UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

July 31, 1985

OFFICE OF
THE ADMINISTRATOR

Hon. Lee M. Thomas
Administrator
U. S. Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20460

Dear Mr. Thomas:

The Science Advisory Board has completed its review, which began on December 19, 1984, of the Agency's ground water research program. We are pleased to forward to you our report, which has been reviewed and approved by the SAB Executive Committee. We find that the research program as a whole is sound, but have also made a number of recommendations for improvement. While these are not listed in priority order, the most important include:

1. The need for centralized direction and management of the ground water research program.

2. The need for increased technology transfer and training.

3. The need for increased resources (together with a recommendation that Superfund monies be authorized for such research).

We would be pleased to brief you on the report's contents.

Our job was greatly aided by the cooperation and assistance we received from the Office of Research and Development and from the Office of Ground Water Protection, and it has been a pleasure to work with them.

If we can answer any questions, or should you wish further review, please call upon us.

Sincerely,

John Quarles, Chairman
Ground Water Research
Review Committee

Norton Nelson, Chairman
Executive Committee
Science Advisory Board

cc: Dr. B. Goldstein
Mr. Erich Bretthauer
Mr. H. Longest
Ms. M. Mlay

REPORT

on the review of

THE ENVIRONMENTAL PROTECTION AGENCY'S

GROUND WATER RESEARCH PROGRAM

by the

Ground Water Research Review Committee
Science Advisory Board
U. S. Environmental Protection Agency

July 1985

EPA NOTICE

This report has been written as a part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency, and hence the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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SECTION I

PRINCIPAL FINDINGS AND RECOMMENDATIONS

The Science Advisory Board was asked by the Deputy Administrator, Alvin L. 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). This review was to cover 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 ground water research in these laboratories are as follows (see Appendix B):

Research Area	Total Dollars (in 1000's)	Person 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 performed is generally 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 deals only with part of the ground water-related research programs. Centralized program direction will also improve interlaboratory coordination and linkages to other Federal agencies.

A major responsibility of this manager would be to develop an integrated, comprehensive ground water research plan. There are presently many research projects supported throughout EPA, primarily associated with hazardous wastes, which have a significant ground water component. These projects for the most part are not coordinated. 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 developments in ground water science and technology in the private sector and in other agencies, as well as the rapidly proliferating and increasingly complex regulatory requirements, the ground water research plan should be amended annually or as needed. The plan should provide for feedback to Headquarters offices, Regions and States each year when the planning process is complete, so that they may have some idea of how their needs are being met, and better understand 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.

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

C. The Committee recommends that EPA develop and implement a plan to identify information required for sound ground water 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 studies necessary 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 contaminants from sources other than hazardous wastes. While the potential ground water impacts of land disposal of wastes defined as hazardous under RCRA are being studied, other types of wastes 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 system 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 (see Appendix B) 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. <u>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.</u>

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

I. <u>The Committee recommends that EPA increase its program of field evaluation of prediction techniques.</u>

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 in 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 impacts on ground water contamination, particularly where local data for deterministic model use may be poor or nonexistent.

J. <u>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.</u>

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 as one of the top-priority items in any fate and transport research program.

K. <u>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 wastes and polluted ground water.</u>

A wide variety of containment techniques such 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. <u>The Committee recommends that EPA develop methods for remedial action in geologic regions characterized by fractured formations or karst topography.</u>

Monitoring procedures and remedial activities are commonly based on the assumption 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. <u>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 confining layer.</u>

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.

<u>Technology Transfer and Training</u>

N. <u>The Committee finds that a greatly expanded ground water technology transfer and training program is a critical Agency need.</u>

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. <u>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.</u>

A critical shortage of trained ground water personnel exists within EPA and State governments. The problem is particularly acute for EPA, because 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 problem. This training should be not only for Headquarters and Regional staff, but also for State and local personnel upon whom EPA will depend when the Ground Water Strategy is implemented.

P. <u>The Committee recommends increased technology transfer among EPA laboratories, Regional offices and State regulatory agencies.</u>

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 programs to make 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.

SECTION II

INTRODUCTION

The Nature of the Ground Water Problem

Ground water is relied upon for approximately one-half of the Nation's drinking water, and supplies a wide variety of industrial and agricultural needs. At the same time, evidence abounds that the contamination of ground water is being detected with increasing frequency, affecting every state in the Nation. Today it is a subject of intense and widespread interest and debate. A solid foundation of knowledge about this problem is lacking; there is significant historical contrast between interest in ground water and interest in similar environmental concerns such as surface water protection (first Federal legislation in 1899) and air quality protection (first Federal legislation in the early 1940's).

Studies of ground water contamination emphasize the large number and extreme diversity of contaminant sources. The benchmark Office of Technology Assessment report (1984) identifies 33 types of sources covering a broad range of activities (Vol. I, pp. 43-46). The same observation stands forth clearly in the Pye, Patrick and Quarles monograph (1984). This contamination has been linked to adverse health, economic, environmental, and social impacts.

A major component of the ground water protection issue concerns toxic substances. Toxic and hazardous compounds are being introduced into the subsurface environment with increasing frequency. The concern with hazardous chemicals, however, is a relatively new frontier in the area of environmental protection. This is true not only in ground water but in all areas of environmental protection. It is important, therefore, that any program to address the ground water problem look at the existing contamination (and potential contamination due to materials already in the subsurface) and also at the minimization of future releases to the subsurface environment.

EPA's Authorities and Responsibilities to Protect Ground Water

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. Virtually all of these have been enacted within the last ten years. They include the following:

A. CERCLA (Superfund) - This act provides for remedial cleanup actions at existing waste disposal sites no longer being actively operated. A major criterion for cleanup is the threat of ground water contamination. This act is also unique in that it does not authorize research.

B. RCRA - This law provides for the management of currently-operating (or new) hazardous waste disposal facilities, and establishes principal ground water protection policies.

C. SDWA - Under this law, the UIC and sole-source aquifer programs provide for water supply protection, and the Act also provides for establishment of drinking water standards.

D. CWA - This law provides a management structure for State water quality programs, including ground water programs.

E. FIFRA - This Act provides the authority to the Agency to control the use of pesticides which may adversely affect ground water.

F. TSCA - This law provides broad authority to the Agency to regulate new and existing chemicals, including their manufacture and ultimate use.

Even statutes of such enormous importance as RCRA and Superfund, however, have little in their legislative histories to suggest that ground water protection was a principal focus, or that there was adequate data available about ground water on which to base legislative decisions.

Unlike surface water or air pollution problems, EPA knows relatively little about ground water problems. Given the emphasis implied in the list of laws above, it should be clear that there is a critical need for adequate research into all aspects of ground water if the Agency is to fulfill its many responsibilities.

Despite the enormous expenditures planned under the Superfund program, the law prohibits use of Superfund monies for research projects (even for documenting, in a research sense, the experiences on specific Superfund cleanups, which could provide a very useful data base for the future). It is not surprising that, within the Federal government, little progress has been made to date to pull together the fragmented and disparate programs pertaining to ground water. Even within EPA itself, which holds the predominant responsibility, efforts to coordinate the management of numerous ground water-related programs are just beginning.

Current EPA Activities

During the past few years EPA has undertaken a number of major initiatives to strengthen its ground water protection programs. A Ground Water Task Force was established to:

A. Identify the areas of serious inconsistencies among programs and institutions at the State, local and Federal levels.

B. Assess the need for greater program coordination within EPA.

C. Help strengthen the States' capabilities to protect ground water resources as they themselves define the need.

The Ground Water Task Force produced a draft report in 1983 which, after extensive internal deliberation, together with extensive comments from the full range of outside interests, became the Agency's Ground Water Protection Strategy (EPA, 1984). The Strategy has four major components, which are:

A. Short-term buildup of institutions at the State level.

B. Assessing the problems that may exist from unaddressed sources of contamination, including leaking storage tanks, surface impoundments and landfills.

C. Issuing guidelines for EPA decisions affecting ground water protection and cleanup.

D. Strengthening EPA's organization for ground water management at the Headquarters and Regional levels, and strengthening EPA's cooperation with Federal and State agencies.

Following the recommendations of the Task Force, the Agency established an Office of Ground Water Protection which, for the first time, delegated to a single office the responsibility to establish policy and coordinate the wide range of EPA programs and activities related to ground water.

Because ground water research was a key element of the Strategy, the Deputy Administrator asked the Science Advisory Board, on July 10, 1984, to review the Agency's ground water research program. Included in the review were the transport, fate and effects of contaminants, abatement and control technologies, modeling, monitoring and analytical methods, and quality assurance. (The SAB was not asked to review the health effects research related to ground water.) The Executive Committee of the SAB accepted the charge, and formed a Ground Water Research Review Committee, chaired by Mr. John Quarles, former Deputy Administrator of EPA, to complete the review, which commenced in December 1984.

Committee Review Procedures

The Committee consisted of fourteen individuals (see Committee Roster, Appendix A) selected by the Administrator based on recommendations from SAB staff, EPA program offices, and outside experts in the field. They were chosen for their expertise in the ground water field, or their experience in administering ground water programs at various levels of State and Federal government.

The Committee was provided a substantial amount of documentary material about the EPA ground water policy and regulatory programs and the ongoing and planned ground water research in EPA and in other Federal agencies. The Committee held six meetings in Washington, D.C. from December 1984 to July 1985. At four of these meetings it heard presentations from EPA staff, other Federal agency staff, and other groups having an interest in the ground water research program. Included were a number of presentations by "users" of ground water research, representing EPA regional offices, the National Governor's Association, the Association of State and Interstate Water Pollution Control Administrators and the Environmental Defense Fund.

These presentations detailed ground water research programs and perceived research needs. In addition to oral presentations, the Committee also reviewed written summaries of research conducted under the auspices of the American Petroleum Institute and the Electric Power Research Institute. The last two meetings were devoted exclusively to finalizing the Committee's report. Minutes of all meetings, which include copies of reference documents and summarized information on each presentation, are available in the offices of the Science Advisory Board.

The Committee divided itself into four Subgroups to conduct detailed portions of the review. These Subgroups were oriented around four major subject areas: Monitoring, Source Control, Transport and Fate, and Remedial Action/ Aquifer Cleanup. Members of these Subgroups attended the RSKERL ground water program review in Oklahoma City, Oklahoma on March 24-25, 1985, and visited HWERL in Cincinnati, Ohio on April 12, 1985.

The Committee's report was drafted by Committee members and Mr. Harry Torno, Executive Secretary to the Committee. In its final form it represents the views of the Committee as a whole.

SECTION III

DESCRIPTION/EVALUATION OF THE EPA GROUND WATER RESEARCH PROGRAM

Source Control

Source control is defined here as technical and managerial approaches for insuring that pollutants which may be released to the terrestrial surface and subsurface are sufficiently attenuated before reaching a critical receptor so there will be no adverse effect to human health and the environment. The technical and managerial approaches include specifically:

A. Reducing or eliminating the problem material (e.g., controlling application of certain toxic organic chemicals, minimizing waste generation and banning certain untreated wastes from land disposal).

B. Treating wastes to remove, transform or immobilize hazardous constituents prior to land disposal (e.g., incineration or physical/chemical/biological treatment).

C. Effective containment of impounded or land-filled wastes, (e.g., multiple-liner systems, leachate collection systems and covers).

D. Physical removal of sources of ground water contamination, e.g., excavation of contaminated soil.

E. In-situ and land treatment processes to increase the degradation, immobilization and other losses of pollutants and decrease the amount available for transport to the subsurface.

Source control must be a key component of any ground water research program because prevention is more cost-effective and more protective of human health and the environment than clean-up. Prevention of additional contamination through source control while continuing clean-up efforts is the only way net progress can be made to reduce current and future ground water contamination. Typical sources requiring control by these strategies are:

A. Chemicals applied to the land for beneficial purposes (e.g., pesticides, deicers and fertilizers).

B. Accidental releases (e.g., transportation accidents and leaking underground storage tanks).

C. Hazardous industrial wastes disposed of on land (e.g., landfills, impoundments, waste piles and injection wells).

D. Domestic wastes stored or disposed of using sanitary landfills, land application of wastewater and wastewater treatment plant sludges, and septic tank effluents.

Only some of these sources are currently regulated at the Federal level. Such regulation does not necessarily reflect their relative importance, but rather reflects a series of legislative responses to perceived critical needs. At the present time, the major source control research efforts are concerned only with the control of specified hazardous wastes and are in support of RCRA.

New information about source control must be based on good science and technology. Reliable information is needed to define the magnitude and importance of each type of source in order to guide legislation and regulation and to set research priorities. Cost-effective approaches to prevent new releases from each potential source must be developed. The mandated clean-up of certain existing sources is proceeding at an enormous cost and is based on a scanty information base regarding which problems are important and which clean-up techniques are effective.

Summary of Current Research

Current EPA research on source control for protection of ground water is limited almost entirely to hazardous wastes as potential sources of ground water contamination. Sources addressed in research programs carried out by other Federal Agencies include agricultural chemicals (USDA) and deicing salts (Federal Highway Administration).

HWERL specifically addresses source control research. This research focuses on clay liners, flexible membranes, waste modification such as solidification, and suitable covers for landfills and units such as ponds and impoundments that require closure. This research emphasizes barriers to the movement of pollutants placed in landfills, barriers to water penetration (thus reducing potential mobility), and methods to render wastes less mobile when placed in landfills.

HWERL is also doing research on alternatives to land disposal in the management of hazardous wastes. The research encompasses thermal destruction (conventional incineration, at-sea incineration, burning in cement kilns, non-flame systems, burning in industrial boilers, supercritical water oxidation, and catalyzed wet air oxidation), and chemical and biological detoxification methods.

The research program at RSKERL has a component that focuses on land treatment of hazardous wastes. RSKERL has had research efforts related to land treatment of municipal wastes, but those efforts have ceased. The goal of land treatment is to degrade, immobilize, or transform contaminants.

USDA research activities are somewhat related to source control. They focus on better use, timing and rate of application of agricultural chemicals (fertilizers and pesticides) to soils and are related to more efficient use of the chemicals and indirectly to source control.

The Department of Energy (DOE) has a research program related to the treatment and disposal of wastes from energy-producing facilities. Much of this effort is related to understanding the basic transformations and transport and fate of pollutants from these sites. A comprehensive source control program, as identified for EPA, does not appear to be included in the DOE effort. The Electric Power Research Institute (EPRI) has a similar general research effort.

The Federal Highway Administration has conducted research on the control of deicing salt applications as a source of ground water contamination. The research efforts include development of substitute deicing chemicals and non-chemical deicing systems.

The U.S. Geological Survey (USGS) has been the primary agency in the United States for ground water research as it relates to water supply. Efforts to monitor and understand the transport and fate of organics and inorganics in the subsurface have been increasing. This work is fundamental to developing and evaluating source control methods.

Gaps and Deficiencies in the Current Source Control Program

The Committee reviewed the source control research activities in EPA and found that the current source control research for protection of ground water resources addresses only a limited number of contaminant sources. There are strong research programs (not all at EPA) on landfill of industrial hazardous waste, use of surface impoundments for treatment or storage of hazardous waste, hazardous waste piles, above ground storage tanks for hazardous wastes, hazardous waste containers, radioactive disposal sites, materials transport and transfer operations, deicing salt applications, and urban runoff.

The review found that, with respect to the source control research related to hazardous waste land disposal conducted at HWERL, the EPA research program is adequate and appropriate both in funding and direction. This source control technology program should be continued, including research on alternative technologies to land disposal and improved land-disposal technologies. These technologies should emphasize methods to immobilize organic wastes.

The program at RSKERL, while not directed at control of specific sources of ground water contamination, is developing scientific principles affecting the sorption, chemical and biological transformation and migration of pollutants in the subsurface. This research provides the scientific basis for much of the research on technological controls for specific sources of ground water contamination.

The efforts at RSKERL also include research on the land treatability of certain hazardous wastes. These efforts are not extensive and will be able to cover only a small fraction of the hazardous wastes that require evaluation. Furthermore, these efforts are directed only toward hazardous wastes. Wastes not listed as hazardous but which, when land-applied, can and have contaminated ground water, also are not included in the EPA land treatability research program.

It is clear that the land disposal of certain hazardous wastes will be prohibited by regulations being developed by EPA. However, there are only three ultimate disposal sites for wastes the atmosphere, the surface waters, and the land. Certainly, the land will continue to be used for the treatment and disposal of many wastes, including some listed hazardous wastes. Therefore, it is important that the land continue to be considered as a waste management and disposal alternative and that research be accelerated to determine the applicability of land treatment as a source control option for many wastes.

The Committee also notes that EPA has done very little research emphasizing generic approaches to the treatment of wastes to render them less hazardous. Also, reducing the generation of hazardous waste, especially the type that will be land-applied, organic and inorganic sludges and residuals, is an important source control method that will reduce the subsequent contamination of ground water.

Other potential sources of ground water contamination that are not adequately addressed by current research programs include septic tanks, municipal wastewater treatment operations such as sludge disposal, injection wells, land disposal of non-hazardous wastes, underground storage tanks, salt dome storage, mining activities, agricultural chemical usage, and multimedia transfers (e.g., atmospheric pollutants as a source of ground water contamination and ground water surface water interactions). Information on the character of these sources is scattered throughout the literature, but conclusions about the importance of their impact on ground water quality have not been drawn.

Because many sources of ground water contamination are not being addressed by current research programs, one objective of the EPA ground water research program should be to develop reliable information about the importance of each type of source (for which EPA already has regulatory authority), and to establish research priorities. Next, cost-effective approaches to prevent new releases from each potential source need to be developed. Finally, the scientific and technological information base to support the clean-up of certain existing sources needs to be expanded to assess which sites are important and which clean-up methods are effective.

Recommendations

A. Sources of ground water contamination.

The current EPA source control research efforts focus almost entirely on hazardous wastes as a result of urgent legislative mandates. As a result, the impacts of land applied non-hazardous wastes on ground water quality are not clear and it is difficult to know what other sources should be controlled and what level of research should be devoted to these other ("non-hazardous") waste sources. Therefore, the Committee recommends that EPA:

1. Determine the magnitude and importance of ground water contamination from "non-hazardous" waste disposal operations, such as sanitary landfills, septic tanks, wastewater collection systems, wastewater treatment facilities, and wastewater/and sludge land treatment operations.

2. For any important "non-hazardous" waste sources, specify the technical and economic feasibility of source control options.

3. In conjunction with USDA, develop more effective application practices that reduce migration of agricultural chemicals to the ground water.

B. Source Control

The current source control research effort related to hazardous waste land disposal technologies appears adequate except for the minimum effort related to the use of land treatment as as source control technology for both hazardous and non-hazardous wastes. The Committee recommends that the current land disposal source control research be continued and that additional research be instigated. Specifically, the Committee recommends that EPA:

1. Continue the program on reducing migration from landfill operations, but emphasize new techniques to immobilize organic wastes.

2. Continue the program on alternatives to land disposal for controlling sources of hazardous wastes. These alternatives include thermal destruction and chemical and biological detoxification.

3. Accelerate research to determine the applicability of land treatment as a source control option for all classes for hazardous and non-hazardous wastes.

C. Source Minimization

As noted in the previous section, little research is focused on reducing the quantity of hazardous wastes being generated, a portion of which will be managed by land treatment or disposal options and could contaminate ground water. There also needs to be additional emphasis on methods to contain spilled materials and treat contaminated soils before contamination reaches ground water. These are two source control methods that have broad application. Therefore, the Committee recommends that EPA:

1. <u>Continue current research on in-situ treatment of contaminated soils to prevent or reduce migration.</u>

2. <u>Develop more effective emergency-response techniques to contain or treat spilled materials before they can reach ground water.</u>

3. <u>Develop techniques to treat wastes to reduce their hazard and increase technology-transfer efforts on existing methods of waste minimization.</u>

<u>Monitoring</u>

Monitoring is defined to include specific protocols for collecting samples of ground water in the field and protocols for analyzing the characteristics of those samples in the laboratory. Ground water monitoring is conducted to determine water quality or water quantity. EPA requires ground water monitoring for determining the quality of the resource in order to enforce the regulatory programs which it administers. Because of the importance and magnitude of EPA's ground water program and its implications for American society, it is imperative that the data gathering which guides the program be reliable. Consequently, it is important that sufficient resources be committed to assure this reliability.

Sample collection encompasses all regulatory programs and all phases of evaluation. Data collected are used to:

A. Determine background and/or existing ground water quality;

B. Determine the physical, chemical, or biological processes that define a ground water system;

C. Calibrate and validate predictive computer models;

D. Identify appropriate designs for pollution control technologies; and

E. Verify the adequacy of those technologies.

Proper collection and analytical protocols are essential to the Agency's ground water protection programs.

Sampling is defined as procedures for extracting significant portions of ground water for chemical analyses and for ground water quality characterization. Sampling is also used to define the characteristics of the geologic media from which the sample is extracted. These samples may be obtained from either a hole (well) made in the media or by a remote-sensing technique.

Analysis is defined as a test procedure for qualitatively and quantitatively determining the physical or chemical characteristics of a sample with known precision and accuracy. Limits of detection and quantitation, as well as competent quality assurance/quality control (QA/QC), are a part of analytical methods development.

Summary of Current Research

The current research emphasis is difficult to quantify because the programs are fragmented. While many of the broader topics related to monitoring are being addressed, the more complex questions that accompany the use of new techniques, methodologies and equipment have not been answered.

Ongoing or planned research at EPA relating to sample collection appears to focus on refining the sensitivity and economy of particular equipment for locating unknown sources of pollution and on materials development for on-site monitoring.

The primary sample collection research is located at EMSL-LV. That laboratory produces state-of-the-art techniques and equipment designed to facilitate identifying problem locations. One example of such a technique is remote-sensing.

Analysis conducted in support of ground water systems characterization and evaluation is presently the focus of substantial activity both within and outside EPA.

The extent of current EPA research in ground water analytical methods development is exemplified below:

EPA LAB	R & D
EMSL/Las Vegas	-Validity, performance of indicator parameters -Field aspects, monitoring
EMSL/Cincinnati	-QA/QC For SW-846 (QA Samples) methods -Evaluation, improvement of SW-846 methods

Gaps and Deficiencies in the Monitoring Research Program

The Committee finds that the program is underfunded and recommends that funding be increased in all aspects of the ground water monitoring program. In addition, the program suffers from management fragmentation, and the results of the program do not always meet the standards of good science.

Specifically, the presently available sample collection and analysis methods are deficient in defined precision and accuracy, in proper validation, and in adequate QA/QC.

When such deficient methods are promulgated, problems often become greater than if there were no approved methods. The regulated community and the regulators must deal with these problems.

EPA's present research effort to validate SW-846 methods by retrofitting the performance/validation/QA-QC requirements (including the preparation of standard analyte solutions) is commendable. This effort, however, is not needed for those 129 Appendix VIII compounds which are also Priority Pollutants under the Clean Water Act. The applicable 304(h) methods have already been developed complete with performance data, QA/QC and standards. These 304(h) methods could and should be referenced as equivalent methods in SW-846. In contrast, there are another 250 Appendix VIII compounds for which there are generally no proven methods, standards, QA/QC, validation or performance data. It is on this latter group that EPA's research efforts should be focused.

Sampling protocols are needed which are correct for both the compounds being tested and the type of geologic media being sampled. For example, protocols for extracting water from fractured rock will differ from those for more homogeneous aquifers, which will also differ from those for rocks of low permeability.

The development of monitoring techniques for anisotropic, nonhomogeneous media including karst, zones of fracture, and fine-grained unconsolidated materials is needed.

The mathematical correlations between the in-situ physical, chemical and biological characteristics of a ground water system and their variation under laboratory conditions must not be overlooked. This is especially important in the development of models.

Sampling points must be sufficient in number to describe statistically the media or define the variations of the geologic medium. The anisotropic and nonhomogeneous nature of the medium must be described in order to extract statistically significant samples of ground water.

Finally, faster and more accurate measuring equipment for in-situ monitoring needs to be developed. This is another area where a significant increase in research is needed by the Agency.

Even with ideal analytical tools, the analysis of some 375 compounds in ground water is tedious and expensive. A deficiency in the program, therefore is the lack of a workable screening test which could eliminate or identify the presence of clusters of contaminants. While EPA has begun this process, there is a great deal of work yet to be done. A similarly deficient area is the use of indicator compounds (water-mobile compounds whose presence could be used as a "trigger" for more detailed groundwater analysis).

Alternate concentration limits (ACL) for RCRA Appendix VIII compounds (based on unit cancer risks, etc.) are being proposed. Most of these ACL's are far below the working limits of detection for any known analytical method. Here, too, research to define practical, measurable, physically significant numbers is necessary.

Recommendations

A. Sample Collection

1. Establish quality assurance procedures for all sample collection techniques, including the development of protocols which will maintain sample integrity.

Quality assurance is a tool which makes a method both reliable and consistent. This is a long-term program need. As sampling techniques and materials continue to be refined, the protocols need to be refined and revalidated.

2. Continue support for the development of monitoring techniques for quickly locating and characterizing sources and contamination plumes.

This is a critical research need Nationwide. The faster and more reliably a pollution source can be located, the sooner it can be addressed in the regulatory framework. The geometric shape, size, biological and chemical composition and transient characteristics of a contaminant plume are critically needed to define the problem and its solution.

3. Develop and implement a research plan designed to identify the physical and chemical characteristics of anistropic, nonhomogeneous media such as fracture zones.

Most monitoring systems are designed with the assumption that the ground water system or aquifer is made up of homogeneous isotropic materials. In most areas of the country, the assumption is not correct, but due to a lack of information, that assumption must be made.

4. Develop mathematical correlations between laboratory results and in-situ physical characteristics (i.e. effective porosity, permeability, transmissivity) to improve the simulation of ground water systems.

With these correlations, predictive computer models could be much more reliable.

5. Develop matrices for locating and constructing monitoring networks that are statistically significant in relation to the system characteristics (i.e., the physical and chemical properties of the ground water system).

This is needed to increase the reliability of data collected, increase the efficiency of monitoring networks and decrease the cost of network installation.

6. Focus the Agency's ground water monitoring equipment research on instruments for field and in-situ measurements.

These instruments should measure physical, chemical and biological characteristics on-site. Monitoring RCRA and Superfund sites requires timely and accurate information on the extent of ground water contamination. These data, if continuous or frequent, may also assist in establishing long-term trends.

B. Analytical Procedures

1. Establish quality assurance procedures, performance and validation data for all analytical methods, existing and new.

Quality assurance allows both the regulator and the regulated community to produce analytical results in which there is confidence.

The methods for detecting RCRA Appendix VIII compounds are the most critical in terms of immediate needs. The performance and validation data should include determining the accuracy of each method, the precision for each method, the limits of quantitation and detection, the confidence interval for those detection limits, and appropriate QA/QC for each method.

2. Emphasize the development of methods for ground water quality analysis.

Responsibility for the entire water quality analysis program should be placed where the greatest expertise in that field is available.

3. Coordinate methods development for water quality analyses between Agency programs.

When an analytical method has been proven and the necessary performance data developed for one program, the work should not be duplicated. Such duplication occurred in listing the priority pollutants for the Clean Water Act, and then again for RCRA ground water analyses. The programs are different, but the medium being analyzed is the same

4. Improve or refine screening methods for classes of compounds that are chemically similar.

When a class of compounds can be easily eliminated as contaminants of concern, the efficiency of monitoring increases and the cost of analysis decreases.

5. Continue to improve the sensitivity of analytical methods for organics.

Analytical methods that can accurately measure the low levels defined by the Agency's programs must be available. An example of this need is the the ACL's in RCRA. There must be reliable analytical methods complete with quality assurance, quality control, and performance and validation data in order to determine compliance.

Transport and Fate

Transport refers to the movement of a contaminant (solute) in the ground water, while fate refers to chemical, physical and biological transformations that result in changes in the original structure of the contaminants. The processes that govern the transport and fate of pollutants in the subsurface can be divided into three major areas: (1) hydrologic, (2) abiotic, and (3) biotic. Hydrologic processes include convection and hydrodynamic dispersion; abiotic processes include sorption/partitioning and chemical degradation; and biotic processes include biodegradation and biotic transformation of pollutants.

The goal of transport and fate prediction is achieved by using the scientific process to understand physical, chemical, and biological processes through field and laboratory observations. This understanding is used to formulate theories which are translated into mathematical terms. The mathematical expressions require a solution which is often achieved with the aid of a computer. The resulting numerical model is used in an attempt to predict the transport and fate of pollutants in the subsurface. A final requirement for effective modeling is site-specific data. This requirement is often the limiting factor in achieving the goal of accurate ground water flow and quality predictions.

Prediction of transport and fate of pollutants (i.e., understanding all of the above processes) is important to every program within EPA concerned with ground water contamination. It is especially important to recent legislation such as RCRA, the Superfund law, UIC regulations, and the CWA. To license a new facility under RCRA, one must be able to predict accurately the transport and fate of potential contaminants. Such prediction becomes even more critical if ACL's are considered. It is necessary to predict contaminant fate at existing sites under Superfund to establish effective remediation and to assess natural resource damage.

Furthermore, some hazardous wastes are also being injected into deep wells. This type of waste disposal is regulated under UIC regulations. As land disposal becomes more restrictive, deep-well injection will become even more important. Drilling monitoring wells at these depths is an expensive undertaking. Therefore, monitoring is limited, and the need for predictive capabilities for these sites is important. The ability to predict accurately the transport and fate of potential contaminants is critical to the success of most regulations concerning ground water.

Current Research

Research in transport and fate prediction is currently occurring at the Department of the Interior (USGS), Department of Agriculture, Department of Defense, Department of Energy, Nuclear Regulatory Commission (NRC), National Science Foundation, Tennessee Valley Authority, and the Environmental Protection Agency (See Appendix C). Even though each of these agencies is interested in different ground water problems, the processes in all contamination problems are similar, and therefore, there is considerable transfer value. For example, the NRC is researching flow and transport in fractured media. Although the emphasis is on radionuclide transport, an improved understanding of the transport processes applies equally well to other solutes.

Of the above agencies, EPA officially coordinates research projects with the USGS, U.S. Air Force, U.S. Army, DOE, and the National Research Council. Within EPA, much research on hydrologic processes is conducted at RSKERL, although some research is performed at other laboratories, particularly the Environmental Research Laboratory in Athens, Georgia.

Additional fate and transport research is being conducted in other countries, as well as by private institutions within the United States. Perhaps the major private source is the Electric Power Research Institute, which has a comprehensive program in the area of transport and fate prediction.

Focusing on RSKERL, research in the three process categories (hydrologic, abiotic, and biotic) may be summarized as follows. Research in hydrologic processes is directed in three areas: (1) physics of flow through porous media, (2) methodologies for evaluating the degree of spatial and temporal heterogeneity (biological, chemical and physical) in the subsurface, and (3) mathematical techniques for predicting the distribution of fluids and chemicals in the subsurface. Much of the current research in ground water focuses on the theory of hydrodynamic dispersion. Several field studies now in progress are designed to test this theory, at least one of which is funded by EPA.

The abiotic processes of primary concern to RSKERL are sorption and chemical degradation. Emphasis to date has been on expanding our knowledge of the sorption process. A major effort is being made to quantify and develop the theory of phase interactions in complex, but realistic, environmental systems. In terms of chemical or abiotic transformation of pollutants, the current effort is in developing tools and procedures for measuring in-situ chemistry in the subsurface. There are few comprehensive studies of chemical transformation processes currently in progress.

The RSKERL research efforts in the biotic processes category are focused on developing necessary information about subsurface biotic processes to predict the transport, fate, and impact of pollutants in the subsurface and to develop control and remedial technology for ground water quality. Much effort to date has focused on obtaining new techniques and procedures for characterizing subsurface biota.

Gaps and Deficiencies in Transport and Fate Research Program

More emphasis should be placed on stochastic models than on deterministic models. Because there is a great deal of uncertainty associated with the subsurface, deterministic results alone are difficult to interpret. Stochastic results help to increase the level of confidence for specific model applications. In some cases, unfortunately, the stochostic approach may require more data. Finally, because there are so many models available--more than 400 models of subsurface fluid flow, for instance (van der Heijde et al., 1985)--it is important for EPA to screen computer models and test them for accuracy.

Another research need concerns the processes which govern contaminant fate and transport, particularly the abiotic and biotic processes. Because ground water movement can be extremely slow, transformations with half-lives in the order of years may be the most significant attenuating process. Fragmentary information available on chemical transformations suggests that hydrolysis, reduction and possibly nucleophilic substitution are potentially important processes in ground water. Most chemical transport and fate models assume that sorption is instantaneous even though sorption, in reality, is a rate-controlled process.

Regardless of the type of model chosen, increased emphasis should be given to field testing and field validation of the models. Data generated in association with remedial action and monitoring of Superfund sites may be used to fulfill model validation requirements. These data should be made available for use by other investigators.

Current information indicates that the deeper subsurface environment contains significant populations of microorganisms. Additional information about the distribution, density, and nature of these organisms in the subsurface is needed. At present, little is known about biodegradation of organic pollutants in the deeper subsurface. Limited results indicate that the potential exists for significant biodegradation of a number of compounds. It is not known whether the limiting factor for biodegradation is nutritional, thermodynamic (energy-limited) or kinetic (rate-limited), nor has the extent of adaptation, physico-chemical environment, and cometabolism been investigated. Very little is known concerning degradation byproducts or whether degradation processes can be manipulated.

There is a major need to educate the users of predictive tools. EPA is faced with examining many potential sites with a small staff, most of whom have limited hydrogeologic training. For these reasons, the potential exists to use inappropriate models to evaluate sites. It is also important to note that some aspects of ground water hydrology are imprecise, and will always be so. Prediction via modeling is one of our best tools for understanding and describing these complex systems. It is important for policy makers to utilize models, but at the same time, recognize their limitations. Additionally, it is important to realize that the model is only as good as the available data and the experience of the model user.

Recommendations

Ground water research is a long-term effort essential to many different EPA regulations. Recognizing this, the Committee encourages the development of projects that bring together the many disciplines for the transport and fate prediction effort, and integrates and interfaces the work of chemists, microbiologists, and hydrologists. The Committee developed a number of recommendations which are listed below:

A. Continue to develop process-oriented studies in the areas of biology and chemistry in addition to fostering projects related to understanding heterogeneous and multiphase fluid flows in both the saturated and unsaturated regimes.

This is particularly important for biotransformation, sorption phenomena, and chemical reactions.

B. Develop numerical models that support process characterization with emphasis on modeling as an aid to understanding transport and fate of solutes.

Efforts to quantify chemical, biological and physical processes influencing the transport and fate of pollutants in the subsurface should be increased. Because of the spatial variability of the subsurface and the uncertainty of underground regimes, a stochastic model would establish more confidence in model validity.

C. Integrate model use and development projects with both field and laboratory activities.

EPA project descriptions and work scopes should include instructions to this effect to produce relevant research products.

D. Make data bases from field research projects available in a timely fashion to other groups.

In all cases we recommend that all project conclusions be supported by publicly available published data. Surprisingly, many publicly funded research efforts have conclusions based upon data not available for peer review.

E. <u>Establish a set of standards for code testing and documentation to be followed for all codes developed by EPA</u>.

Adequate user manuals should be generated and mass balance routines should be made part of all codes.

<u>Remedial Action/Aquifer Cleanup</u>

Remedial Action encompasses those activities described in Chapter 8 of a recent Office of Technology Assessment report (OTA, 1984) which groups fifteen corrective action technologies into four major categories: containment, withdrawal, treatment and in-situ rehabilitation. Two of these major categories, withdrawal and treatment, have been combined in this report.

Containment technologies are physical or geohydrologic measures designed to contain contaminants at their source in order to prevent or minimize further migration. Containment methods include the emplacment of cover materials, liners or vertical barriers as well as the addition of chemicals to stabilize or solidify wastes. Containment technologies are frequently combined with withdrawal and treatment of contaminated ground water or in-situ rehabilitation of the aquifer.

Withdrawal and treatment deal with aquifer restoration where water is withdrawn from the aquifer and is treated prior to recharge, use, or discharge to surface drainage. Aquifer restoration of this type depends upon the proper location of pumping wells or gravity collection systems. After water collection, the problem becomes one of treatment of ground water with generally low concentration contamination. The technology for water renovation falls outside the field of ground water research except in those situations where special attention must be given to prevent clogging from particulate matter or biological growth.

In-situ aquifer rehabilitation involves in-situ treatment of contaminated soils, buried wastes, and contaminated ground water. Methods range from physical modification of soils to stimulation of naturally-occurring bacteria that biodegrade organic chemicals.

Summary of Current Research

EPA's containment research is managed primarily by the HWERL in Cincinnati (and its sister laboratory in Edison, NJ). Most of the projects are designed to meet the urgent, short-term and practical needs of RCRA and CERCLA at headquarters, in the Regions and the States. The containment research at HWERL is almostly exclusively extramural, and deals with the properties of materials, as well as the interactions between cover, liner or barrier materials and the wastes, waste degradation products or leachate to be contained. Investigations of waste stabilization are also in progress. EPA is currently sponsoring research on the effectiveness of various soil materials and alternatives (such as flexible membranes, fly ash or paper-mill sludges) to contain contaminants under different conditions. The effect of subsidence on cover integrity is being tested. Vegetative covers are being evaluated. Much of the originality and creativity in adapting established ground water containment technologies (or in combining them), appears to originate in the private sector.

Current research on liners focuses on their effectiveness to contain or minimize the migration of pollutants into ground water, particularly the organic solvents. Laboratory and field research projects are underway to assess the effects of inorganic salts and organic solvents on clay soils (liners). Field studies of sites where clay liners have failed are in progress to determine causes of failure. EPA is also conducting active research to evaluate the effectiveness of synthetic membranes or flexible membrane liners (FML's) as alternatives to soil-based materials.

EPA has recently sponsored extensive research on barriers such as slurry walls, grout curtains and sheet piling cutoff walls, some in combination with flexible membranes. This research has focused on the reactivity of these materials with the wastes to be contained, particularly organics. EPA is now sponsoring full-scale evaluations of containment technologies at three sites, two of which are Superfund sites.

EPA has sponsored little work on hydrodynamic barriers. Efforts to date have concentrated on pumping in connection with treatment. EPA research program managers plan future research directed toward reducing operating and maintenance costs for hydrodynamic barrier systems.

The EPA research program on remedial action is fragmented and the investigators and contractors at the laboratories appear to have little contact with each other. This isolation retards the translation of new knowledge gained from basic research on processes, fate and transport into engineering applications.

Current research on withdrawal and treatment at HWERL deals with technology which includes the use of activated carbon, air stripping, and the application of ozone for the removal of organic chemicals. Research on technology for recharging water after it has been withdrawn has been going on for many years, and has dealt primarily with well clogging due to silts or particulate matter or from biological growths within the screened area of the aquifer. This work has traditionally been carried out by the USGS and the USDA. The technology for locating withdrawal wells and determining the proper pumping rate and the design and construction of gravity collection systems has also been advanced and research is ongoing. Little effort has been made in the utilization of withdrawn and treated recharge water to flush contaminants through the unsaturated zone.

Current in-situ aquifer rehabilitation research on the part of both EPA and the private sector involves treatment by physical modification of soils and biological methods. Enrichment of indigenous biodegrading microflora and inoculation with biotransforming microflora are being tested.

Research Needs

The current research program on containment technology is mature. It deals with adaptation, refinement, selection and performance; with testing new permutations and combinations of materials and methods; and with long-term performance evaluation and documentation. Continued emphasis should be placed on the shift in emphasis from laboratory or bench-scale experiments to field validation, application assessment and long-term performance monitoring of covers, liners and barriers. These research projects should be long-term to provide continuity and consistency in data collection. Superfund sites should be used, whenever possible, for research on long-range effectiveness of containment and remedial actions. Real data on which to base costly decisions on closing landfills and stabilized surface impoundments is lacking. With the closing of many of these facilities now underway, there is an ideal opportunity to collect this critical information.

The regular and systematic integration of new research results or field validation and performance data into the data base is necessary for maximum utility of user-friendly computer programs being developed to assist permit writers and remedial action plan reviewers. Extensive training is needed for appropriate use of these computer programs.

In light of the success achieved in this type of containment technology, however, it should be recognized that it has now reached a mature state and will require lower relative funding levels in the future. This contrasts with increasing financial needs for monitoring, prediction, and aquifer restoration if we are to increase effectiveness and economic efficiency of these management techniques in the future.

Except for high-level radioactive waste disposal, there seems to be little or no work under way, basic or applied, addressing the problems associated with contamination, fate, transport or containment and rehabilitation of ground water in fractured formations and/or karst regions. The acute need for research in this area was expressed by several users.

Deep well injection could play an important role in the safe disposal of contaminated liquids and high fluid sludges being removed from closed RCRA facilities and Superfund sites. Because of the heavy use of injection wells and concern regarding their long-term safety, research is needed for improving monitoring and construction technology.

Recommendations

A. Continue to test, assess and improve the application of available containment technologies (e.g., caps, liners, barriers and hydrodynamic control) for containment of wastes and polluted ground water.

EPA's present program of examining the efficiency and durability of caps, liners and underground walls should be expanded to provide realistic data on susceptibility of materials to typical chemical contaminants. Various techniques currently being used for installing containment barriers should be tested in detail for their long-term efficiency. A major step up in analyzing the economic effectiveness of hydrodynamic control systems is dictated.

B. Expand the use of RCRA facilities and Superfund sites as field laboratories for the verification of predictive models, performance evaluation of new (or adapted) containment methods, documentation of installation and maintenance costs, and assessment of aquifer rehabilitation.

Containment walls of various types are presently being planned at a large number of RCRA or Superfund sites; this is an excellent opportunity to collect first-hand field information on the usefulness of these techniques.

C. Place major research emphasis on in-situ chemical and biological contaminant reduction as a restoration or clean-up technique.

EPA should continue research on the role that indigenous or introduced soil microorganisms play in reducing the concentration of chemical contaminants. EPA should also strengthen its investigations into the stimulation and acceleration of abiotic processes as a means of in-situ aquifer rehabilitation.

D. Develop remedial methods for contaminated ground water for use in geologic regions characterized by fractured formations or karst topography.

E. Initiate research on construction of underground injection wells and identification of suitable geologic environments for isolating hazardous wastes.

SECTION IV

TECHNOLOGY TRANSFER AND TRAINING

Introduction

With the passage of RCRA and CERCLA and the corresponding increased regulatory control over ground water resources on the State and local level, the need for trained and well informed ground water professionals has risen dramatically over the past decade. Investigations of ground water conditions at sites of known or suspected ground water contamination can be complex and require a wide range of scientific disciplines. The design of such investigations and the interpretation of data obtained call for specialized training. Where new sites are proposed for land disposal of wastes or where RCRA/Superfund facilities are to be closed or remediated, public agency personnel must be equipped with enough knowledge of the ground water field to enable them to make proper decisions.

Regulatory agencies on all levels of government have been forced to meet the growing need for ground water professionals by using existing staff with little, if any, formal training or experience in ground water technology. The need to train such personnel and to provide up-to-date technology to them is immediate and critical. In the absence of such training and information, uninformed decisions are being made which could have significant adverse impact on public health and the environment.

This critical need was echoed by virtually all of the individuals and organizations interviewed by the Committee (and in many of the references reviewed by the Committee as well). This is a major concern, because the Agency Ground Water Strategy assumes that the States bear the brunt of technical activity.

EPA has some strong technology transfer components it currently supports. The International Ground Water Modeling Center at the Holcomb Research Institute in Indianapolis, Indiana is funded in part by EPA and provides extensive training and support of ground water models, information on model selection and application, and software distribution. The National Water Well Association (NWWA), under the sponsorship of EPA, operates a National Ground Water Information Center which provides information and training to thousands of ground water professionals each year, including some short courses for EPA personnel. RSKERL has a program of disseminating research results, through the existing mechanism at the Center for Environmental Research Information (CERI) at Cincinnati, Ohio through workshops, seminars, and various manuals related to ground water monitoring and protection.

Technology Transfer and Training Needs

The most critical need is for an Agency commitment to provide the increased technical support, recognizing that existing efforts are inadequate. In this regard, the Agency must first look to its own house, and increase the numbers of its staff trained in ground water hydrology and pollutant transport and fate. This does not mean only hiring new staff, but also making a concerted effort to provide current staff with the training they need to do their job properly. Career development training such as this typically takes a back seat to day-to-day operational needs; this is a short-sighted policy.

Another urgent need is for much wider dissemination and accessibility of available technology and results of research projects to ground water professionals and managers throughout the Nation. Many of EPA's research projects, for instance, though published at the National Technical Information Service (NTIS), a slow, poor-quality source, are never entered in one of the standard library reference systems. Therefore, they are not accessed by broad-based computer searches and, in effect, are lost to many potential users. We recognize that ORD has greatly increased the emphasis on publishing research results in the peer-reviewed literature, and that their project summaries are well done, but the audience remains limited. This accessibility and dissemination applies not only to in-house projects, but also to those done by EPA program offices (which can have significant impact), consultants and other outside organizations.

Another critical need is for improved interlaboratory coordination within EPA. As the ground water programs in EPA are fragmented, so is the research that supports these programs. There must be frequent and extensive interchanges of information, both formal and informal, to remedy this situation.

Recommendations

A. EPA must increase by an order of magnitude its emphasis on and support for technology transfer and training.

The number of trained ground water specialists has not kept up with the demand created by recent legislation.

B. EPA should thoroughly reexamine its current approach and methodology for technology transfer and training in the ground water area.

While this activity should be centered in the Office of Research and Development, the responsibility should be shared by the EPA program offices. The Committee encourages the use of information specialists in achieving the goal of effective communication of available technology, research results and data to ground water professionals and managers throughout the Nation.

C. The Committee recommends that EPA establish a National Center for Ground Water Training.

This should be an in-house center for technical training, staffed by as few as two or three full-time employees, supplemented by scientists from EPA and elsewhere. A possible solution could be the resurrection of the training facility that once existed at RSKERL. Training should be aimed primarily at EPA in-house staff, and available to government employees at the State and local level. Taped TV courses about regulatory issues such as RCRA permits, Superfund site clean-up or ACL determinations could also be included in the curriculum.

D. The Committee recommends broader availability of research reports and guidance documents.

This would include a stronger effort in selection and publication of more research reports and guidance documents rather than just research summaries, and availability through EPA sources rather than just through NTIS, which does not provide quality service. Such documents are catalogued by NWWA; training should be provided to EPA personnel in accessing such a computerized information base.

Also included would be the establishment of formal linkages to information available at other Federal agencies, such as the USGS Ground Water Site Inventory.

E. The Committee recommends increased technology transfer among EPA laboratories, Regional offices and State regulatory agencies.

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 UIC, CERCLA, RCRA, LUST and the implementation of the ground water strategy. State and local personnel should be encouraged to attend. This series of presentations would not only provide a means of updating Federal and State field personnel on advances in ground water research, but would also be the basis for input to the research laboratories. Although these conferences would require a considerable amount of staff time, cross-fertilization and training would make this time highly productive.

F. As described more fully in the transport and fate section of this report, the Committee recommends that EPA continue technology transfer activities on information cataloging and retrieval (now via NWWA) and on transport/transformation models (now via Holcomb Research Institute).

SECTION V

POLICY ASPECTS OF GROUND WATER RESEARCH

This report has concentrated on evaluating the nature and adequacy of the current research program, applying the term "research" in its traditional sense to support EPA's regulatory responsibilities in the protection of ground water quality. The basic conclusion of the Committee is that such research should be substantially increased. In addition to reviewing these research issues, however, the Committee was asked by the Deputy Administrator to make recommendations on information needs for policy development. Because both the efforts and the expertise of the Committee have been focused predominantly on the research program itself, our review of prospective policy issues and related information needs has been limited. Nonetheless, the Committee believes that EPA faces substantial needs to collect factual data and conduct studies to strengthen the informational foundation on which future policy decisions will be made.

The many statutes which authorize EPA to protect ground water have been listed already in Section II of this report. An undesirable feature of this regulatory framework is that it is a patchwork of disconnected programs. Nearly all of the statutes originally were written, and subsequently have been implemented, with little explicit focus on the objective of ground water protection. Although these laws all pertain to ground water, they have no theme of consistency linking them together. They also rest on a shallow knowledge base.

As governmental efforts to protect ground water gather momentum, increasing numbers of decisions on major policy issues must be made. Such decisions should rest on a solid foundation of knowledge concerning many basic questions. These include: Which sources of ground water contamination warrant greater emphasis? Which technologies promise the best results for protection or remediation? What levels of protection or remediation are technologically feasible? To what extent can sources of contamination be reduced? Can exposure of humans to ground water contaminants be accurately determined or predicted? Can present and potential health effects be quantified, and what are they? Can institutional controls be developed to safeguard against human exposure? Does a scientific basis exist to conclude that compliance with proposed laws and regulations is feasible? What will such compliance cost? What is the dependence of different localities on ground water, and what alternatives exist to meet such needs? How much difference will protective controls and clean-up efforts make on the actual supply of clean ground water to meet those needs? More detailed questions arise with respect to individual policy issues.

Any review of the current regulatory framework must highlight disparaties in the intensity and nature of efforts directed at different components of the ground water quality problem. More stringent requirements generally are applied to selected point sources than to other categories, as noted in the 1984 OTA report, and industrial hazardous waste units receive much more emphasis (at far greater cost) than municipal landfills, even though the latter may present equally serious problems. Efforts directed at petroleum residues and pesticides in ground water are in their infancy.

A major reason for the confusion and disparaties which envelop the subject of ground water protection is the speed with which concern over ground water quality has emerged as an urgent public priority. Intense publicity of individual situations such as the contamination at Love Canal has combined with public anxieties over the effects of hazardous chemicals. These have produced vigorous demands through our political process for the rapid establishment of ground water protection controls. The speed of this process has exceeded the ability of existing institutional capacities to provide supporting data and analyses for the complex policy decisions which are required.

Basic questions concerning the goals of controls arise under both Superfund and RCRA. The current raging debate over "how clean is clean" under Superfund illustrates the need for more data on all the basic issues of risks, costs, and feasibilities. Under RCRA, EPA in its permit regulations has essentially mandated an absolutist approach of clean-up to background levels, unless a permit establishes an Alternate Concentration Limit. Confusion exists, however, as to what standards will be applied to determine when ACLs will be granted and what criteria they will employ.

A more specific example of the information needs for Policy guidance is presented by the requirement in the 1984 amendments to RCRA that EPA must examine every listed hazardous waste to determine whether land disposal of each waste should not be prohibited. The statute establishes a series of tight deadlines for the completion of these decisions by EPA. In order to complete this decision making in a manner that wisely fulfills the public interest, EPA not only needs detailed knowledge concerning the hazardous characteristics of each waste but also must have extensive information concerning all practicable alternatives for the handling and disposal of these wastes. That includes vast quantities of data concerning the different circumstances under which such wastes might be handled, the technologies available for treatment or disposal of such wastes, and the costs, energy implications, and other environmental impacts which may attach to each possible alternative.

The EPA Ground Water Protection Strategy also raises a host of information needs. A principal feature of the strategy is to encourage the classification of ground water. The needs for hydrogeologic data on the location, nature, and condition of aquifers throughout the Country are obvious. Systems for the collection of such data must be developed, and numerous supportive technical capabilities must be developed or refined to complete a physical evaluation of existing aquifers. A thorough review of all information requirements implicit in EPA's proposed classification strategy should be undertaken promptly.

Underlying all of the policy information needs suggested by a review of pending regulatory decisions, statutory requirements, and legislative proposals, is the basic and fundamental need to develop a more thorough understanding of the ground water resource itself. A serious limitation on prospects for the successful development of ground water policy is the weakness of general understanding concerning this resource. An urgent need is to transmit such knowledge as is possessed among technical experts to policy officials and the general public.

Sound policy decisions require an understanding of such features of the ground water resource as its rates of flow under differing circumstances, its quantities, its recharge rates, the rates of dispersion and attenuation of contaminants within the ground water system, and its current quality. Although there is widespread recognition of the general dependence of society on ground water, a more sophisticated and detailed knowledge is required as to the extent and nature of that dependence in differing localities.

The research described in earlier portions of this report should address many of these information needs. Such research should be planned not only to support the implementation of current programs but also to provide guidance for future policy decisions. Many essential ingredients to the policy decisions, however, lie outside the limits of the technical ground water research program. To a limited extent, these needs may be met by studies conducted by the Office of Technology Assessment, EPA's Office of Policy Analysis, or others. In the view of the Committee, the current level of attention to these needs for policy information is inadequate when matched against the dynamic state of policy formulation in this field.

APPENDIX A

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GROUND-WATER RESEARCH PROGRAMS

OFFICE OF RESEARCH AND DEVELOPMENT

U.S. ENVIRONMENTAL PROTECTION AGENCY

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INTRODUCTION

Many kinds of information are needed by the Environmental Protection Agency and the States for developing, implementing, and evaluating the progress of ground-water protection programs. In general, ground-water protection programs need to:

- determine the number and types of sources
- assess the extent and nature of current and potential contamination
- predict and/or measure the resulting concentrations of contaminants in water supplies
- ascertain the health implications of those concentrations
- compare the capabilities and costs of alternative prevention measures (source control and management)
- determine the capabilities and costs of cleanup measures
- evaluate program effectiveness

This is a description of research carried out by the Office of Research and Development (ORD) to meet these needs.

SCOPE

Our science for assessing and predicting the impacts of ground-water pollution is growing. In the past few years important gains have been made by the EPA Ground Water Research Program in technology for accessing the subsurface and taking samples that are uncontaminated by the sampling process. Further, we know reasonably well how a few organic chemicals of concern behave in a few geological materials. However, the state-of-the-art for ground-water monitoring is cumbersome, expensive, and insufficiently precise. Our capability for predicting the behavior of organic and microbiological contaminants is limited. Finally, there is little information available on the effectiveness or the costs of methods for in-situ cleanup of already polluted aquifers. The EPA Ground-Water Research Program consists of research addressing the needs in these three areas: monitoring, prediction, and cleanup.

Other ORD research programs are also contributing towards decision-making on ground-water problems. In particular, our hazardous waste engineering research is developing and evaluating technology for control of some of the most important sources of ground-water contamination. This program also provides ways to clean up sites already contaminated with hazardous wastes.

A significant portion of the research on the health effects and removal of drinking water contaminants is directed towards chemicals found in ground water. Since many contaminants occur in both surface and ground water, and since technology and health research needs are the same for both, it does not make sense to develop a separate ground-water health and technology research program. Consequently, this description of the EPA ground-water-related research does not include these programs. Likewise, the major research activities under way to improve our capability to analyze a water sample for its contaminant concentrations are independent of whether the water is surface or ground water, so these are also not described.

MANAGEMENT

Ground-water research has many clients. The EPA Program Offices with responsibilities in ground water include the Office of Water (Safe Drinking Water Act; Clean Water Act), the Office of Pesticides and Toxic Substances (Federal Insecticide, Fungicide, and Rodenticide Act; Toxic Substances Control Act), and the Office of Solid Waste and Emergency Response (Resource Conservation and Recovery Act; Comprehensive Environmental Response, Compensation and Liability Act). The EPA Regional Offices complete the list of EPA clients. As emphasized by the EPA Ground-Water Protection Strategy, however, perhaps the even more important clients are the State and local officials who must make their own decisions about ground water protection, management, and cleanup. Our research is providing tools for decision-making at all levels to enhance assessment and management of ground-water problems.

To ensure that our research programs are designed to meet the needs of our EPA clients, the Office of Research and Development has established Research Committees. There is one for each Program Office, and each has Regional representatives. We have also established a Cooperative Agreement with the National Governor's Association to provide a mechanism for interactions with the States on research needs.

Since the major funding for ground-water research comes from the Safe Drinking Water Act and the Resource Conservation and Recovery Act, we have established in addition a Ground-Water Research Planning Group which reports to both the Water Research Committee and the Hazardous Waste/Superfund Research Committee. This group advises ORD on the planning of ground-water monitoring, prediction, and cleanup research. We have made sure that all interested EPA clients are represented. In addition to ORD personnel, participants are included from:

Office of Ground-Water Protection
Office of Drinking Water
Office of Solid Waste
Office of Emergency and Remedial Response
Office of Waste Programs Enforcement
Office of Pesticide Programs
Office of Toxic Substances
Office of Policy, Planning, and Evaluation
Regions I, IV, VI, and X

The Office of Research and Development conducts its programs via fourteen laboratories and several field stations. Each laboratory conducts its own research as well as funds research at other institutions, including universities and colleges, consulting and engineering firms, State and other Federal laboratories, associations, and private industry. The laboratories whose ground-water related programs are described here are the Environmental Monitoring Systems Laboratory-Las Vegas, the Robert S. Kerr Environmental Research Laboratory-Ada, and the Hazardous Waste Engineering Research Laboratory-Cincinnati.

COORDINATION WITH OTHER FEDERAL AGENCIES

In addition to designing a research program to satisfy multiple client needs, ORD works with other Federal Agencies concerned with ground-water problems. The major funding of Federal ground-water research is through the U.S. Geological Survey (USGS). A Memorandum of Understanding between EPA and USGS was completed in August, 1981, and provides an umbrella under which each Agency's programs are formally coordinated. Ground water, of course, is a major element of that coordination. We conduct joint research projects with several other agencies, including the U.S. Air Force, the U.S. Army, Department of Energy, and the National Research Council.

RESOURCES (Fiscal Year 1985, President's Budget)

Research Area	Total Dollars (in thousands)	Man-Years
Monitoring	1763.0	9.4
Prediction	6307.1	31.0
Aquifer Cleanup	853.6	6.7
Hazardous Waste Engineering	9272.0	46.2
TOTALS	18,195.7	93.3

MONITORING

The Environmental Monitoring Systems Laboratory in Las Vegas is conducting ground-water monitoring research to support the Underground Injection Control (UIC) Regulations of the Safe Drinking Water Act and the Ground-Water Protection Regulations of the Resource Conservation and Recovery Act. Spin-off from these programs has established a geophysical technical support program to assist Superfund hazardous waste site investigations. This research may also offer techniques to detect leaks from underground storage tanks.

The program includes research in three primary areas: ground-water monitoring and sampling methods in both the unsaturated and saturated zones, the application of surface and downhole geophysics to subsurface characterization, and data interpretation and analysis. Quality assurance is addressed in all areas.

GROUND-WATER SAMPLING

Research in this area is directed towards the development and evaluation of ground-water sampling and monitoring methods and providing operating guidance to program office, regional office and state agencies. The program includes research in:

- Sources of variance of ground-water data
- The validity and performance of indicator parameters
- Monitoring well construction methods
- Vadose zone monitoring techniques
- Advanced monitoring techniques such as laser fiber optics
- Ground-water flow measurement.

GEOPHYSICS

This program includes research into the geophysical and geochemical detection and mapping of shallow contaminant plumes with both surface-based and downhole methods, the more difficult problem of mapping deeply-buried contaminant plumes associated with injection wells, and the location of abandoned wells.

In the area of surface-based geophysical techniques, research will demonstrate and evaluate geophysical and geochemical methods for detection and mapping of subsurface leachate and ground-water contaminant plumes. In the area of downhole sensing, the research objectives are to survey, develop, test, and evaluate downhole sensors and methods which can be used for hazardous waste site monitoring and for preconstruction hydrogeologic investigations, principally using small-diameter, shallow-depth boreholes. In the area of mapping fluids from injection wells, several techniques are being evaluated for use on deeply buried contaminant plumes. In the area of locating abandoned wells, magnetometers along with aerial photography are being evaluated for locating abandoned wells in the vicinity of proposed new injection wells.

DATA ANALYSIS

Research in this area primarily involves the development and evaluation of statistical methods for data analysis and monitoring network design, including:

- Appropriate applications of elementary statistics
- Improved techniques for probabilistic kriging
- Optimum sample size estimation
- Methods for data presentation.

PREDICTION

The Robert S. Kerr Environmental Research Laboratory (RSKERL) has the responsibility for developing the scientific knowledge of pollutant behavior in the subsurface that permits intelligent management of ground water resources. Management considerations include the ability to identify, evaluate, and control potential sources of ground-water contamination; to assess the risks and impacts associated with emergency spill situations and other contamination events; and to take remedial action in the restoration of ground water quality.

The processes that govern the transport and fate of pollutants in the subsurface can be divided for research purposes into three major areas: (1) hydrologic, (2) abiotic, and (3) biotic. These processes will act to influence the movement of water, the primary vehicle for subsurface pollutant movement; the physical and chemical interactions that will cause pollutants to move at rates different from those of the water; and the decomposition, chemical or microbial, that will transform the pollutants in the subsurface to nontoxic substances. The elucidation of the magnitude of the various mechanisms functioning in the three process areas will ultimately provide the knowledge to integrate the influences of these processes into a singular understanding of pollutant behavior in the subsurface. Research under each of these process areas is organized into a series of tasks focusing on methods development, subsurface characterization, pollutant attenuation, process kinetics, field application and mathematical model development and application.

It must be realized that the division of subsurface processes into three types (i.e., hydrologic, abiotic, biotic) is an arbitrary division primarily for organizational purposes. An effective research program must address the interdependency of and interaction between these processes.

HYDROLOGIC PROCESSES

Research at RSKERL in hydrologic processes is directed in three areas: (1) expanding our understanding of the physics of fluid flow through porous media, (2) developing methodology for evaluating the degree of heterogeneity (spatial variability) both physically and chemically in the subsurface and (3) advancing the mathematical techniques for forecasting the spatial and temporal distibution of chemicals in the subsurface as well as fluid fluxes in the subsurface environment.

During the past two decades, considerable research has been conducted on the movement of water through subsurface porous media. The physics of water flow is reasonably well understood for homogeneous media. Environmental problems, however, must be analyzed where there are many discontinuities in porous media as well as the fluid phases. These discontinuities can result in strong accelerating influences on ground water recharge as well as chemical transport flow counter to the mass movement of the water. Current RSKERL research is trying to improve our understanding of how immiscible fluids will move through porous media and the impact of the immiscible fluids on the physical properties of the porous media.

To analyze the magnitude and importance of spatial variability in the subsurface environment requires: the development of methodology for obtaining unaltered samples of subsurface material for physical, chemical and biological analysis; the evaluation of the impact of spatial variability on the transport processes and chemical and biological reactions; and evaluation of statistical techniques for determining how many samples are required to describe a hydrologic system and where the next sample should be taken to obtain the maximum refinement in an understanding of the overall system. This whole area of research is just beginning to receive RSKERL funding and the full significance to describing and predicting pollutant movement, remains to be defined. The complexity of the subsurface and the difficulty of obtaining representative samples have hindered progress in this area.

There are presently over 400 documented mathematical models describing movement of fluids in the subsurface. These range from very simple analytical solutions compatible with hand-held calculators to highly complex numerical models that require large main-frame computers to operate. The majority of these models are for the movement of water and the transport of chemicals miscible with water. Current activities of RSKERL to advance the capabilities for modeling fluid transport are devoted principally to development of techniques to describe the transport of immiscible fluids. The principal avenue of model information transfer is the International Ground Water Modeling Center (IGWMC) at Butler University. The Center maintains annotated data bases of mathematical models used to simulate fluid movement and contaminant transport, offers hands-on training courses and conducts research to develop benchmark methods for the intercomparison and validation of existing models.

ABIOTIC PROCESSES

The abiotic processes of primary concern to RSKERL are sorption/partitioning and chemical degradation. Emphasis to date has been on enlarging our knowledge of the sorption process. Knowledge of the sorbate, sorbent, and solvent characteristics that affect the rate and degree of sorption will permit refinement of models describing transport and fate of pollutants in the subsurface. Empirical and semi-empirical relationships developed to estimate the sorption of hydrophobic organic pollutants from aqueous solutions onto surface soils and sediments are being evaluated to determine their efficacy for predicting the sorptive interactions of these compounds on deeper subsurface soils and geologic materials. Several investigations have observed that currently available theory and models often fail to describe the sorption of hydrophobic organic solutes on soils having very low organic carbon content or where the clay mineral to organic carbon ratio is very large. Various techniques are being used to determine the relative contributions of mineral and organic soil components. These techniques involve the use of state-of-the-art instrumentation such as Laser Raman and Fourier Transform Infrared spectrometer equipment, and include application of High Pressure Liquid Chromatographic methods for investigating sorption in dynamic, flow-through systems as well as conventional laboratory procedures for measuring sorption in static systems.

Because of the complex nature of many environmental contaminants, it is important to understand the contributions of various phase interactions to the behavior of chemicals in subsurface environments. Interactions which must be considered are sorbate-sorbent, solvent-sorbent, sorbate-sorbate, solvent-solvent, and sorbate-solvent. The sorbate-sorbent interaction, or sorption, has been intensively studied; however, most of the work has been done in relatively simple systems consisting of an aqueous solution of a single solute. Little is known about the influence of solvent or sorbate mixtures on the sorption process. Thus, a major effort of the abiotic research program is to quantify the phase interactions in complex, but realistic, environmental systems; to develop theories to describe sorption in light of these interactions; and to incorporate this knowledge into predictive models.

Another important aspect of the sorption process is the rate at which it occurs. Most chemical transport and fate models in use assume that the sorption process is instantaneous. Laboratory and field experiments have clearly shown the fallacy of this assumption for many solute-soil combinations. Two basic hypotheses have been prepared to explain non-equilibrium sorption in dynamic porous media systems. The first of these is that the kinetics of the reaction are slow relative to the rate of movement of the chemical through the system. The second hypothesis is that the rate of approach to equilibrium is controlled by the diffusion of the sorbate from the solution to the site of adsorption. To date, neither theory adequately describes the observed behavior of many environmentally significant chemicals.

The chemical or abiotic transformation of pollutants is an important process which must be addressed in any comprehensive subsurface transport and fate research program. However, almost no comprehensive studies of chemical transformation processes are currently in progress. Fragmentary information available in this area suggests that hydrolysis, reduction, and possibly nucleophilic substitution are potentially important process es in ground water. Movement of ground water can be extremely slow, therefore, transformations which have half-lives in the order of years may be the most significant attenuating processes in these systems.

The greatest impediment to the study of abiotic transformation is the lack of techniques for adequately measuring the in-situ chemistry of the subsurface. Tools and procedures must be developed for assessing the potential for and measuring the extent of chemical reactions in this remote environment.

BIOTIC PROCESSES

The RSKERL research efforts in the biotic processes category are focused on developing necessary information on subsurface biotic processes to predict the transport, fate, and impact of pollutants in the subsurface and to develop control and remedial technology for ground water quality. Considerable progress has been made in recent years by RSKERL and associated grantees in developing methods for obtaining uncontaminated samples, in developing new techniques and procedures for characterizing subsurface biota, and in developing technology for determining how biological processes affect pollutant transport and fate. However, improvement is needed in all of these areas.

Current information indicates that the deeper subsurface environment is not sterile but harbors significant populations of microorganisms and that there may be considerable spatial variation in these populations both from a qualitative and quantitative standpoint. These conclusions, however, are based on a very limited number of studies and far more information on the distribution, density, and nature of organisms in the subsurface, both above and below the water table, is needed. Future studies should emphasize correlating the occurrence and activities of organisms with the geological and mineralogical properties and the environmental conditions of the subsurface regions where the organisms exist.

At present little is known about biodegradation of organic pollutants in the deeper subsurface. A limited amount of pollutant biodegradation research has been done using the indigenous flora of the subsurface and foreign pollutants; virtually no work has been accomplished in situ. These results have indicated that the potential for significant biodegradation of a number of compounds exists. However, the question remains unanswered as to the degree to which these reactions will proceed in the subsurface. The limitations have not been clearly defined to be either thermodynamic (energy-limited) or kinetic (rate-limited) nor has the extent of adaptation and co-metabolism been investigated in detail. Very little is known concerning degradation byproducts or whether degradation processes can be manipulated.

Little is known concerning environmental conditions in subsurface habitats and the effect such conditions have on biological activity and the biotic transformation of pollutants. Important factors governing the extent and/or nature of biological activity include (1) the concentration and utility of electron acceptors; (2) the concentration and availability of essential nutrients; (3) the oxidation-reduction potential; (4) the pH; (5) the ionic composition; (6) the availability of water; (7) the temperature; (8) the hydrostatic pressure; (9) the nature of the solid phase; and (10) the nature of the pore space. All of the above factors interact with each other to influence the activity of organisms in the subsurface.

Biodegradability and the associated kinetic relationships should be determined prior to development and use of mathematical models for predicting the movement and fate of pollutants in the subsurface environment. Volatilization and sorption should be determined to predict biodegradation, since a mass balance is required. Reaction kinetics should be determined for modeling. Studies are required to determine: (1) the effect of concentration of pollutant on the rate law for transformation; (2) the effect of concentration of pollutant on the density of microbes active against that pollutant; and (3) the correlation between the rate of transformation of the pollutant and the density of viable microbes, or the concentration of some biochemical constituent of the microbes used as an indicator of biomass or nutritional state. Current information is scant.

To use laboratory and field information about subsurface biotic reactions to predict the fate of pollutants requires the development of mathematical submodels that describe the kinetics of biological transformations in the subsurface, and which can be incorporated into more sophisticated mass transport models describing water movement and abiotic attenuation of pollutants.

AQUIFER CLEANUP

RSKERL's research dealing specifically with aquifer restoration supports six inhouse and extramural projects in FY '85. The National Water Well Association is preparing a report, which is due in May 1985, to assist decision makers in dealing with contaminated ground water which is a public water supply. The report will discuss various alternatives available, their cost effectiveness, and the institutional problems associated with the implementation of various options. Lawrence Berkeley Laboratory is developing a report, also due in the spring of 1985, to assist agencies involved in cleanup of contaminated ground water in evaluating "how clean is clean." The report will evaluate the incremental benefits versus incremental costs of cleaning up a waste site. The University of Tennessee is evaluating the feasibility of enhancing the in-situ biological degradation of contaminants in ground water by the use of genetically-engineered organisms. A project with Florida State University is being initiated to study the occurrence and ecology of organisms necessary for the in-situ cleanup of contaminated aquifers. An inhouse project at RSKERL is underway to evaluate the use of simulated aquifers for developing in-situ biological cleanup methods for such contaminants as nitrates and synthetic chemicals. A major inhouse and extramural effort is underway at RSKERL and Stanford University to develop an in-situ biological process for restoration of ground water contaminated with trichloroethylene and related organic compounds.

HAZARDOUS WASTE ENGINEERING

A major source of ground-water pollution is the disposal of hazardous waste. The Hazardous Waste Engineering Research Laboratory (HWERL) in Cincinnatti, Ohio has two programmatic areas that support research and development of hazardous waste source control. The first program is in support of the Resource Conservation and Recovery Act (RCRA) and is concerned with the disposal of hazardous waste in landfills, surface impoundments, and other geologic storage facilities. The second program is in support of the Comprehensive Environmental Response, Compensation and Liability Act (Superfund) and is concerned with the development of technology for the cleanup of uncontrolled hazardous waste sites.

LAND DISPOSAL

The hazardous waste land disposal research program is collecting data necessary to support implementation of disposal guidelines mandated by the Resource Conservation and Recovery Act of 1976 (RCRA), PL 94-580. This program relating to landfills, surface impoundments, and geologic storage encompasses state-of-the-art documents, laboratory analysis, economic assessment, bench and pilot studies, and full-scale field verification studies. The results of this research are reported as Technical Resource Documents (TRD's) in support of the RCRA Guidance Documents. These documents will be used to provide guidance for conducting the review and evaluation of land disposal permit applications. The work can be divided into the following areas: (1) Landfills: cover systems, waste leaching, liners, and waste modification; (2) Surface Impoundments: assessment of design and containment systems; (3) Geologic Storage, e.g., underground mines and salt domes.

Landfills

Cover Systems--The objective of this activity is to develop and evaluate the effectiveness of various cover systems in relation to their functional requirements for actual field application. Validation efforts are being performed in the laboratory and field with model work development being pursued for eventual incorporation into a TRD.

Waste Leaching--The objective of this activity is to develop and evaluate laboratory techniques for working with a sample of a waste or a mixture of wastes to predict the composition of actual leachates obtained under field conditions. Results from laboratory and model predictions are being compared with results from pilot scale and field scale work to develop better procedures and an updated TRD on waste leaching.

Clay Soil Liners--The objective of this activity is to evaluate the effectiveness of clay soils as liners and surface caps to contain or minimize leachate movement and infiltration and to predict performance with time. Laboratory and field studies are being performed to develop tools for predicting and evaluating performance of soil liners.

Flexible Membrane Liners--The objective of this activity is to evaluate the effectiveness of synthetic membranes or flexible membranes as liners and caps to contain leachates/moisture infiltration and to predict their performance with time. Both laboratory and field efforts are developing tools to establish flexible membrane liner performance criteria.

Waste Modification--The objective of this activity is to evaluate the effectiveness of chemical stabilization and encapsulation processes relating to improving handling; reducing surface area; limiting solubility; detoxifying pollutants; and predicting performance with time. Validation efforts in the laboratory and field will correlate compatibility of the individual processes to specific waste types and predict durability and leaching performance with time. Information produced will be published in a TRD.

Surface Impoundments

The surface impoundment research program has been developed to provide a comprehensive understanding of the design, operation, and maintenance of surface impoundments as options for hazardous waste disposal. Information is being developed on the use of natural soils as liners and dikes. Also, the correlation of laboratory measurements with the construction standards achievable in the field is being investigated. Of particular interest is the degree to which specification of construction techniques and inspection practice can influence uniformity and performance of the finished impoundment.

Geologic Storage

The objective of this activity is to update the state-of-the-art technology on the use of underground mines for emplacement of hazardous waste. Efforts are being pursued both by literature review and planned field demonstration. An evaluation of other geologic storage options are also being investigated, e.g., salt domes.

UNCONTROLLED SITE CLEANUP

The Land Pollution Control Division (LPCD), HWERL, has the responsibility for the control development program in support of Superfund. The LPCD research and development program has been organized to correspond with the Superfund legislation, i.e., the Releases Control Branch deals with removal actions (emergencies), and the Containment Branch deals with remedial actions. The program is one of technology development and asessment to determine cost and effectiveness, adaptation of technologies to the uncontrolled waste site problem, field evaluation of technologies that show promise, development of guidance material for the EPA Office of Emergency and Remedial Response (OERR), technical assistance to OERR, and EPA Regional Offices.

Removal (Emergency) Action

This program has been divided into three major areas of activity: (1) Personnel Health and Safety; (2) Evaluation of Equipment; and (3) Chemical Countermeasures. The goal of the personnel health and safety activity is to develop protective equipment and procedures for personnel working on land or underwater in environments which are known or suspected to be immediately dangerous to life or health, so that personnel can conduct operations related to investigating, monitoring, or cleaning up hazardous substances.

The goal of the equipment evaluation activity is to modify, adapt, and field test hazardous substances spill control equipment for appropriate utilization for removal action at uncontrolled dump sites. Examples of this equipment are the mobile incinerator, modular transportable incinerator, carbon regenerator, and soils washer.

The goal of the chemical countermeasures activity is to evaluate the efficiency of in-situ physical/chemical/biological treatment of large volumes of subsurface soils and large relatively quiescent waterbodies for the purpose of controlling the hazardous contaminants within those media. Technical criteria for the use of chemicals and other additives to control hazardous release situations are being developed.

Remedial Action

This program is designed to assist the Office of Emergency and Remedial Response, Regional Offices, States, and industry to meet the challenge of protecting the public from the environmental effects of uncontrolled hazardous waste sites. The major emphasis of the program is to take "off-the-shelf" technology and adapt it to the uncontrolled hazardous waste site situation. Many existing technologies, such as those used in the construction industry, wastewater treatment, and spill cleanup, can be applied to uncontrolled waste sites. However, their application must be tested, cost and effectiveness determined, and limitations understood so that they may be effectively and economically utilized. It is a major function of this program to evaluate these techniques and combine them into cost-effective remedial actions for the various situations found at uncontrolled waste sites.

This program has been divided into four areas of activity: (1) Survey and Assessment of Current Technologies; (2) Laboratory and Site Design Analysis; (3) Field Evaluation and Verification of Techniques; and (4) Technical Handbooks.

Survey and Assessment of Current Technologies--The goal of this activity is to review and evaluate the effectiveness of remedial action long-term control techniques that are being used and have been used to contain pollutants at uncontrolled hazardous waste sites. Analyses include defining the site specific problem, determining the problems associated with implementing the techniques, determining the effectiveness, and identifying costs. This activity also includes the development and use of models.

Laboratory and Site Design Analysis--The goal of this activity is to perform laboratory studies to simulate field conditions and evaluate the adequacy of adapting the lab control technology schemes to actual field conditions.

Field Evaluation and Verification of Techniques--The goal of this activity is to field test control technology techniques that look very promising and/or test the technique being installed to determine performance with time and to validate promising control techniques being developed by lab and pilot studies.

SUMMARY OF FEDERAL AGENCY, ELECTRIC POWER RESEARCH INSTITUTE AND AMERICAN PETROLEUM INSTITUTE GROUND WATER RESEARCH PROGRAMS

(Prepared by Dr. James Davidson)

Although no Federal laws and few state laws have ground water contamination as their major focus, there are many Federal and State statutes that can control or mitigate ground water contamination. The legal framework for Federal agencies to protect ground water is a group of statutes aimed primarily at other environmental problems that focus indirectly on ground water. Because of this lack of focus and the diversity of sources for ground water contamination, numerous Federal and state agencies are involved in ground water research. Agencies which support ground water research internally and/or extramurally are as follows:

Environmental Protection Agency

Most ground water research programs in the Environmental Protection Agency are under the responsibility of the Office of Research and Development. Funds to support this program come from the Safe Drinking Water Act (SDWA) of 1974 and the Resource Conservation and Recovery Act (RCRA) of 1976. Two internal research committees advise the Office of Research and Development (ORD) regarding ground water research needs. These committees are (i) the Hazardous Waste Research Committee and (ii) the Water Research Committee. The Office of Research and Development directs programs in fourteen laboratories and at several field stations. In addition to designing a research program to satisfy multiple client needs, ORD works with other Federal agencies concerned with ground water. A Memorandum of Understanding between EPA and the US Geological Survey (USGS) was established in August 1981, and provides an umbrella under which the agencies programs are formally coordinated. EPA also conducts joint research projects with several other agencies, including the US Air Force, the US Department of Energy, and the National Research Council.

EPA laboratories with major responsibilities in the area of ground water quality are the Environmental Monitoring Systems Laboratory-Las Vegas (EMSL), the Robert S. Kerr Environmental Research Laboratory-Ada (RSKERL), and the Hazardous Waste Engineering Research Laboratory-Cincinnati (HWERL). Resources dedicated to research underway in these laboratories are as follows:

Research Area	Total Dollars (in 1000's)*	Man-Years
Monitoring	1,763.0	9.4
Prediction	6,307.1	31
Aquifer Cleanup or Restoration	853.6	6.7
Hazardous Waste Engineering	9,272.0	46.2
Totals	18,195.7	93.3

The Environmental Monitoring Systems Laboratory (EMSL) conducts ground water monitoring research to support the underground injection control regulations for the Safe Drinking Water Act and the Ground Water Protection Regulation of the Resource Conservation and Recovery Act. Spin-off from these programs has established geophysical technical support to assist Superfund hazardous waste site investigations. This research also offers techniques to detect leaks from underground storage tanks. The program supports research in three primary areas: ground water monitoring and sampling methods in both unsaturated and saturated zones, application of surface and downhole geophysics for subsurface characterization and data interpretation and analysis. Quality assurance is addressed in all areas.

The Robert S. Kerr Environmental Research Laboratory (RSKERL) has the responsibility for conducting investigations to provide technical information for those ground water issues which are addressed in a number of environmental laws. Management considerations include the ability to identify, evaluate, and control potential sources of ground water contamination; assess the risk and impacts associated with emergency spill situations and other contamination events; and to take remedial action in the restoration of ground water quality. Research at RSKERL in hydrologic processes is directed toward three areas: (i) expanding the understanding of the physics of fluid flow through porous media, (ii) developing methodology for evaluating the degree of heterogeneity (spatial variability) both physically and chemically in the subsurface and (iii) advancing the techniques for forecasting the spatial and temporal distribution of chemicals in the subsurface as well as fluid fluxes in the subsurface environment. Land treatment as a source reduction technique also is studied at RSKERL.

The Hazardous Waste Engineering Research Laboratory (HWERL) has two programmatic areas that support research and development of hazardous waste source control. The first program is in the support of Resource Conservation and Recovery Act (RCRA) and is concerned with the disposal of hazardous waste in landfills, surface impoundments, and other geological storage facilities; alternatives to land disposal are also developed. The second program is in the support of the Comprehensive Environmental Response, Compensation and Liability Act (Superfund) and is concerned with the development of technology for the cleanup of uncontrolled hazardous waste sites.

In addition to the in-house programs conducted in the above three laboratories, EPA also provides extramural support for research programs outside the Agency. Among these is the National Center for Ground Water Research, a consortium between Oklahoma University, Oklahoma State University and Rice University. In addition to the National Ground Water Center, numerous grants and contracts support research in other universities. Some pertinent work is done at ERL-Athens, e.g. hydrolysis, adsorption, etc..

US Geological Survey

Ground water activities in the U.S. Geological Survey (USGS) are multidisciplinary in nature and are related to many program elements in the Environmental Protection Agency. Ground water activities include geology, hydraulics, water chemistry, hydrology, biology, geochemistry, and ground water/surface water interactions. In FY 1984 the total amount of funding available to the Water Resources Division was approximately $225 million (including appropriated funds, reimbursable funds, and matching funds from the States) -- of this amount approximately $90 million was expended for the collection of ground water quantity, and to a lesser extent, quality, data and for conducting ground water investigations. USGS Programs are intended to improve the understanding of the hydrologic, geologic, geochemical and microbiologic processes that control the movement, alteration and fate of toxic substances in ground water. These programs receive approximately $8.5 million to support basic and applied research in the preceeding areas. The dollars are used for both in-house and extramural funding.

US Department of Agriculture

The current water quality research commitment in the Agricultural Research Service (ARS) exceeds $6 million, but about ninety percent is devoted to the development of techniques for assessing and enhancing the quality of surface water. The current ARS Program on ground water quality can be described under four major categories: (i) nutrients; (ii) pesticides; (iii) salinity; and (iv) modeling. Recent progress in ground water quality is based on advances in agricultural chemical technology and soil water chemistry in eight areas: (i) efficiency of use; (ii) integrated pest management; (iii) improved chemical disposal practices; (iv) environmental modeling., (v) soil chemistry; (vi) salinity; (vii) nutrients., and (viii) process models. ARS has proposed a plan to expand their ground water quality research. The plan involves an estimated increase of 25 man-years at a cost of $5 million annually.

The Cooperative State Research Service (CSRS) involves the State Agricultural Experiment Stations at Land-Grant Universities in the United States. This program has approximately 250 projects with a ground water research emphasis. These projects are primarily concerned with water and contaminant transport in the unsaturated zone and the modeling of these processes. Approximately $1.75 million in state, Hatch and grant funds are spent for ground water research.

US Department of Energy

The US Department of Energy (DOE) is conducting a major ground water research program. They are spending approximately $20 million per year on source control, $20 million per year on aquifer clean up and $10 million per year on monitoring. Objectives of the program are to provide a base of fundamental scientific information so that the geochemical, hydrological and biophysical mechanisms that contribute to the transport and long-term fate of energy-related contaminants in natural systems can be understood and described. Areas of emphasis include the understanding of geochemical processes and transport of energy-related organic compounds and mixtures in the subsurface environment. A proposed ten year program to develop a "new generation" prediction model is being studied by the agency. The program involves the application of supercomputers, laboratory/university consortia and control field-scale experiments. This program proposal has been reviewed by the National Research Council's Ground Water Committee and their recommendations returned to the Department of Energy for consideration.

US Air Force

The major thrust of this program is to develop methods for predicting the impact of various Air Force activities including the fate of solvents, waste disposal and accidental spills which may result in ground water contamination. Delineation of the extent and impacts of dioxin contamination resulting primarily from the use, storage, and disposal of agent orange is also a major thrust. Procedures for the restoration of ground water quality are also being investigated. Topics under investigation include sorption and degradation of trichloroethylene (TCE), other chlorinated compounds, and aromatic hydrocarbons in subsurface environments, assessment of heavy metal mobility at several Air Force bases, incineration of dioxin-contaminated soils, feasibility of applied genetic engineering techniques to achieve dioxin biodegradation, and evaluation of methods to enhance in situ biodegradation of TCE and other organic compounds in contaminated soils and ground water.

US Army

The objective of this program is to develop cost-effective pollution control monitoring systems, provide environmental and health effects data on Army-unique pollutants, and promote efficient management of environmental quality programs through the development of management systems and information data bases. Areas receiving emphasis include: (i) treatment methods for ground water and soil contamination; (ii) environmental early warning systems; (iii) landfill leachate control methods; (iv) hazardous waste management techniques., and (v) advanced technology for contaminant control/cleanup.

Tennessee Valley Authority

The objectives in this program are to provide the information and tools needed for assessing the significance of potential pollutant sources, preventing contamination and isolating the sources of contamination. Ongoing activities include the assessment of potential problems resulting from the disposal of power plant wastes, development and demonstration of methods for disposal or utilization of fly ash, flue gas desulfurization/sludge, coal cleaning waste and fluidized bed combustion waste and development of a comprehensive data base and management method for land application of waste water treatment sludge.

Electric Power Research Institute

The Electric Power Research Institute (EPRI) initiated the Solid Waste Environmental Studies (SWES) program in order to assist in the development of data and methods for predicting the fate of constituents in solid waste at utility disposal sites. The ultimate goal of the SWES project is to improve (develop) and validate geohydrochemical models for predicting the release, transport, transformation and environmental fate of chemicals associated with utility solid waste. The goals of the SWES project are divided into near-term and long-term objectives.

American Petroleum Institute

Research related to ground water largely concerns cleanup of immiscible liquids in the subsurface.

Summary

In addition to the above programs there are numerous research programs underway in state and private universities. These programs are funded by Federal, state and private agencies or companies, and frequently work cooperatively with the above agencies as well as independently. In general, the quality of this research is excellent and is addressing major issues surrounding the potential for ground water contamination and the cleanup of ground water. The area which does not appear to be receiving appropriate attention is the transfer of this technology into the user community whether that be state or private.

A summary of the research areas or topics being studied in federal agencies is provided in the following table:

FEDERAL AGENCY GROUND-WATER RESEARCH PROGRAMS
RESEARCH AREAS

AGENCY	SOURCE CONTROL	PREDICTION	MONITORING	CLEANUP
US Department of Agriculture	X	X	X	
US Army	X			X
US Air Force	X	X	X	X
US Department of Energy	X	X	X	
US Geological Survey		X	X	
US Environmental Protection Agency	X	X	X	X
Tennessee Valley Authority	X	X	X	

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