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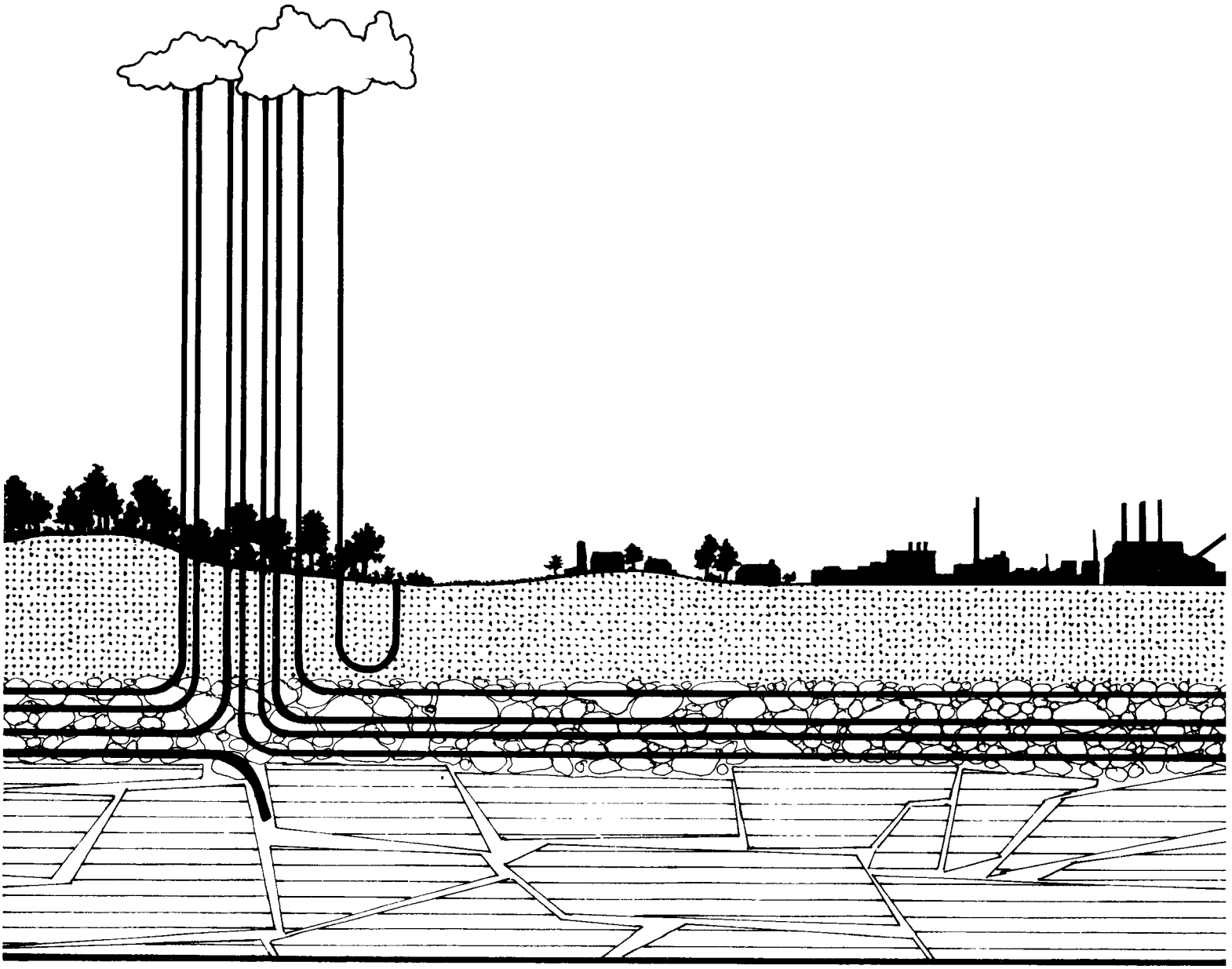
Research Program Description

Ground-Water Research



Ground-Water Research

Program Description and Plans

Prepared for the

Office of Research and Development
Office of Environmental Engineering and Technology Demonstration
U.S. Environmental Protection Agency
Washington, D.C. 20460

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NOTICE

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PREFACE

This plan describes the ground-water research program conducted by EPA's Office of Research and Development (ORD). The research program is carried out by the Offices of Environmental Processes and Effects Research (OEPER), Acid Deposition, Environmental Monitoring and Quality Assurance (OADEMQA), Environmental Engineering and Technology Demonstration (OEETD), and Exploratory Research (OER). Of the 16 ORD laboratories, four have lead responsibilities and base budgets in ground water: Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma; Environmental Research Laboratory in Athens, Georgia; Environmental Monitoring Systems Laboratory in Las Vegas, Nevada; and Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio.

The overall program is coordinated by the ORD Matrix Manager for Ground-Water Research. The current matrix manager is John Skinner, Director of the Office of Environmental Engineering and Technology Demonstration.

Five of the six functional areas within the ground-water research program are covered in this plan: monitoring, fate and transport, aquifer reclamation, source control, and technology transfer and technical assistance. Health effects research of drinking water exposure, conducted by laboratories in Research Triangle Park, North Carolina and Cincinnati, Ohio, is not specific to ground water and is treated elsewhere.

Base funding for ground-water research comes from Budget Subactivities D109 (Hazardous Waste), Y105 (Superfund), C104 (Drinking Water), and E104 (Pesticides). Appendix A in this plan lists the associated planned program activities (PPAs).

Further information may be obtained by contacting the directors of the following ORD facilities:

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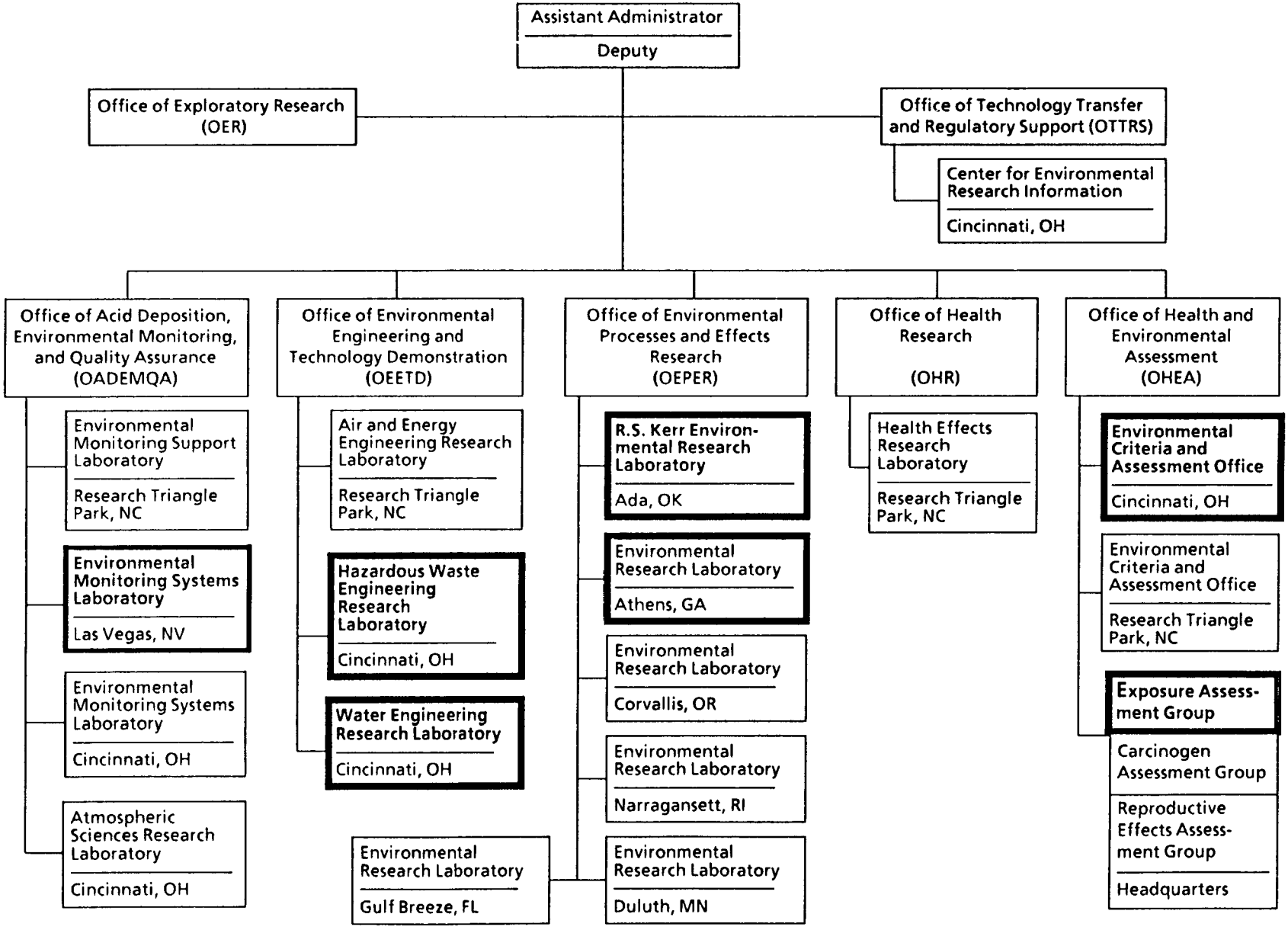
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. Environmental Protection Agency



INTRODUCTION

Ground water is a vital natural resource in the United States, supplying about 25% of all fresh water used. Over 50% of the American public--117 million people--obtain all or part of their drinking water from ground water, and 95% of rural Americans depend on it. As recently as 10 years ago, ground water was generally considered a pristine resource: pure and ever-available. It was used, and sometimes abused, without being fully understood. In the 1970s, synthetic organic chemicals were discovered in ground-water-supplied drinking water sources in several states. Currently, 40 states have documented instances of serious ground-water contamination.

Background

While EPA has no single authority under which it is charged to protect ground water, virtually every major piece of legislation that governs the Agency's mission addresses the need to protect ground water, including the Clean Water Act (CWA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), the Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the Toxic Substances Control Act, together with their amendments. However, this broad spectrum of statutory authority within the Agency also contributed to a fragmentation of ground-water issues, priorities, and regulations.

As a result of a growing concern among Congress and top managers within EPA, the Office of Ground-Water Protection established a comprehensive, agencywide Ground-Water Protection Strategy in 1984. The main tenets of the strategy are:

- Short-term buildup of institutions at the state level.

- Assessment of problems that may exist from unaddressed sources of contamination--in particular, leaking underground storage tanks, surface impoundments, and landfills.

- Guidelines for EPA decisions affecting ground-water protection and cleanup. EPA's ground-water strategy classifies aquifers on the basis of use or potential use, with drinking-water supplies afforded the most stringent protection.

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

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

EPA Ground-water research reflects the diverse priorities among eight program office clients (Drinking Water, Ground-Water Protection, Solid Waste, Emergency and Remedial Response, Waste Programs Enforcement, Underground Storage Tanks, Toxic Substances, Pesticide Programs), ten Regions, and a number of cross-media offices and task forces. The overall research program is guided by a complex relationship involving three research committees (Water, Solid Waste and Superfund, Pesticides), four Office of Research and Development (ORD) offices (Atmospheric Deposition, Environmental Monitoring, and Quality Assurance; Environmental Processes and Effects Research; Environmental Engineering and Technology Demonstration; Exploratory Research), and four lead laboratories (Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma [RSKERL-Ada]; Environmental Research Laboratory in Athens, Georgia [ERL-Athens]; Environmental Monitoring Systems Laboratory in Las Vegas, Nevada [EMSL-LV]; and Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio [HWERL-Cin]).

The research program is divided into six functional areas, reflecting the primary concerns of the client offices:

- **Monitoring.** The placement and spacing of monitoring wells, together with acceptable procedures for sample collection and preservation and quality assurance and quality control procedures (QA/QC), is a fundamental requirement for credible decisions on ground-water protection. ORD's monitoring research program is developing, evaluating, and adapting geochemical and geophysical monitoring techniques to meet the

needs of EPA and the regulated community; evaluating existing site characterization methods for improved monitoring well network design; and refining existing methods and developing new procedures for data reduction and interpretation. The lead laboratory in monitoring research is EMSL-LV.

■ **Source Control.** A major source of ground-water contamination is the improper disposal of hazardous wastes. Contamination may occur from such sources as landfills, surface impoundments, or injection wells. ORD's research program in source control addresses all aspects of the technology and operational strategies associated with reducing the risk of contamination by treating or containing wastes--component development and evaluation; system design and construction; removal actions; and remedial actions. The lead laboratory for source control research is HWERL-Cin.

■ **Fate and Transport.** Predicting contaminant behavior in the subsurface is one of the most difficult--and important--tasks for ground-water protection programs. EPA's research into transport and fate phenomena and prediction considers both the physical movement of ground water in the unsaturated and saturated zones and the change in ground-water quality through natural or enhanced degradation or differential separation of constituents. The lead laboratories involved in fate and transport research are ERL-Athens and RSKERL-Ada.

■ **Aquifer Reclamation.** Restoring a polluted aquifer is generally an extremely expensive process, if it can be done at all. Until a range of inexpensive, effective cleanup methods is developed, managers who must decide whether to restore an aquifer face a series of difficult decisions. ORD's reclamation research is examining ways to make restoration techniques less expensive, and assessing case histories of reclamation efforts to identify factors contributing to their success or failure. RSKERL-Ada is the lead laboratory in this area.

■ **Health Effects.** The major route of exposure to ground-water contaminants is through drinking water; illness attributed to ground-water contamination accounts for 28% of all reported waterborne diseases. While not specific to ground water, research on the health effects of particular pollutants is very important to the ability of decisionmakers to establish credible drinking-water standards and to demonstrate to the public that the standards are based on sound data. ORD's drinking-water health-effects research program emphasizes the effects of exposure to contaminants found in drinking-water supplies. Since health effects caused by contaminant exposure are the same regardless of the pathway, research on health effects is not addressed separately for ground water, and is not considered further in this plan.

■ **Technical Assistance and Technology Transfer.** To be effective, research results must target and be disseminated to operational personnel, program managers, and decisionmakers in a timely manner. Field personnel in EPA Regions, states, and local government agencies must deal with an extremely broad and complex range of data and information, and deserve close support from scientists and engineers in ORD laboratories. While there is no ORD technical assistance line item specific to ground water, ground-water issues are becoming a major focus of technical requests from client offices. ORD's lead in technology transfer is the Center for Environmental Research Information (CERI), although all laboratories routinely conduct technology transfer and offer technical assistance.

■ **Treatment Technology.** Information on treatment technologies is also being developed by the drinking water research program. This program provides attainability and cost data on the available technologies. It is focused on removal of volatile and non-volatile organics, inorganics, metals, and microbes. ORD is supporting the pending revision of the National Drinking Water Standards, but this is not a formal part of the ground-water research program and will not be further discussed. The Water Engineering Research Laboratory (WERL) is the lead laboratory in this program.

Research Needs

Responding in part to a recommendation of the Science Advisory Board, the Assistant Administrator for Research and Development created a matrix manager for ground-water research early in 1986, whose responsibility included cross-office, cross-research-committee coordination among competing priorities. The matrix manager chaired two landmark meetings (October 8, 1986, and March 27, 1987) in which representatives from all program offices with ground-water concerns and a number of Regions

participated. These meetings focused on program office priorities and cross-media research communications in monitoring research, fate and transport, and aquifer reclamation. The meetings also considered earlier recommendations of the Science Advisory Board's July, 1985, review of the ground-water research program and Hazardous Waste Ground-Water Task Force (January, 1986) recommendations. The outcome of this process was a consolidated, ranked list of program priorities in each area of ground-water research, which formed the basis for present ORD directions in ground water.

In between these meetings, program office and ORD technical specialists and managers participated in presentations of the fate and transport and aquifer reclamation programs (Ada, Oklahoma) and monitoring program (Las Vegas, Nevada) to review research priorities and outputs, and to recommend to the full Committee where research focus should be adjusted.

PROGRAM OVERVIEW

EPA's ground-water research program is divided among five major areas, each with a number of projects: monitoring, fate and transport, aquifer reclamation, source control, and technology transfer and technical assistance. The program has base funding in four budget subactivities and 29 separate planned program activities (PPAs). The FY87 research budget consists of over $30 million and 130 work years. About 30% of the FY87 budget is in monitoring, 47% is in fate and transport and aquifer reclamation, and 23% is in source control.

Structure and Areas of Emphasis

As a result of continuing coordination between ORD and the program offices, a series of high priority research areas receive greatest attention. Past research has emphasized transport and fate phenomena, but recent recommendations from the Science Advisory Board, the Hazardous Waste Ground-Water Task Force, and the ground-water coordinating committee have resulted in a gradual increase in monitoring and QA/QC. Source control activities, once dominated by research into land covers and landfill liners, are moving more towards supporting the underground storage tank, underground injection control, and Superfund programs. Fate and transport research continues to emphasize the development and validation of mathematical models to accurately predict subsurface flow and the physiochemical interaction between the contaminants and the aquifer. Aquifer reclamation research, closely tied to the fate and transport work, is concentrating on biodegradation.

Monitoring

To make good decisions on well placement, sampling frequency, and placement of monitoring devices in the unsaturated zone, a site must be sufficiently characterized in terms of its hydrological, meteorological, geological, hydrogeochemical, biological, and demographic data. The information collected during site characterization is used to design adequate environmental monitoring networks and to evaluate existing or proposed waste management engineering designs to assure the protection of human health and the environment. In the monitoring area, there are six priority research areas:

- Develop methods for extracting samples of ground water that are truly representative of the source; samples with less loss or chemical conversion and less cross-contamination; and statistically valid sampling and analytical methods.

- Develop methods and guidance on site characterization, to include such methods as aquifer testing, core sampling, and collection and interpretation of existing information.

- Demonstrate the application of site characterization information for determining sampling frequency and monitoring well network design.

- Evaluate and provide guidance on techniques for monitoring in the vadose zone that can provide early warning of leaking contaminants.

- Establish a list of critical indicator parameters that will provide reliable and cost-effective indication of ground-water contamination, specifically to detect leakage from hazardous waste disposal facilities, over-application of pesticides, leachate migration from municipal solid waste landfills, and other potential sources of aquifer contamination.

- Evaluate and improve existing methods for the collection and analysis of hydrogeologic information at the sampling point.

In addition, an initiative has been proposed to

determine the range of agricultural chemicals in surface waters and develop appropriate ground-water monitoring strategies based on critical areas susceptible to contamination. This initiative is being coordinated with the Office of Pesticide Programs.

Fate and Transport

The fate and transport research priorities are:

- Develop methods and models to predict the change in pollutant behavior in ground water due to physical and chemical processes, such as sorption, hydrolysis, reduction, precipitation, and volatilization.

- Determine how biological processes affect the fate and transport of organic substances in the subsurface environment through biodegradation.

- Develop methods to improve the prediction of three-dimensional flow of contaminants in ground water.

- Develop standardized models for evaluating and predicting releases from hazardous waste disposal sites, and the fate and transport of constituents through the unsaturated zone.

Aquifer Reclamation

Aquifer reclamation research is often intertwined with fate and transport research; research is conducted by the same laboratories often in joint projects. Its priority is to evaluate and develop cost-effective methods for *in situ* aquifer cleanup, including biodegradation.

Source Control

Source control (engineering) research focuses on technologies to reduce risk by containing or treating wastes and contaminants at the surface. The priorities include:

- Develop underground injection controls (lead laboratory is RSKERL-Ada).

- Develop and evaluate tank leak detection devices and tank testing equipment.

- Evaluate, improve, and field-verify land-disposal containment systems, such as landfill covers and flexible membrane and soil liners for landfills and surface impoundments.

- Evaluate technologies for treating wastes to reduce toxicity and leachability.

Technology Transfer and Technical Assistance

Information dissemination is a key element in the research program. While technology transfer and technical assistance is an integral part of all laboratory activities, the priority is to develop timely and effective methods of transferring technical information to appropriate federal, state, local, and general public organizations through publications, workshops, training courses, and other communication mechanisms.

Strategy to Meet Needs

Not unexpectedly, ground-water technical information needs are often common to more than one of the five primary program office clients (Solid Waste, Superfund, Drinking Water, Ground-Water Protection, Pesticides). In practice, research activities must be attributed to specific budget elements, even though the results have broader applicability. For planning purposes, and to eliminate overlap and redundancy, the research priorities discussed above are grouped according to budget element. In FY88, the ORD RCRA budget in ground-water research (D109) is $15.5 million; Superfund (Y105) is $6.6 million; Drinking Water (C104) is $5.9 million; and Pesticides (E104) is $0.95 million.

The following sections summarize the major research needs, by functional area, of the Program and Regional Offices and states.

Monitoring

Hazardous Waste (RCRA)

1. Develop and evaluate ground-water monitoring methods and strategies for RCRA hazardous waste sites and to satisfy the RCRA land disposal regulations.

- Develop statistically valid sampling and analytical methods.

- Develop methodologies and guidance on well spacing and sampling depths that will result in accurate interception of contaminant plumes.

- Develop guidance on proper sampling frequency for ground-water monitoring, considering

seasonal and spatial variables.

- Evaluate and provide guidance on different techniques for monitoring the unsaturated zone that could provide early warning of leaking contaminants.

- Establish a short list of parameters that will provide a reliable indication of ground-water contamination.

- Develop improved methods that provide better or lower cost hydrogeologic information using geophysical and borehole logging techniques.
- Develop a monitoring quality assurance program to determine performance criteria for monitoring equipment; test protocols for equipment; set procedures for equipment use; and perform field audits based on protocols.

2. Develop methods for external leak detection at underground storage tank sites.

- Establish network designs for placement of leak detectors around tanks for vapor and ground-water monitoring.

- Develop guidelines for data analysis to determine when a system is leaking.

- Establish performance tests for external petroleum leak detection devices.

Superfund (CERCLA/SARA)

3. Provide monitoring techniques and procedures for Superfund site and situation assessments.

- Develop remote sensing methods for analysis of present and historical site operations and conditions.

- Evaluate the role of geographical information systems in the remedial investigation/feasibility study process for the storage, analysis, and presentation of site information.

- Develop application of near-surface seismic reflection technology to hazardous waste sites.

- Produce practical guidance on aquifer test analysis.

4. Provide technical support on Superfund settlement agreements, especially to enforcement programs in Regions and states.

- Conduct sampling and analytical quality assurance.

- Review monitoring plans, QA/QC materials, ground-water sampling and network designs.

- Conduct on-site laboratory reviews for the Contract Laboratory Program.

5. Develop and evaluate new field-monitoring techniques and systems that are rapid, inexpensive, and more sensitive.

- Develop new screening methods for single compounds or for classes of compounds using immunoassays.

- Accelerate the development of emerging field-portable systems, such as fiber-optic sensors.

Drinking Water (SDWA)

6. Provide the scientific data base and methods for regulatory, enforcement, and management decisions concerning protection of ground-water resources.

- Develop methods for extracting representative samples of ground water with an emphasis on minimizing sampling error.

- Assess the utility of geophysical methods to determine movement of contaminants from underground injection wells.

- Develop *in situ* monitoring methods for detecting contaminants from leaking injection wells.

- Develop monitoring strategies for wellhead protection areas.

7. Develop uniform standards, policy, and guidance for collecting and storing ground-water data, including standard record formats.

- Determine key data that must be collected and stored by EPA.

- Provide a user-friendly environment for users of STORET and other data bases.

- Develop guidance in the use of analytical tools for the manipulation of ground-water-related data, including geographic information

systems.

Fate and Transport

Hazardous Waste (RCRA/HSWA)

1. Provide field-evaluated methods and data to predict concentrations of waste organic and metal constituents that escape or are released into the subsurface environment from the treatment, storage, or disposal of hazardous wastes.

- Investigate important processes such as dispersion, sorption, complexation, speciation, biodegradation, hydrolysis, volatilization, and clay alterations that govern the transport rates, transformations, and fates of hazardous waste constituents in the subsurface.
- Evaluate, and demonstrate through field experiments, available mathematical models that describe solute transport in the subsurface.
- Provide assistance to the Office of Solid Waste on decision models and to permit writers on ACL determinations.

2. Provide integrated (multimedia) methods and data for implementing the RCRA Land Disposal Banning Rule, including the waiver process, and for evaluating waste management and treatment needs based on potential health and environmental impacts.

- Develop screening level and more site-specific multimedia exposure-assessment models for organic pollutants and heavy metals.
- Develop probabilistic techniques to address uncertainty.
- Produce a manual for the Office of Solid Waste on the Organics Multimedia Human Exposure model.
- Study the kinetics of sorption, desorption, and other dominant speciation reactions of metals in subsurface environments.

3. Provide techniques and data to predict the rate and extent of movement and transformation of 2,3,7,8-tetrachlorodibenzene-P-dioxin in soils and ground water.

Superfund (CERCLA/SARA)

4. Evaluate abilities of natural and engineered microorganisms to biodegrade hazardous substances in support of Superfund remedial actions.

- Evaluate naturally occurring and improved microorganisms for ground-water and soil cleanup.
- Develop methods for application of biodegradation organisms and evaluate their potential ecological risk.

Drinking Water (SDWA)

5. Develop methods to predict subsurface contaminant concentrations to support risk analysis and source control.

- Identify characteristics of chemicals (or pathogens) that have similar transport behavior, and characteristics of subsurface materials, to predict pollutant impact in specific locations.
- Determine physical and chemical processes affecting dispersion.
- Predict microbial contaminant concentrations.
- Predict biotransformation of subsurface contaminants.
- Determine subsurface microbial activity.

6. Develop methods to determine the effects of underground injection, and develop safer injection technologies to support underground injection control.

- Develop methods for determining the mechanical integrity of injection wells.
- Assess the impact of Class I wells on subsurface geological materials.
- Assess the effectiveness of drilling mud as a plugging agent in abandoned oil or gas wells.
- Produce a report on Class V injection-well practices in the United States.

7. Evaluate models and management strategies in support of state wellhead-protection programs mandated by SDWA.

- Develop methods for wellhead protection.
- Assess ground-water models for wellhead protection area (WHPA) delineation.

Pesticides (FIFRA)

8. Determine how pesticides contaminate ground water and identify the processes involved and those remedial actions necessary to alleviate the problem.

- Characterize pesticide processes in soils and ground water.
- Determine spatial variability in subsurface soils.
- Investigate leaching factors controlling contamination and explore agricultural management practices that could help prevent percolation to ground water.
- Assess methods and models at field scale to ensure integrity and the incorporation of appropriate management practices.

9. Develop information and techniques, including mathematical models, on pesticide transport, degradation, residuals, and fate for Agency use and provide direct technical support and guidance to OPP.

- Develop information on such parameters as sorption kinetics in sediments, abiotic pesticide transformations, and volatility.
- Study mechanisms and rates of degradation by natural microbial organisms.
- Develop comprehensive, linked unsaturated-saturated zone models and exposure concentration estimates.

Aquifer Reclamation

Drinking Water (SDWA)

Develop new methods for *in situ* aquifer restoration and provide cost and feasibility data to support corrective action decisions.

- Study laboratory and field evaluations of methods for *in situ* aquifer restoration.
- Assess microbial response to aquifer contamination and reactivation.

Source Control

Hazardous Waste (RCRA/HSWA)

1. Develop and field-verify improved design, operation, and closure procedures for hazardous and nonhazardous landfills, surface impoundments, waste piles, and underground storage facilities used to contain wastes and reduce the risk of contaminant migration to ground water.

- Continue design studies on cover systems, single and composite soil/flexible membrane liner systems, leak detection, and waste solidification and stabilization.
- Develop expert systems to provide consistent, cost-effective approaches to evaluating RCRA permits.
- Produce updated Technical Resource Documents for Office of Solid Waste on cover systems, modeling, waste solidification/stabilization, construction, operation, and closure of hazardous waste management facilities.

2. Identify and evaluate improved practices to prevent releases from new/existing underground storage tanks and detect and measure leak rates from underground storage tanks and associated piping.

3. Demonstrate new or improved approaches for stopping releases from a leaking tank system and preventing associated environmental damages.

4. Determine the applicability and cost-effectiveness of *in situ* reclamation techniques to unsaturated-zone and ground-water contamination resulting from leaking underground storage tanks and other hazardous waste sources.

- Provide guidance on corrective actions.
- Evaluate leak detection methods.
- Develop improved techniques for *in situ* cleanup of contaminated ground water.

5. Develop a comprehensive technical data base on new and existing technologies for land treatment of hazardous wastes for which incineration or land disposal are inappropriate.

Superfund (CERCLA/SARA)

6. Provide response technologies to support cleanup actions for contaminated ground water and soils.

- Evaluate on-site and *in situ* treatment processes from pilot- through full-scale field tests.

7. Provide engineering support for site and situation assessments of ground-water resources at uncontrolled hazardous waste sites.

Technology Transfer and Technical Assistance

Hazardous Waste (RCRA/HSWA)

1. Develop more timely and effective methods for transferring technical information to appropriate federal, state, local, and general public organizations through publications, workshops, training courses, and other communications mechanisms.

Superfund (CERCLA/SARA)

2. Provide best available technical evidence, testimony, and information to Regions, states, and the Department of Justice.

- Establish a clearinghouse for information on ground-water remedial action technologies.

- Establish a ground-water technology transfer center for training Superfund Regional staff and to serve as an information clearinghouse.

Drinking Water (SDWA)

3. Develop and transfer improved methods for measuring subsurface parameters that influence contaminant behavior.

- Maintain a clearinghouse for ground-water models and a national library for ground-water information.

- Develop procedures on selecting sampling methods for determining oxygen concentration in the saturated and unsaturated zones.

- Develop and disseminate improved methods for sampling subsurface microbial populations.

Other Research and Development Programs

The Exposure Assessment Group (EAG), part of ORD's Office of Health and Environmental Assessment, conducts a research program to develop means to predict human exposure risks from hazardous materials. EAG's multimedia exposure assessment activities are assisting the Superfund office and EPA's Regions in the selection of appropriate ground-water models and in evaluating remedial and regulatory alternatives to clean up contaminated ground water. Current activities that are related to ground water are:

- Characterization of contaminant dispersion in ground water using data from recent field experiments to develop a realistic approach to modeling dispersive transport in exposure assessments.

- Criteria for the selection of mathematical models that can be applied to exposure assessments. Use of the criteria will help eliminate the use of inappropriate models for estimating contaminant migration in ground water.

- A technical support document to help select ground-water fate and transport models for quick assessments as well as for detailed analyses.

- Experimental studies to investigate the migration characteristics of concentrated organics in ground water for use in developing two-phase transport models.

Relationship to Other R&D Activities

In addition to the obvious need to coordinate research programs within the Agency, EPA scientists in all involved laboratories are working with counterparts in other federal agencies, universities, and professional and trade associations, such as the American Society for Testing and Materials and the Electric Power Research Institute.

The greatest federal ground-water research effort is managed by the U.S. Geological Survey (USGS), Department of the Interior. EPA and USGS signed a Memorandum of Understanding (MOU) in August, 1981, providing an umbrella under which each agency's programs are coordinated. A second MOU was signed in June, 1985, to coordinate ground-water data collection and technical assistance. In addition, EPA and USGS regularly exchange visiting scientists and participate in each other's technical meetings on ground-water. RSKERL-Ada has a cooperative

agreement with the Department of Agriculture to develop geostatistical methods for reducing variance in data by properly locating sampling wells at ground-water contamination sites. EPA is also conducting joint ground-water research projects with the U.S. Air Force, U.S. Army, U.S. Coast Guard, U.S. Navy, Nuclear Regulatory Commission, Department of Energy, National Research Council, and the Tennessee Valley Authority.

EPA is a major sponsor of the International Ground Water Modeling Center (IGWMC) at Butler University in Indianapolis, Indiana, the National Center for Ground-Water Research (NCGWR), and the National Ground Water Information Center (NGWIC) at the National Water Well Association in Dublin, Ohio.

The IGWMC is a clearinghouse for technical information on the exchange and use of mathematical models and software, offers regular short courses and seminars, and carries out a research program supporting the Center's technology transfer and educational activities in ground-water subjects. The two major tasks of the clearinghouse are the dissemination of information regarding ground-water model selection and application and the distribution and support of modeling software. IGWMC produces a periodic newsletter.

EPA established the NCGWR in 1979 as a consortium of Rice University, Oklahoma State University, and the University of Oklahoma. Part of EPA's Centers of Excellence Program, NCGWR is charged with developing and conducting a long-range exploratory research program to help anticipate and solve emerging ground water problems. Base funding is provided by EPA's Office of Exploratory Research. The major areas of responsibility for NCGWR are: (1) development of methods for ground-water quality investigations; (2) transport and fate of subsurface pollutants; (4) characterization of the subsurface environment with respect to pollutant transport; and (4) technology transfer.

The NGWIC houses a computerized ground-water information base that can be accessed by subscription. The data base, comprised of about 120 technical and trade journals and newsletters from around the world, is constantly updated by qualified specialists in ground-water development, quality, monitoring and protection, restoration, law, and water-well technology. Over 50,000 citations are now in the data base, with about 500 new items added per month.

The Center for Exposure Assessment Modeling was established at the Environmental Research Laboratory-Athens in 1987. The Center facilitates state-of-the-art model applications to ground-water (and other) threat assessments and remedial action evaluations involving organic and metallic hazardous wastes and pesticides.

PROGRAM DIRECTION

The ground-water research program supports the regulatory and enforcement objectives of the various statutes that EPA administers. In addition, ORD and the Program Offices identify emerging or potential issues that, while not directly mandated by statute, require basic developmental or evaluative research in order to position the Agency for the future or to anticipate future Congressional action.

Current Program

The ground-water research program is organized into five functional areas, excluding health effects: monitoring; fate and transport; source control; aquifer reclamation; and technology transfer and technical assistance. The Program Overview section established the objectives and structure of the overall ground-water research program within this framework based upon regulatory and enforcement needs among the client offices. The FY87-FY89 ground-water research budgets are itemized by PPA in Appendix A.

Expected accomplishments, which include work supported from earlier years and new activities are shown in Appendix B, which represents the best estimates for FY87 and FY88; the resources for FY89 have been expanded to reflect some of the anticipated resources stemming from the reauthorizations of Superfund, SDWA, and HSWA.

Future Program

Although the research program is designed primarily to respond to current and specific Agency requirements, a number of identified or emerging priorities should be expanded or accelerated. Future research activities span monitoring, fate and transport, source control, and technology transfer and technical training.

Monitoring

Research concerning RCRA Subtitle D facilities is critical to the success of numerous state and local agencies' ground-water management programs. In proposed revisions to the solid waste disposal criteria under Subtitle D, owners and operators would be encouraged to characterize their own sites. However, states need guidance to characterize the spatial variability of the subsurface directly beneath and around the site.

Consistent and comprehensive implementation of the proposed revisions will require considerable guidance and technology transfer to the owners, operators, permit applicants, and state and local regulatory personnel. Some of this would be done through the development of guidance documents and expert systems.

Research for Subtitle D facilities will focus on the special monitoring needs of wet environments, where subsurface flows differ considerably from dryer areas. This research will entail surface water and biota monitoring. Other Subtitle D research will include evaluating and developing fracture trace and lineament analysis of aerial photographs for site characterization and developing ground-water monitoring strategies for facilities in karst terrains.

Recent amendments to the Safe Drinking Water Act include the establishment of wellhead protection areas to protect the quality of subsurface drinking water supplies. Research will focus on developing monitoring strategies for wellhead protection areas.

New and continuing monitoring research under Superfund will be supported through the Advanced Field Monitoring Methods Program. This has been established to address the need for rapid, low-cost field methods to support hazardous waste site monitoring and characterization activities anticipated under SARA. Specific program objectives and organization are discussed in the management plan.

Fate and Transport

Information necessary to understand subsurface contaminant behavior subsurface can be divided into three categories: aqueous phase transport; facilitated transport; and complex wastes.

In aqueous phase transport it is important that the roles of such things as organic carbon, *E*h, *p*H, and solubility be understood. There is still much to be understood before adequate predictive capabilities can be developed and relied upon.

Facilitated transport is a newly recognized phenomenon and consequently there is much to be done. It is now believed that many of the questions in this area can be grouped into flow through macropores and fractures, water miscible solvents, and transport on dissolved organic carbon. Particular attention is directed toward transport by sorption on suspended particles and micelles.

The newest area of research, with respect to contaminant transport, concerns complex wastes. Although some work has been done, this is proving to be an important area, particularly with respect to waste sites. The residual saturation of the immiscible phase, its effect on sorption, and methods for its removal are of greatest interest in this area. In addition, considerable work is required concerning the weathering and compositional changes of the wastes.

The processes driving transformation of subsurface contaminants can essentially be considered abiotic or biotic. In abiotic transformations, there is a need to develop methods for measuring Eh and *p*H in the subsurface as well as an understanding of the effect of these parameters on process kinetics. Mineral surface catalysis is another area requiring further research.

Research in biotic transformations must deal with developing a better understanding on the native microbial population particularly with respect to density, activity, and distribution. In addition, work is required on the effects of the contaminant on the microbial community as well as degradability when dealing with complex wastes.

There continues to be a great need to conduct research in the abiotic processes area. The general effects of Eh and pH need further investigation; in fact, methods for making these measurements in situ need to be further developed. In addition, mineral surface catalysis investigations are required in terms of contaminant transformations.

Subsurface pesticide transport is governed by

the same processes that control all of solute transport. However, due to the diversity and complex structures of many pesticides compared to solvent and hydrocarbon wastes, complex interactions may arise that affect pesticide transport. Since protection of ground water from agricultural chemicals is a major concern, additional research is needed to understand the fate of pesticides and nitrates in the saturated and unsaturated zones.

Aquifer Reclamation

Although all of the research discussed above under *Fate and Transport* applies equally to aquifer reclamation, there are additional research needs specific to this remediation technology. From the standpoint of hydrogeology, the effects of low and variable permeability must be understood along with proper well placement and pumping rates in order to maximize the efficiency of pumping.

A great deal of research needs remain with respect to the kinetics of sorption and desorption. In this regard, special attention must be given to problems associated with the residual saturation of the immiscible phase. Obviously, to make the pump and treat option of aquifer remediation more promising, it will be necessary to develop means of enhanced desorption including the use of water miscible solvents and surfactants.

Considerable work remains in the research, development, and demonstration of enhanced *in situ* contaminant degradation--both abiotic and biotic. Abiotic processes involved the investigation of free radical generation and hydrogen peroxide oxidations. It is also important to continue research into the amendment of biotic systems using (for example) the addition of alkanes and hydrogen peroxide. These investigations must include the development of methods which allow an estimation of the demand of the amendment chemicals; ways to determine the effects of these chemicals and enhanced processes on aquifer characteristics; and develop methods to efficiently deliver the amendment chemicals to the aquifer and properly monitor the system.

Source Control

As states address ground-water contamination problems, more information on control technologies is needed to define the feasibility and cost-effectiveness of protection and cleanup methods.

Research on full-scale application of *in situ* treatment methods for aquifer remediation must be accelerated.

Technology Transfer and Training

As new research tools and methods are developed, programs that transfer this information must be expanded, coordinated, and upgraded to offer the newest computer-assisted technologies.

Training needs to be further emphasized, and deserves a stable budget. EPA regional and state personnel experience a significant turnover rate, and new staff must have the opportunity to become familiar with new technologies, policies, and practices. States will need to have their personnel trained in many developing aspects of ground-water management and protection.

EMSL-LV, in conjunction with the Office of Emergency and Remedial Response, is establishing a Superfund Ground-Water Technology Transfer Center to collect and disseminate information, provide on-site instruction, and offer an technical assistance hotline. The first year's effort (FY88) will develop the courses, to be taught by EMSL-LV staff augmented by experts from other federal agencies and the private sector. The first year will also include plans for a monitoring clearinghouse and the technical assistance hotline.

REVIEWS AND PUBLICATIONS

Scientific and Technical Reviews

The Science Advisory Board issued a comprehensive review of EPA's ground-water research program in July, 1985. Among its major recommendations were the creation of a strong central direction for the research effort, greatly increased resources for training and technology transfer, proactive research on ground-water contamination sources not addressed by specific mandates, and expedited ground-water sampling and analytical methods and QA/QC. Increases or initiatives were also recommended in specific ground-water research areas: monitoring; basic transport and fate; containment techniques; remedial methods in fractured geologic formations; and identification of suitable geologic environments for isolating hazardous wastes in injection wells.

As a component of their overall evaluation of the RCRA Subpart F Ground-Water Monitoring Program submitted to the Assistant Administrator for Solid Waste and Emergency Response in January, 1986, the Hazardous Waste Ground-Water Task Force considered technical problems in ground-water monitoring technology. They identified six technological gaps: (1) insufficient understanding of the behavior of individual contaminants and contaminant classes, and no defined sampling strategy for each class; (2) uncertainties about plume dispersion as a basis for horizontal spacing, screen depth, and length; (3) identification of sampling equipment and techniques best suited for specific hydrologic settings or monitoring purpose; (4) estimation of the effect of interactive sample-contact surfaces on the monitoring data; (5) selection of key indicators for contaminant classes according to geological setting; and (6) establishment of analytic methods for certain hazardous constituents.

As a result of the October, 1986, meeting sponsored by EPA's ground-water research matrix manager, three technical reviews were held on Monitoring Research and Fate and Transport and Aquifer Reclamation Research. The panels consisted of representatives from each of the interested Program Offices (OSWER, OW, OPTS), together with several regions. Technical specialists from ORD laboratories discussed the scientific results of the ongoing research in context of the programmatic, regulatory, and enforcement priorities of the client offices.

The fate and transport and aquifer reclamation panel (Ada, OK, December 9-10, 1986) emphasized the need for guidance on how to determine vulnerable aquifers factoring in transport mechanisms and modeling; use of chemical and biological fate and transport processes in developing and modeling closure standards; and where to set ACLs for hazardous waste sites. The Regions identified strong needs for "Best Management Practices" for the use of agricultural chemicals that consider ground-water protection, especially linking transport and fate of ground-water pollutants with field application practices, and for improved methods to predict ground-water transport in fractured rock. Other priorities that emerged included guidance on fate and transport mechanisms incorporating biotransformation and biodegradation of contaminants, types of models that should be used to define wellhead area, predict multiple-source, multiple-contaminant pollutant transport, and differential transport.

The monitoring panels (Las Vegas, NV, December 16-17, 1986 and Atlanta, GA, February 18-19, 1987) recognized a pressing need for standard methods and guidance in saturated zone monitoring and sampling protocols; well spacing, construction and installation; well-completion depths; and sampling frequency. They noted that, while guidance exists for unsaturated zone monitoring, the number of installations and the regulatory emphasis are greater in the saturated zone for which no guidance exists.

In November, 1986, the Ground-Water Monitoring Research Program at EMSL-LV underwent peer review. The peer panel report, issued in January, 1987, identified virtually the same technical issues stressed by the monitoring group of Program Office and Regional technical specialists.

Each year, ORD laboratories host technical program reviews in concert with the budget cycle. The FY87 hazardous waste/Superfund laboratory reviews were at EMSL-LV (including EMSL-RTP and EMSL-Cin) on March 18-19 for monitoring, HWERL (including CERI) on April 20 for control technologies and technology transfer, and at Headquarters for the RSKERL-Ada, ERL-Athens, and exploratory research programs on April 16-17.

Publications and Presentations

The EPA ground-water research program has produced major reports and technical assistance documents for nearly 20 years. In March, 1987, ORD produced the *Technical Assistance Directory for Ground Water Research* (EPA/600/9-87/008) that includes an annotated bibliography of 68 essential references for permitting or other regulatory personnel involved in ground-water protection and treatment. The references are organized into seven functional categories.

Appendix C lists reports from the last three years that were produced under the EPA ground-water research program. EPA scientists and engineers have made frequent presentations at professional meetings and EPA symposia, and extramural investigators additionally have made numerous presentations and produced several hundred additional publications.

Appendix A. ORD Ground-Water Research Budget

Program Elements PPAs	FY 1987 FTE	FY 1987 S&E	FY 1987 R&D	FY 1988 FTE	FY 1988 S&E	FY 1988 R&D
Monitoring System & Quality Assurance (OADEMQA)						
HW 112: Evaluate/Validate Methods (EMSL-LV)	1.5	90.0	300.0	1.5	90.0	300.0
HW 115: Field Methods of Subsurface Monitoring (EMSL-LV)	9.8	806.0	2,916.0	9.8	971.0	2,436.7
HW R62: UST Leak Monitoring (EMSL-LV)	3.2	204.6	1,152.8	3.5	323.0	1,060.5
Subtotal	14.5	1,100.6	4,368.8	14.8	1,384.0	3,797.2
SF A04: Site & Situation Assessment (EMSL-LV)	5.0	425.7	999.0	5.0	470.5	1,555.7
SF F06: Technical Support/Geophysical Survey (EMSL-LV)	3.2	272.4	1,073.9	3.1	291.7	1,211.0
Subtotal	8.2	698.1	2,072.9	8.1	762.2	2,766.7
GW F81: GW-DW Quality Assurance (EMSL-LV)	5.2	166.3	800.1	4.7	274.6	524.5
Subtotal	5.2	166.3	800.1	4.7	274.6	524.5
OADEMQA Subtotal	27.9	1,965.0	7,241.8	27.6	2,420.8	7,088.4
Environmental Processes & Effects (OEPER)						
HW C25: Prediction of Env. Concern of Haz. Waste (Ada)	18.0	958.9	1,922.4	23.3	1,532.5	2,295.7
HW C28: Land Disp. Ban Assess/Eval. Other Mgmt. Sys. (Ath)	10.8	569.5	2,538.0	13.7	735.5	2,444.0
HW D54: Mvmt. & Persist. Dioxin in Soil & GW (Ada/Ath)	1.6	86.9	212.8	1.6	86.5	110.0
HW L44: Land Treatment of Hazardous Waste (Ada)	5.3	287.8	480.2	--	--	--
HW R64: UST Correct. Action Models/Biodegradation (Ada)	2.7	147.3	201.4	2.4	129.8	106.1
Subtotal	38.4	2,050.4	5,354.8	41.0	2,484.3	4,955.8
SF B02: Subsurface Biodegradation (Ada/GB)	1.0	64.0	100.0	1.0	84.1	250.0
SF F22: Enforcement & Technical Support (Ada)	3.4	217.6	706.0	3.4	286.0	700.0
Subtotal	4.4	281.6	806.0	4.4	370.1	950.0
GW F82: Methods for GW Investigation (Ada)	2.0	95.0	600.0	1.1	55.7	350.0
GW F83: Prediction of Contaminant Concentrations (Ada)	13.3	604.8	1,063.9	14.0	735.1	1,264.1
GW F84: In-Situ Aquifer Restoration (Ada)	5.0	306.0	900.0	5.0	253.2	900.0
GW F87: GW Research with China (Ada)		105.0	20.0	0.0	105.0	20.0
GW F88: Support UIC Reg. & Implementation (Ada)	4.0	200.7	730.0	4.0	202.6	730.0
GW F89: Wellhead Protection (Ada)	2.5	150.0	160.0	2.5	126.6	160.0
Subtotal	26.8	1,461.5	3,473.9	26.6	1,478.2	3,424.1
PE D07: Validate Predictive Techniques (Ath/HQ)	3.0	189.4	600.0	3 0	152.1	455.0
PE D08: Predictive Techn. for Environ. Exposure (Ath)	2.6	164.3	--	3.5	177.7	--
Subtotal	5.6	353.7	600.0	6.5	329.8	455.0
OEPER Subtotal	75.2	4,147.2	10,234.7	78.5	4,662.4	9,784.9
Environ. Engineering & Technology Demonstration (OEETD)						
HW A41: Waste Modification (One-Third) (HWERL)	0.0	0.0	200.0	0.0	0.0	200.0
HW L42: HW Land Disposal (One-Half) (HWERL)	10.4	447.7	596.9	3.5	200.9	148.6
HW L45: Subtitle D (One-Half) (HWERL)	1.5	76.3	290.0	1.5	76.5	350.0
HW R63: Prevent & Control Leaking USTs (HWERL)	9.0	510.6	2,103.1	10.0	621.8	1,301.2
Subtotal	20.9	1,034.6	3,190.0	15.0	899.2	1,999.8
SF B01: Control Technology Evaluation (HWERL)	6.1	423.1	1,666.7	5 4	407.0	1,333.3
Subtotal	6.1	423.1	1,666.7	5 4	407.0	1,333.3
OEETD Subtotal	27.0	1,457.7	4,856.7	20.4	1,306.2	3,333.1

Appendix A. (Continued)

Program Elements PPAs	FY 1987 FTE	FY 1987 S&E	FY 1987 R&D	FY 1988 FTE	FY 1988 S&E	FY 1988 R&D
Exploratory Research (OER)						
Research Center			650.0			540.0
OER Subtotal	0.0	0.0	650.0	0.0	0.0	540.0
Hazardous Waste Total	73 8	4,185.6	12,913.6	70 8	4,767 5	10,752 8
Superfund Total	18.7	1,402.8	4,545.6	17.9	1,539 3	5,050.0
Ground Water (DW) Total	32.0	1,627.8	4,274.0	31.3	1,752.8	3,948.6
Pesticides Total	5.6	353.7	600 0	6.5	329.8	455.0
University Center Total	0.0	0.0	650 0	0 0	0 0	540.0
Grand Total	130 1	7,569.9	22,983.2	126.5	8,389.4	20,746.4

APPENDIX B. SUMMARY OF OUTPUTS FROM GROUND-WATER RESEARCH PROJECTS
(R&D Resources in Thousands)

	FY87	FY88	Outyear
Monitoring			
Hazardous Waste (RCRA)			
Develop and evaluate ground-water monitoring methods and strategies for RCRA hazardous waste sites and to satisfy RCRA Land Disposal Regulations (PPA I15, I16).	$3,216.0	$2,736.7	$2,736.7
Internal Report--Bibliography of Ground-Water Sampling Methods.	09/87		
Internal Report--Ground-Water Sampling Chart.		02/88	
Internal Report--Results of First Field Testing of Eight Ground-Water Sampling Methods.	06/87		
Project Report on Field Comparison of Six Ground-Water Sampling Methods at Hazardous Waste Sites.			10/89
Journal Article on Protocol for Testing Ground-Water Samplers.			07/90
Project Report on Nature and Hydrologic Significance of Fracture Trace and Lineament Related Structures with Application to the Design and Placement of Ground-Water Monitoring Wells.		07/88	
Internal Report on Monitoring Strategies for Subtitle D Facilities located in Karst Terrains.		09/88	
Internal Report on the Comparison of Water Samples from Side-by-Side, Teflon-, PVC-, and Stainless-Steel-Cased Wells.		12/88	
Project Report on the Optimization of Sampling Frequency at Hazardous Waste Sites.		06/88	
Journal Article on Conceptual Design of Adaptive Monitoring Strategies.	10/86		
Journal Article on a Comparison of Ground-Water Monitoring Data from CERCLA and RCRA Sites.	12/86		
Journal Article on Results of Testing the Volatile Organic Scan as an Indicator Parameter.		12/87	
Journal Article on Organic Contamination of Ground Water near Hazardous Waste Disposal Sites: A Synoptic Overview.	06/87		
Internal Report on Evaluation of Control Chart Methodologies for RCRA Waste Sites.		01/88	
Project Report on Geostatistics for Ground-Water Monitoring.			12/88
Project Report on Multi-Dimensional Kriging.		12/87	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
User's Guide on Monitoring Statistics.			12/89
Internal Report on a Case Study on Soil Gas Sampling Field Testing.		12/87	
Internal Report on Performance Evaluation of Interpolation Methods.			12/88
Project Report on Feasibility of Using Control Chart Strategies for Detecting Trends in Ground-Water Pollutants.			12/88
Develop methods for external leak detection at underground storage tank sites (PPA R62).	$1,152.8	$1,060.5	$1,060.5
Technical Report on Available Methods for Detecting Underground Storage Tank Leaks.	06/87		
Technical Report on Soil Gas Sensing for Detecting and Mapping Volatile Organic Compounds.	03/87		
Guidance Manual for Network Design of External Leak Detection Systems.		09/88	
Results of Long-Term Monitoring at Three UST Sites.			12/88
Computer Modeling of Vapor Phase Movement in Relation to UST Leak Detection.		02/88	
Report on Results of Real World Data Collection at UST Sites.		04/88	
Report on Commercial External Leak Detection Devices.		03/88	
Performance Test Procedures for Out-of-Tank Leak Detection Systems.		09/88	
Internal Report on Indirect Pore-Liquid Vadose Zone Monitoring Equipment: Standardized Testing Procedures and Performance Standards.		01/88	
Superfund (CERCLA/SARA)			
Provide monitoring techniques and procedures for Superfund site and situation assessments (PPA A04).	$999.0	$1,555.7	$1,555.7
Provide technical support on Superfund settlement agreements, especially to enforcement programs in Regions and states (PPA F06).	$1,073.9	$1,211.0	$1,211.0
Develop and evaluate new field-monitoring techniques and systems that are rapid, inexpensive, and more sensitive (PPA H03, S01).			
Project Report on Application of Borehole Geophysics to Waste Site Monitoring.			10/89

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Conference Proceedings Article on Hydrologic Interpretation of Borehole Geophysical Data.		07/88	
Internal Report on Field Validation Study for the Fiber Optics Sensor.	09/87		
Internal Report on *In Situ* Monitoring at Superfund Sites with Fiber Optics. II. Plan for Development.			11/87
Journal Article on Fiber Optics Systems Development for *In Situ* Monitoring.		06/88	
Internal Report on Development and Demonstration of Immunoassay Detection System for Rapid Screening at Superfund Sites.		10/87	
Internal Performance Report on Field Test of Martin Marietta Portable X-ray Fluorescence (XRF) Unit.		04/88	
Internal Report on Comparison of Commercially Available and Prototype Portable XRF Systems for Hazardous Waste Investigations.		06/88	
Internal Report on Methods for XRF Field Analysis and Sample Preparation.			03/89
Project Report on Portable XRF for Characterization of Hazardous Waste Sites.			12/89
Drinking Water (SDWA)			
Provide the scientific data base and methods for regulatory, enforcement, and management decisions concerning protection of ground-water resources (PPA F81).	$800.1	$524.5	$524.5
Journal Article on Drilling and Constructing Monitoring Wells with Hollow-Stem Augers.	06/87		
Project Report on Handbook of Suggested Practices for the Design and Installation of Ground-Water Wells.			10/88
Project Report on Fiber Optics for Monitoring Ground-Water Contaminants.		12/87	
Use of Geophysical Methods to Determine the Movement of Contaminants from UIC Class I Injection Wells.			12/88
Journal Article on the Design of a Monitoring-Well Network for Investigation of Seasonal Variability of Ground-Water Contamination.			03/88

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Fate and transport			
Hazardous Waste			
Provide field-evaluated methods and data to predict the concentrations of wastes that escape or are released into the environment from the treatment, storage, and disposal of hazardous wastes (PPA C25).	$1,922.4	$2,295.7	$2,295.7
Report on Evaluation of Land Treatability Decision Models.			3/89
Report on Impact of Sensitive RITZ Model Parameters.		5/88	
Interim Report (Internal) - Predictive Models for Describing Fate of Residual Organics in Contaminated Soils.			12/88
Final Report (Internal) - Predictive Models for Describing Fate of Residual Organics in Contaminated Soils.			12/90
Article on Comparison of Steady-State Solutions for Transport of Contaminants in Leaky Aquifers.			10/88
Report on Reliability of Ground-Water Solute Transport Models and Applications of Stochastic Theories.		3/88	
Internal Report on the Feasibility of a Ground-Water Database Clearinghouse.		11/87	
Report on characterization of Physical Aquifer Models.			11/88
Article on Nitrate Contamination Studies.			5/90
Report on Implementation of a Ground-Water Database Clearinghouse.			11/88
Internal Report on Issues Related to Field Application of Ground-Water Models.	8/87		
Briefing on Issues Related to Field Application of Ground-Water Models.	8/87		
Report on Validation of Existing Saturated and Unsaturated Contaminant Transport Models.		1/88	
Report on Field Validation of Solute Transport Model for Prediction of Waste Concentration in Ground Water.			10/88
Report on the Use of Ground-Water Models for Regulatory Purposes.			6/89
Article on Developed Solutions to Second Order Transformations Including Advection and Dispersion Terms.			10/89
Report on Use of Microcosms for Transport and Fate Parameters.	10/86		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on Factors Affecting the Mobility of Trace and Toxic Metals in Ground-Water and Subsurface Soils.	5/87		
Report on Subsurface Characteristics Contributing to Heavy Metal Contamination of Ground-Water at Hazardous Waste Sites.		4/88	
Article Describing Mechanisms of Multiphase Transport.	6/87		
Report on Immiscible Flow Processes.		10/87	
Publication on Immiscible Chemical Transport.	10/86		
Article on Facilitated Transport of Contaminants in a Sandy Soil Column with Dissolved Organic Materials.	10/86		
Article on Influence of Miscible Solvents on Leaching of Hydrophobic Organics.	6/87		
Article on Transport of Hydrophobic Organic Chemicals in Multi-Solvent Systems.			12/90
Article on Leaching of Soluble Aromatics from Fuel-Contaminated Aquifer.	4/87		
Article on Toluene Mobility in Fuel-Contaminated Aquifer Material.		10/87	
Report on Criteria for Selection of Potential Field Sites.	11/86		
Report on Determining Hydrologic Properties of Subsurface Environments.			12/89
Report on the Feasibility of Conducting Large Scale Field Experiments.	12/86		
Report on Characterization of Spatial Variability of Hydrologic Properties in a Coastal Aquifer.		4/88	
Report on Techniques for Handling Spatial Variability of the Physical, Chemical, and Biological Properties of Subsurface Environments.			12/89
Report on Demonstration Project.	6/87		
Report on Computer Graphics Demonstration of DRASTIC.		10/87	
Report on Land Treatability of Listed Hazardous Wastes--Volume I.		12/87	
Report on Land Treatability of PCP and Creosote Wastes.			1/89
Report on Land Treatability of Listed Hazardous Wastes--Volume II.		9/88	
Report on Land Treatability of Listed Hazardous Wastes--Volume III.		9/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
User Friendly Program for Land Treatment Decision Models.	11/87		
Report on Field Evaluation of RITZ Model.			12/88
Report on Fate and Transport of Residual Matrix Constituents in Soil.			9/89
Report on Case Studies for Selected Subtitle D Wastes.			7/89
Provide integrated, multimedia methods and data for implementing the land disposal banning rule, including the waiver process. Evaluate waste management and treatment needs based on potential human health and environmental impacts (PPA C28).	$2,538.0	$2,444.0	$2,444.0
Journal Article on Use of Standard Reference Compounds in Transformation Rate Constants Measurements.	3/87		
Third Report on Hydrolysis Rate Constants for Land Banning Decision Rule.		4/88	
Third Report on Partition Coefficients for Land Banning Decision Rule.		4/88	
Second Report on Hydrolysis Rate Constants for Land Banning Decision Rule.	5/87		
Second Report on Partition Coefficients for Land Banning Decision Rule.	5/87		
Interim Protocol for Measurement of Hydrolysis Rate Constants.		3/88	
Third Report on Partition Coefficients for Land Disposal Assessment.		4/88	
Report on Hydrolysis Rate Constants for Enhancing Property-Reactivity Correlations.			6/89
Interim Protocol for Measuring Microbial Transformation Rate Constants for Suspended Populations.		11/87	
Report on Microbial Transformation Rate Constants for Suspended Populations.		12/87	
Report on Correlation of Molecular Spectroscopic Properties with Microbial Transformation Rates.		5/88	
Journal Article on Preclusion of Microbial Transformations of Pollutants by High Pollutant Concentrations.		3/88	
Report on Criteria for Evaluating the Reliability of Literature Data on Environmental Process Constants.	7/87		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on Effectiveness of Literature Evaluation Techniques for Chemical Hydrolysis Rate Constants.			3/89
Journal Article Describing Metal-Microbial Interactions: Role of Microbial Species and Life Stage on Metals Sorption.			12/88
Journal Article on Distribution Coefficients for Sorption of Metal Complexed by Soils, Sediments, and Aquifer Materials.		7/88	
Report on Distribution Coefficients of Metals Sorbed to Aquifer Substrates.	1/87		
Interim Report to OSW Describing Mathematical Formalism of Initial Sorption Model to be Employed for Adding Metal Sorption Capability to the OSW Transport Model.	2/87		
Interim Report to OSW Including Summarized Input Data for Use in Implementing the Initial Sorption Model in Re-Listing Scenarios to be Proposed for November 1987.	9/87		
Final Report on Mathematical Form of Proposed Sorption Model Incorporating Revisions Due to the Availability of New Data and Results of Public Comments.			12/89
Final Report on Input Data Distributions for Implementing the Sorption Model in OSW Rule-Making Scenarios.			12/89
Development of First-Pass Generic Leachate Recipe and Compilation of MINTEQ Formatted Thermodynamic Database Using Readily Available Data.		10/87	
Interim Report on Preliminary Leachate Analyses and Proposed List of Compounds for Detailed Analysis of Equilibrium Constants.			6/89
Final Report of Formatted Database of Equilibrium Constants for Reactions of all 13 OSW Metals with Compounds in the Generic Mixture with Complexing Ability.			6/90
Report on Analyses for Part I: Analytical Data Report to OSW.		12/87	
Report on Interpretation of Test Results for Part III: Mixture-specific MINTEQ Datasets for OSW.			2/88
Final Report on MINTEQ Bench Scale Testing.			12/88
Journal Article on Feasibility of Predicting Metal Distribution Coefficients on Humic and Microbial Surfaces.			5/89
Report on Prediction of Sorption Based on Chemical Behavior and Distribution of Metal Reactive Phases.		7/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Journal Article on Kinetics of Sorption and Desorption of Metals in Subsurface Environments.			7/89
Journal Article Describing Metal Sorption on Mineral Surfaces.		9/87	
Internal Report on Metal Interactions with Humic Materials.		2/88	
Internal Report on Metal Interactions with Metal Surfaces.		2/88	
Journal Article on Tested Model for Predicting Metal Distribution Coefficients in Environmental Samples.			10/89
Journal Article Describing Role of Competitive Ion Character on Metal Speciation.		9/88	
Journal Article Describing Kinetics of Complexation Phenomenon for Metals in Aqueous Systems.			7/89
Report on Computer Simulation of Metal Speciation in Presence of Naturally Occurring Organics.		10/87	
Journal Article Defining Specific Complexation/Chelation Sites in Humic and Fulvic Substances.			3/89
Report on Laser Spectrometry Applied to Metal-Organic Speciation in Water.	12/86		
Report on Metal Binding to Humic-Fulvic Materials.	8/87		
Internal Report on Speciation and Fate of Toxic Metals in Aquatic Environments.		6/88	
Journal Article on Microbial Transformation Kinetics of High Concentrations of Hazardous Chemicals.	4/87		
Journal Article on Predicting the Rate of Trace Organic Compound Removal by Natural Biofilms.	12/86		
Report on Environmental Factors Affecting Anaerobic Biodegradation.		6/88	
Internal Report on Protocol for Obtaining Microbiological Transformation Rate Data for Chemicals in the Soil Subsurface.	1/87		
Journal Article on Implications of Multiphasic Kinetics for Predictive Models.		1/88	
Journal Article on Preclusion of Microbial Transformation of Pollutants by Higher Concentrations of the Pollutants.		3/88	
Journal Article on Environmental Factors Affecting Microbial Transformation Rates of Pollutants.	8/87		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Journal Article on Aerobic Biodegradation of Complex Organic Mixtures.	4/87		
Report on Equations for Predicting Anaerobic Transformations Within the Saturated Zones.			11/89
Testing and Evaluation of OTS-SESOIL Model.	3/87		
Users Manual Describing Appropriate MINTEQ Code Implemented on Microcomputer.		7/88	
Users Manual for Metal Speciation Modeling--MINTEQ.	3/87		
Interim Report on Sensitivity Analysis and Simplified MINTEQ.		8/88	
Final Report on Monte Carlo Version of MINTEQ.			10/88
Report on MINTEQ Predictions for Part II for OSW and CB.		1/88	
MINTEQ Tapes with Thermodynamic Data Bases, Including SB and CN Reactions.		1/88	
Documentation on the Antimony and Cyanide Data Bases.		7/88	
Updated MINTEQ-A1 Code and PRODEF-A1 Preprocessor Code.	3/87		
Raw, Interim Numeric Results from MINTEQ Provided to OSW.		3/88	
Interim Report to OSW on Model Predictions Using Interim Methodology for Implementation of Re-Listing Scenarios.		6/88	
Report on Organic Multimedia Human Exposure Model.	5/87		
Journal Article on Anaerobic Degradation of Dichlorophenols in Freshwater Pond Sediments.		9/87	
Internal Report on Microbiological Process Research Highlights.			8/88
Report on Risk Assessment Methodology for Hazardous Waste Management.			10/88
Project Report on Components of Multimedia Environmental and Human Exposure Modeling.		8/88	
Report on Procedures for Estimating Indoor-Outdoor Exposures.		8/88	
Report on Risk Uncertainty and Assessment Data Collection Optimization.			6/89
Project Report on Performance Test of OSW Modeling Using Field Data.		2/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on the Impact of Uncertainty in Leachate Tests and ADI Data on Overall Uncertainty in OSW Evaluations.		8/88	
Report on Impact of Treated Waste Forms on Exposure/Risk from Land Disposal of Hazardous Waste.			6/89
Project Report on Uncertainty Analysis of Multimedia, Transient-Finite Source Land Disposal Model.	9/87		
Journal Article on Simulation of Solute Transport in Aggregated Media--Numerical Solution.	1/87		
User's Manual for Multimedia, Transient, Land Disposal Model.		2/88	
Journal Article on Kinetic Studies of Aromatic Azo Compounds in Anaerobic Sediment/Water Systems.	12/86		
Journal Article on the Role of Soils in Mediating the Hydrolysis of Organic Compounds.			1/89
Journal Article on the Scope of Hydrolysis of Organic Compounds in Soil Systems.		12/87	
Journal Article on Abiotic Redox Reactions in Sediment-Soil Systems.	10/86		
Report Describing the Kinetics of Redox Reactions in Soil-Water Environment.			4/89
Initial Estimates of Groundwater Redox Distributions Provided to AERL.		12/87	
Report on Selection of Redox Parameters and Redox Potential Distributions.		8/88	
Internal Report on the Fate of Organic Pollutants in the Subsurface Environment.		5/88	
Journal Article on Abiotic Transformation Processes in Water, Sediments, and Soils.			6/89
Journal Article on Sorption of Ionic Organic Compounds on Sediments. Users Manual for Sarah 2.		1/88 5/88	
Report on Sorption Kinetics of Ionic Species on Aggregated Media.		1/88	
Journal Article on the Fate of Synthetic Dyestuffs in Natural Waters and Sediments.		9/87	
Internal Report on Fate of Textile Dyes in the Aquatic Environment.		8/88	
Journal Article on Use and Expected Behavior of Chemicals (Dyes, etc.) used in Textile Industry.		6/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Journal Article Describing Algorithms for Estimating Hydrolytic Rate Constants.		7/88	
Journal Article on Estimating PKAs of Organic Acids and Bases.		4/88	
Journal Article on Techniques for Using Chemical Properties to Estimate Photochemical Rate Constants.		6/88	
Internal Report on Expert System to Estimate Reactivity Parameters (Rate Constants, Equilibrium Constants) for the Transformation of Organic Pollutants.		7/88	
Provide techniques and data to predict the rate and extent of movement and transformation of 2,3,7,8-tetrachlorodibenzene-P-dioxin in soils and ground water (PPA D54).	$212.8	$110.0	$110.0
Internal Report on Mobility of Other Selected Dioxin Isomers in Soils.	11/86		
Article on Desorption of 2,3,7,8-TCDD from Soil into Water/Methanol and Methanol Liquid Phases.	11/86		
Report on Mobility of Dioxins in Soils.		3/88	
Internal Report on Enhanced Degradation of 2,3,7,8-TCDD.		1/88	
Report on Enhanced Degradation of Dioxin Isomers.			10/88
Report on Photodegradation Evaluation of Dioxin (2,3,7,8-TCDD) in Soils.		8/88	
Published Paper on Environmental Chemistry of 2,3,7,8-TCDD.	3/87		
Journal Article on Octachlorodibenzodioxin Dechlorination on Soil Surfaces.			11/89
Internal Report on Application of the Multimedia Exposure Assessment Model to Estimate Downgradient Concentrations of Dioxin.	6/87		
Superfund			
Evaluate abilities of natural and engineered microorganisms for biodegradation of hazardous substances in support of Superfund remedial actions (PPA B02).	$100.0	$250.0	$250.0
Journal Article on Enhanced Biorestoration of Contaminated Ground Water.			1/89
Development of Procedures for Biological Cleanup of Trichloroethylene-Contaminated Hazardous Waste Areas.		9/89	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Article on Bench-Scale Demonstration of Feasibility for In Situ Biodegradation of Trichloroethylene.	9/87		
Feasibility of Bioremediation of TCE-Contaminated Waste: Bacterial Characterization and Degradation Factors.			1/90
Pesticides			
Determine how pesticides contaminate ground waters, identify processes involved, and those remedial actions necessary to alleviate the problem PPA D07).	$600.0	$455.0	$455.0
Feasibility Report for Unsaturated-Saturated Zone Pesticide Model.		11/87	
Users Manual for Exposure Assessment Model of Pesticide Contamination of Ground Water.		6/88	
Journal Article on Spatial Variability of Pesticide Application.	11/86		
Journal Article on Results of Field Studies of PRZM and PESTANS Leaching Models for Coastal Plain Soils.		12/87	
Interim Report on Validation Status of Pesticide Leaching and Ground-Water Transport Models.		8/88	
Ground-Water Pesticides/Assessment Manual for OPP, States, and County Extension Professionals.			6/89
Analyses of Pesticide Residues in the Unsaturated and Saturated Zones at a Selected Site in the Dougherty Plain Area of Georgia.	Continuing		
Report on Spatial Variability of Soil Release Characteristics (Dougherty Plain Site) for Use in PRZM (Testing).	3/87		
Dougherty Plain Annual Report.	9/87		
Dougherty Plain Annual Report.		9/88	
Report Describing Pesticide Ground-Water Threat Test Results.			9/89
Final Dougherty Plain Report Including Pesticide Groundwater Threat Assessment Methodology Test Results.			9/89
Journal article on Method for developing Joint Probability Distributions of Soil-Water Retention Characteristics.	6/87		
Journal Article on a Simulation Procedure for Groundwater Quality Assessments of Pesticides.		9/87	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Internal Report on the Validation Status of Pesticide Leaching and Groundwater Transport Models.		8/88	
Develop information and techniques, including mathematical models, on pesticide transport, degradation, residuals, and fate for agency use and provide direct technical support and guidance to OPP (PPA D08).	$0.0	$0.0	$0.0
Report on Mechanisms of Biodegradation of Pesticides in Sediments.			12/90
Role of Microbial Biomass in the Enhanced Degradation of Pesticide Products in Sediment.	9/87		
Report on Characterization of Pesticide Biodegradation Products in Estuarine Sediments.			12/91
Report on Sensitivity Analysis and Testing, Temik Contamination Potential.		8/88	
Feasibility Report for Unsaturated-Saturated Zone Pesticide Model.	1/87		
Report on Linking Saturated Zone Model to Unsaturated Zone Code.		11/87	
Users Manual for Exposure Assessment Model of Pesticide Contamination of Ground Water.		6/88	
Journal Article on Abiotic Transformations of Pesticides in the Hydrosphere.		7/88	
Article on Sorption of Water Soluble-Ionic Pesticides to Soils Sediments.			4/89
Journal Article on Pesticide Transformations on Environmental Surfaces.			5/89
Drinking Water			
Develop methods to predict subsurface contaminant concentrations to support risk analysis and source control (PPA F83).	$1,063.9	$1,264.1	$1,264.1
Article Evaluating the Potential of Ground-Water Colloids to Facilitate Organic Pollutant Transport.		4/88	
Article on Abiotic Transformation Kinetics of Selected Contaminants in the Subsurface.			2/89
Article on Mineral Surface Effects on Abiotic Transformation Rates.	2/87		
Article on Haloalkane Reduction by Ferrous and Sulfide Ions.		12/87	
Describing Movement of Non-Polar Compounds Associated with Dissolved Organic Carbon.	2/87		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Article on Methods for Characterizing Subsurface DOC.		6/88	
Article on Spatial and Temporal Gradients of Redox Conditions in an Aquifer.		11/87	
Article on Metal Complexation by Organic Materials in Ground Water.		11/87	
Article on Diffusion of Oxygen and Volatile Organics Through Well Tubing.		10/87	
Article on Electrode Measurement of Redox Potential.		10/87	
Article on Relationship of Redox Potential to Chemical Constituents of Aquifer Systems.			10/88
Article on Evaluating the Redox State of Anaerobic Aquifers.			10/88
Article on Organic Cation Effects on the Retention of Metals and Neutral Organic Compounds on Aquifer Materials.		11/87	
Article on Co-Solute Effects on Solute Retardation.		6/88	
Article on Fate of Norwalk Agent in Ground Water.			12/88
Article on Fate of Rotavirus in Ground Water.			12/88
Behavior of Hepatitis A Virus in Unsaturated Zone.			10/88
Report on Predictive Model for Viruses in the Unsaturated Zone.			12/89
Article on Adaption of Subsurface Microbes to Degrade Organic Pollutants.	1/87		
Article on Minimum Concentrations of Selected Waste Components to Support Microbial Transformations.		10/87	
Article on Kinetics of Microbial Adaptation to Organic Contamination at Field Scale.		12/87	
Report on Anaerobic Biotransformation of Contaminants in the Subsurface.			10/89
Article on Anaerobic Biotransformation of Aromatic Compounds in the Subsurface.		12/87	
Article on Sequential Reduction of Halogenated Organic Compounds.		10/87	
Article on Microbial Ecology of a Shallow Unconfined Ground-Water Aquifer Polluted by Municipal Landfill Leachate.		9/87	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Develop methods to determine the fate of underground injected wastes and develop safer technologies in support of underground injection control (PPA F88).	$730.0	$730.0	$730.0
Conduct Agency Briefing on Cement Bonding of Injection Wells.	12/86		
Report on Cement Bonding of Injection Wells.	5/87		
Report on Field Tested Methods for Determining Mechanical Integrity of Injection Wells.		10/87	
Report on Methods for Evaluating Cement Bonding Behind Steel and Fiberglass Casing.			12/88
Report on Laboratory Research on Interaction of Fluids with Geologic Materials--Class I Wells.		11/87	
Report on the Physical Hydrology of a Saline Aquifer Used for Disposal of Wastes.		10/87	
Report on Physical Hydrology and Hydrochemical Characterization of a Saline Aquifer Used for Disposal of Wastes.		7/88	
Report on Effectiveness of Drilling Mud in Research Wells.			1/90
Report on Methods for Regional Evaluation of Confining Bed Integrity.			12/88
State-of-the-Art Report on Class V Injection Well Practices.			10/88
Report on Options for Improving Class V Injection Well Practices.			10/89
Evaluate models and management strategies in support of State wellhead protection programs mandated by the Safe Drinking Water Act Amendments of 1986 (PPA F89).	$160.0	$160.0	$160.0
In-House Report Reviewing and Evaluating Ground-Water Flow, Fate, and Transport Models Applicable for Wellhead Protection Area Delineation.	6/87		
Technical Resource Document Concerning Management Strategies for Wellhead Protection.			10/88
Aquifer Reclamation			
Drinking Water			
Develop new methods for the restoration of contaminated aquifers and provide cost and feasibility data to support corrective action decisions (PPA F84).	$900.0	$900.0	$900.0

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on In Situ Restoration of an Aquifer Contaminated with Halogenated Organic Contaminants.		10/87	
Report on Criteria for In Situ Restoration of an Aquifer Contaminated with Halogenated Organic Concentrations.			6/89
Report on Monitoring of Subsurface Microbial Populations During Bioreclamation Activities.		9/88	
Journal Article Describing Expert System for Estimation of Parameters for Operating Aquifer Restoration Models.			10/89
Internal Report on Full-Scale Treatment Design for TCE in Ground-Water Design, Criteria, and Economics.			3/89
Computer Code and Appropriate Documentation for Attenuation of Ground Water Contaminants Due to Natural Processes.		10/87	
Article on Field Validation of Model.		12/87	
Source Control			
Hazardous Waste			
Develop and field-verify improved design, operation, and closure procedures for hazardous and nonhazardous landfills, surface impoundments, waste piles, and underground storage facilities used to contain wastes and reduce the risk of contaminant migration to ground water (PPA L42).	$596.9	$200.9	$200.9
Report on field verification of landfill cover system construction to provide hydrologic isolation.		12/87	
Report on maintenance free vegetation systems for landfill covers.		4/88	
Technical Resource Document on design, construction, and evaluation of clay liners, revised to incorporate public comments.	9/87		
Report on effects of organic materials on clay soil liners.	9/87		
Report on effective porosity of geologic materials.		12/87	
Report on determination of effective porosity of soil materials.		12/87	
Report on effects of hydraulic gradient and field testing on measurement of hydraulic conductivity of soils.			12/89
Report on influence of aggressive permeant liquids on bentonite soil liners.		05/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Technical Resource Document on batch-type adsorption procedures for estimating soil attenuation of chemicals, revised to incorporate public comments.		6/88	
Technical Resource Document update on flexible membrane liners.		09/88	
Report on the chemical resistance of flexible membrane liners.	6/87		
Report evaluating the use of cohesive energy density numbers for determining chemical resistance.	9/87		
Report on the use of synthetic liner physical properties in design.	4/87		
Report evaluating the relevance of chemical resistance data in determining the service life of FMLs.		10/87	
Report on the inspection procedures and criteria for installation of liners.	6/87		
Report on development of automated systems to assist in decisions concerning hazardous-waste facilities.		8/88	
User support for the HELP model at hazardous waste disposal facilities.		1/88	
Report on the use of expert systems for determining flexible membrane liner compatibility with waste chemicals.	9/87		
Report on waste analysis plan evaluation system of RCRA permits.			12/88
Report on field verification of rate-of-release model.	9/87		
Report on development of criteria and standards for design and evaluation of stabilization and solidification processes.		1/88	
Report on expert system to evaluate closure plans.		9/88	
Report and software to develop a method for FML reliability.			12/89
Report comparing the batch and column leaching methods.		4/88	
Technical Resource Document on surface impoundments.			9/90
Technical Resource Document update on chemically stabilized and solidified waste.			9/90
Report on evaluation and assessment of stabilization processes to determine extent of fixation.			10/88

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on treatment technology for major hazardous waste streams.			12/89
Identify and Evaluate Improved Practices to Prevent Releases from New/Existing Underground Storage Tanks and Detect and Measure Leak Rates from Underground Storage Tanks and Associated Piping (PPA R63).	$2,103.1	$1,301.2	$1,301.2
Report on Tank Equipment Installation Practices and Environmental Factors on Tank Life.	12/86		
State of the Art Report on Repair Techniques Effective for Preventing Releases from USTs.		9/88	
State of the Art Report on Secondary Containment Systems and Liners for USTs.		9/88	
Evaluation of "Prevention Methods" Over Long-Term Operation.			9/89
Report on the Effectiveness of Cathodic Protection for New/Existing USTs and Development of Guidelines for Inspecting, Testing, and Maintaining Cathodic Protection Systems.			9/90
Guidelines for Retrofitting Existing UST Installations with Secondary Containment Systems.			9/91
Evaluation Report on Leak Detection Methods for Petroleum Storage Tanks Interim Report.		12/87	
Evaluation Report on Leak Detection Methods for Petroleum Storage Tanks Interim Report Final Report.		9/88	
Evaluation Report on Leak Detection Methods for Chemical Storage Tanks Interim Report.			12/88
Evaluation Report on Leak Detection Methods for Chemical Storage Tanks Final Report.			9/89
Evaluation Report on Product Level Monitoring Devices Interim Report.		1/88	
Evaluation Report on Product Level Monitoring Devices Final Report.		1/88	
Development of New/Improved Leak Detection Methods.			9/91
Demonstrate New/Improved Approaches for Stopping Releases from a Leaking Tank System and Preventing Associated Environmental Damages (PPA R63).	$0.0	$950.0	$2,100.0
Interim Guidance on Corrective Actions for Leaking Underground Storage Tanks.	2/87		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on Case Studies of Past and Ongoing Corrective Actions at UST Sites.		2/88	
Corrective Action Guidance Document for Application to Leaking UST Situations 5/8erim Report on the Performance Evaluation of LUST Corrective Action Technologies.			2/89
Development of a Technology Transfer Seminar on LUST Corrective Action Technology.			9/89
Report on Tank Equipment Installation Practices and Environmental Factors on Tank Life.			12/88
State of the Art Report on Repair Techniques Effective for Preventing Releases from USTs.		9/88	
State of the Art Report on Secondary Containment Systems and Liners for USTs.		9/88	
Evaluation of "Prevention Methods" Over Long-Term Operation.			9/89
Report on the Effectiveness of Cathodic Protection for New/Existing USTs and Development of Guidelines for Inspecting, Testing, and Maintaining Cathodic Protection Systems.			9/90
Guidelines for Retrofitting Existing UST Installations with Secondary Containment Systems.			9/91
Determine the applicability and cost-effectiveness of *in situ* reclamation techniques to unsaturated-zone and ground-water contamination resulting from leaking underground storage tanks (UST) and other hazardous waste sources (PPA R64).	$201.4	$106.1	$106.1
Report on Hydrogeological Approaches for Mobilizing Immiscible Wastes for Corrective Actions.		9/88	
Report on Improved Techniques for In situ UST Corrective Actions.			10/89
Report on In situ Treatment Process for Water Contaminated with Wastes from UST Releases.	8/88		
State-of-the-Art Report for Existing In situ Corrective Action Techniques Applicable to UST.	10/86		
Develop a comprehensive technical data base on new and existing technologies for land treatment of hazardous wastes for which incineration or conventional land disposal are inappropriate, infeasible, or ineffective (PPA L44). (This PPA no longer exists)	$480.0	$0.0	$0.0
Internal Report on Pilot Plant.	10/86		
Technical Resource Document on Selection Procedures.	2/87		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Article on Evaluation of RITZ Model Using Project Data Base.	1/87		
Journal Article on Mathematical Modeling for Pesticides Behavior in Soil Using Soil Treatability Study Data.	12/86		
Report on Land Treatability of Selected Hazardous Wastes, Vol. I.		12/87	
Report on Land Treatability of Hazardous Wastes, Vol. II.		9/88	
Report on Land Treatability of Selected Hazardous Wastes, Vol. III.		9/88	
Internal Report on Land Treatability Evaluation for Selected Subtitle D Wastes.	4/87		
Report on Land Treatability of PCP and Creosote Wastes.			1/89
Report on Bench/Pilot Scale Land Treatability of PCP and Creosote Wastes.	4/87		
Users Guide for Land Treatability Decision Models.			6/89
Report on Evaluation of Land Treatability Decision Models.			3/89
Report on Soil Fate and Effects Literature Assessment.	3/87		
Computerized Data Bank on Fate and Effects of Hazardous Organics in Soil.	6/87		
Report on Impact of Sensitive RITZ Model Parameters.		5/88	
Report on Computerized Literature Search on Fate and Effects of Appendix VIII Organics in Soil.	12/86		
User-Friendly Program for Land Treatment Decision Models.	9/87		
Report on Field Evaluation of RITZ Model.			12/88
Report on Fate and Transport of Residual Matrix Constituents in Soil at Closed Sites.			4/89
Report on Land Treatment Case Studies for Selected Subtitle D Wastes.			2/89
Superfund			
Provide Response Technologies to Support Cleanup Actions for Contaminated Ground Water and Soils at Uncontrolled Waste Sites (PPA B01).	$1,666.7	$1,333.3	$1,333.3
Handbook on Leachate Treatment Techniques.		12/86	
Report on Utilization of Plants for Organic Uptake from Soil.		4/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on Sorption Technology.			08/89
Report on Slurry Wall and Grout Systems.	4/87		
Report on Freezing Techniques.			9/89
Reports on the Uses of Hydrofracturing and Horizontal Drilling in Innovative *In situ* Recovery Processes.		4/88	
Report on Commercial Point-of-Entry Water Treatment for Superfund Applications.		6/88	
Report on Support Aerated Biofilms for Biodegradation of Organics.			08/90
Report on Gene-Engineered Yeast for Biodegradation of Wastes.			09/89
Report on Flow-Through Processes for Treatment of Contaminants in Soils.			10/91
Report on the Use of Surfactants as Additives for Aqueous Extraction of Organics in Soils.			10/89
Report on Transportable System for Biodegrading Leachate/Extract from Soil.		4/88	9/89
Handbook on *In-Situ* Treatment of Hazardous Waste Contaminated Soils.			09/90
Provide Engineering Support for Site and Situation Assessments of Ground-Water Resources at Uncontrolled Hazardous Waste Sites (PPA A31).			
Report on Biodegradation of Environmental Pollutants.			5/90
Report and Paper on Measurement of Liquid Travel time through Soil Barriers.		7/88	
Report and Paper on Characterization of Landfill Leachates Potential to NPL Sites.			10/90
Report on Use of Geosynthetics to Stabilize Covers.			10/90
<u>Technology Transfer and Technical Assistance</u>			
Develop timely and effective methods of transferring technical information to appropriate federal, state, local, and general public groups through publications, workshops, training courses, and other communication mechanisms.	$1,300.0	$1,300.0	$1,300.0
EMSL-LV/RSKERL Subsurface Monitoring Symposium.	11/86		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods.	05/87		
Transport and Fate of Contaminants in the Subsurface (2-day Workshops).		2/88	
Continuing Compliance Guidelines for Treatment, Storage, and Disposal Facilities.			10/88
Application of Geophysical Methods to Ground Water.			9/89
Handbook on Evaluating the Design, Construction, and Operation of Hazardous Waste Disposal Facilities.			1/89
Seminars on Corrective Action: Procedures, Technologies, and Costs.		6/88	
Handbook on Installation, Construction, and Maintenance of Flexible Membrane Liners.		9/88	
Seminars on Land Disposal Restriction Program Implementation.		9/88	
Two-Day Seminars on Alternative Treatment Technologies for Superfund Waste Sites.		3/88	
Publication on Lessons Learned from Remedial Response Case Studies.		7/88	
Tenth Annual Ground-Water Research Symposium--Fate and Transport.	4/87	4/88	
Advanced Field Monitoring Instrumentation Conference.	5/87	5/88	
Drinking Water			
Develop and transfer improved methods for measuring subsurface parameters that influence contaminant behavior (PPA F82).	$600.0	$350.0	$350.0
Training Manual on Ground Water Contaminant Modeling.	7/86		
Training Course Document on Conducting GW Investigation.	12/86		
Development of a Slide Tape Program.		6/88	
Report on Existing Ground-Water Models.			10/88
Proceedings on Workshop and Symposia on Microbial Problems in Ground Water.	6/87		
Development of a National Library Center for Ground Water Information Data Base.	Continuing		
Conduct Technology Workshops.	Continuing		

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on Vertical Distribution and Movement of Volatile Organic Compounds in the Subsurface.		1/88	
Joint U.S.-Peoples Republic of China Environmental Protection Protocol supporting joint research on the impact of wastewater land treatment on ground-water supplies (PPA F87).	$20.0	$20.0	$0.0
Final Report on Chinese - EPA Cooperative Land Treatment Research Project - Rapid Infiltration.		3/88	
Superfund			
Provide Superfund enforcement and response programs with rapid access to the best available technical information, evidence, and testimony (PPA F22).	$706.0	$700.0	$700.0
Establish Clearinghouse for Information on Ground Water Remedial Action Technologies.		8/88	
Internal Report on Technical Support to Region III to Develop Methods for Assessing the Effectiveness of Soil Removal as a Remedial Action.		11/87	
Technology Transfer Document on Use of Assessment Models for Remedial Action.			1/89
Internal Report on Regional Ground Water Modeling Information Needs and Assistance as Provided.			10/88
Users Manual on Use of Geostatistical Models for Managing Soil and Water Contamination.			12/89
Technology Transfer Seminar Publication entitled "Transfer and Fate of Contaminants in the Subsurface."			12/88
Ground-Water Technology Workshops.			12/88
Technology Transfer Document on Evaluation of Bioremediation as a Remedial Action Technology.			1/89
Report on Technical Support to Regions for Multimedia Exposure Assessments Related to Remedial Actions.		8/88	
Report on Technical Support to Regions for Multimedia Exposure Assessments Related to Remedial Actions.			11/88
Report on Procedure for Relative Risk Assessment and Ranking for Action Among Listed Sites and RCRA Closure Activities.			2/89
Report on Identification of Unlisted Chemicals for Evaluation as Drinking Water Contaminants.		8/88	

Appendix B. Summary of Outputs from Ground-Water Research Projects (Continued)

	FY87	FY88	Outyear
Report on Environmental Factors Affecting Anaerobic Biodegradation.		6/88	
Report on Equations for Predicting Anaerobic Transformations within the Saturated Zones.			11/89
Report on Applicable Methods for Estimating the Magnitude and Areal Extent of Ecological Risks at Marine Superfund Sites.			9/90
Report on Integrated Assessment Methods and Strategies for Estimating and Reducing Risks at Marine Superfund Sites.			12/92

APPENDIX C: RECENT GROUND-WATER PUBLICATIONS

EPA publications in the 600 and 625 series (ORD) and 540 series (OERR) may be obtained by calling FTS 684-7562 (513-569-7562). Publications in the 530 series (OSW) may be obtained by calling FTS 382-4646 or 800-424-9346.

General

EPA Ground-Water Research Programs. EPA/600/8-86/004, PB86 212-552, April 1986.

Protection of Public Water Supplies from Ground-Water Contamination. EPA/625/4-85/016, PB86 168-358 September, 1985.

Handbook: Ground Water. EPA/625/6-87/016, March 1987.

Monitoring

Underground Tank Leak Detection Methods: A State-of-the-Art Review. EPA/600/2-86/001, PB86 137-155, January 1986.

Practical Guide for Ground-Water Sampling. EPA/600/2-85/104, PB86 137-304, September 1985.

"Sorption of Organics by Monitoring Well Construction Materials." A.L. Sykes, R.A. McAllister, and J.B. Homolya, Ground Water Monitoring Review, 6(4):44-47, Fall 1986.

"Underground Storage Tank Monitoring: Observation Well Based Systems." R.A. Scheinfeld, J.B. Robertson, and T.G. Schwendeman, Ground Water Monitoring Review, 6(4):49-55, Fall 1986.

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