticides in ground water, and measures salinity in ground water as influenced by irrigation practices. Advances have been made in agricultural and chemical technology and soil and water chemistry in several areas: the study of chemical and biological processes, model development and testing, the design of management and control practices, and the development of data bases. The goals of this research program are to improve water management practices, conservation tillage, and other cropping systems; to devise new chemical control technologies; and to develop more efficient application practices for pesticides and fertilizers.

U.S. Department of Energy

The U.S. Department of Energy Subsurface Transport Program studies the influence of chemical, physical, hydrological, and biological processes on the transport and long-term fate of energy-related contaminants such as trace metals, organic compounds, and radionuclides. Current studies concern the relationship of chemical processes to the transport of energy-related organic compounds. Long-term plans include a 10-year program to develop the second generation of predictive models, through a combination of complex computer systems, laboratory and university consortia, and field experiments.

U.S. Air Force

The Air Force is collaborating with the EPA to develop methods for predicting the impact of various Air Force activities on ground water, for example, solvent use, fire-fighting training, waste disposal, and accidental spills. In addition, Air Force researchers are collaborating with the EPA to determine the extent and impact of dioxin contamination resulting primarily from the use, storage, and disposal of Agent Orange. A third collaborative area of study is the development of methods for the restoration of ground-water quality.

U.S. Army Corps of Engineers

The Army Corps of Engineers does research to develop cost-effective pollution control and monitoring systems, to provide environmental and health effects data on pollutants unique to the Army, and to improve management systems and data bases. Areas being studied include methods and processes for containment and decontamination of ground water, landfill leachate control methods, and hazardous waste management techniques.

The Tennessee Valley Authority

The Tennessee Valley Authority (TVA) Research Program is designed to protect and preserve the ground-water resources of the Tennessee Valley. The program evaluates methods for identifying recharge areas that have complex geologic structures; determines the characteristics and fates of toxic contaminants at selected problem sites; develops methods to predict the effects of abandoned waste dumps and mining activities on ground water; assesses the potential effects of power plant wastes on ground-water quality; and implements the ground-water protection plan in the First Tennessee-Virginia Development District.

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