United States
Environmental Protection
Agency

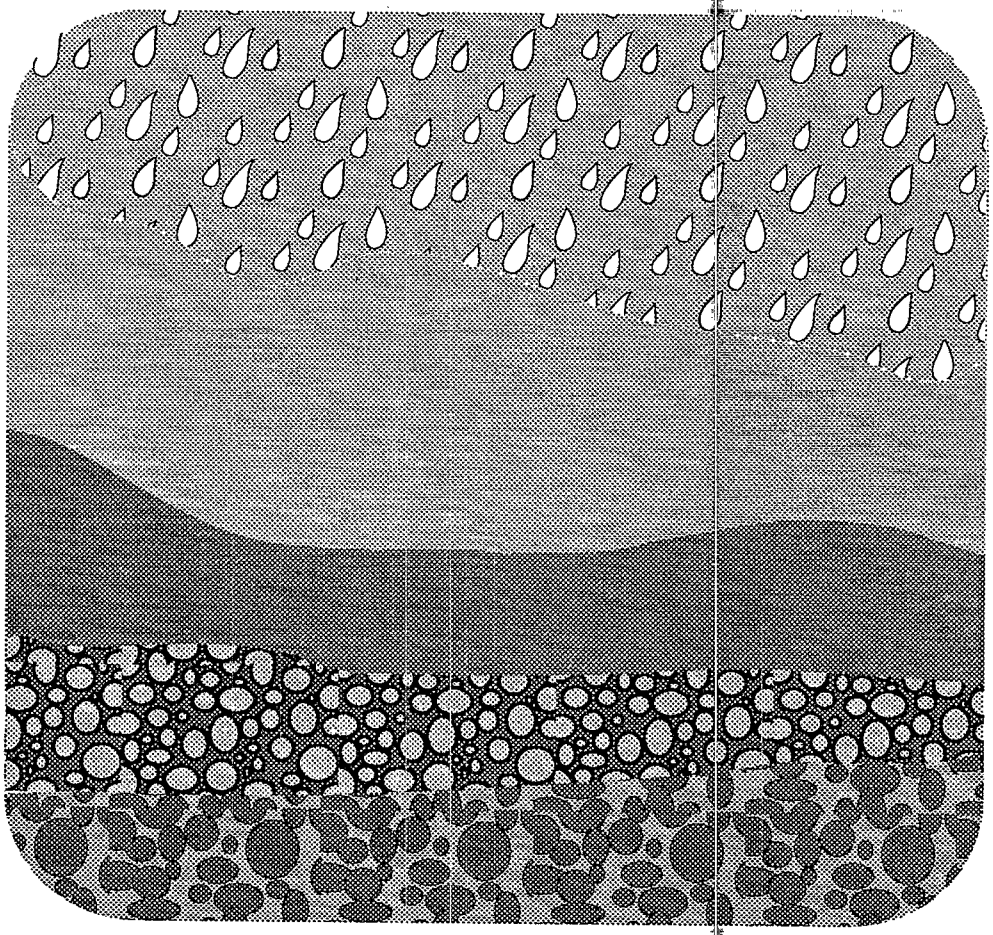
Office of Technology
Transfer and Regulatory Support
Washington DC 20460

EPA/600/9-89/088
October 1989

EPA

Ground-Water Research

Research Description



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Prepared for the

Office of Research and Development
Office of Technology Transfer and Regulatory Support
U.S. Environmental Protection Agency
Washington D.C. 20460

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NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This document describes the ground-water research program conducted by EPA's Office of Research and Development (ORD). It updates the earlier *Research Program Description, Ground Water Research* (EPA/600/9-88/005, March 1988). The research program is carried out by the Offices of Environmental Processes and Effects Research (OEPER), Modeling, Monitoring Systems, and Quality Assurance (OMMSQA), Environmental Engineering and Technology Demonstration (OEETD), and Exploratory Research (OER). Of ORD's 12 laboratories and four research groups, four laboratories have lead responsibilities and base budgets in ground water: OEPER's Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma (RSKERL-Ada); OEPER's Environmental Research Laboratory in Athens, Georgia (ERL-Athens); OMMSQA's Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV); and OEETD's Risk Reduction Engineering Laboratory in Cincinnati, Ohio (RREL-Cin). ORD's Center for Environmental Research Information (CERI) conducts educational seminars and prints and disseminates publications in support of the ground-water research program. The overall program is coordinated by the ORD Matrix Manager for Ground-Water Research. The current matrix manager is Peter Preuss, Director of ORD's Office of Technology Transfer and Regulatory Support. Further information may be obtained by contacting the ORD laboratories, offices, and technical experts listed in the *Ground-Water Research Technical Assistance Directory* (EPA/600/9-89/048, May 1989), which is available from CERI at FTS-684-7391 or 513-569-7391.

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

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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 obtains their drinking water from ground-water supplies, including 34 of the 100 largest cities in the United States and 95% of rural Americans. Until recent years, ground water was generally considered a pristine resource: pure and ever-available. It was used, and sometimes abused, without a full understanding of the consequences of its use. In the late 1960s, synthetic organic chemicals were discovered in ground-water-supplied drinking water sources in several states. Since then, most 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, most statutes that govern the Agency's mission address the need to protect ground water, including the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), Safe Drinking Water Act (SDWA), Clean Water Act (CWA), and Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), together with their amendments. This broad spectrum of statutory authority within the Agency has contributed to a variety of ground-water issues, priorities, regulations, and research needs.

EPA ground-water research reflects the diverse priorities among seven program office clients—Office of Drinking Water (ODW), Office of Ground-Water Protection (OGWP), Office of Solid Waste (OSW), Office of Emergency and Remedial Response (OERR), Office of Waste Programs Enforcement (OWPE), Office of Underground Storage Tanks (OUST), and Office of Pesticide Programs (OPP). The research program also supports EPA's ten Regions, and a number of cross-media offices and task forces. Because of statutory delegation to the states of ground-water protection responsibilities and regional variations in hydrogeology, EPA is increasing its emphasis on transferring technologies and providing technical assistance to state and local agencies that must apply new knowledge and technologies to local problems.

The overall research and technology transfer program is guided by a complex relationship involving three EPA research committees and four Office of Research and Development (ORD) offices. The research committees—Water, Hazardous Waste/Superfund, and Pesticides—are joint ORD/program office committees responsible for reviewing research programs, ranking research needs, and recommending allocations of research funds to ORD's Assistant Administrator. ORD's research offices—Modeling, Monitoring Systems, and Quality Assurance (OMMSQA), Environmental Processes and Effects Research (OEPER), Environmental Engineering and Technology Demonstration (OEETD), and Exploratory Research (OER)—are responsible for coordinating research programs and overseeing the operations of the research laboratories within their program areas.

Responding in part to a recommendation by the Science Advisory Board, ORD's Assistant Administrator created, early in 1986, a matrix manager for ground-water research to be responsible for cross-office, cross-research-committee coordination among competing priorities. Program office and ORD technical specialists and managers participate in annual reviews, led by the matrix manager, of ground-water research priorities and outputs. The reviews serve to refine research priorities based on the evolving knowledge of ground-water science and needs of the program offices and form the basis for present ORD directions in ground-water research.

EPA's responsibilities in ground water include providing technical and financial assistance to guide state and local governments in the development of their ground-water protection and management programs, and developing policies to ensure integration and consistency of approach for federal programs focused on ground-water protection. To support EPA responsibilities, ORD offices and laboratories conduct their own research as well as fund research at other institutions, including universities and colleges, state and other federal laboratories, associations, and consulting and engineering firms. ORD research provides tools for decision-making at all government levels to improve the protection of ground-water resources from man-made contamination. In addition to designing a research program to satisfy multiple needs, ORD coordinates with other federal agencies concerned with ground-water problems.

The objectives of ORD's ground-water research programs are the development of methods,

data, and guidance for detecting and monitoring various point and nonpoint sources of contamination, predicting subsurface transport and fate processes to better assess human exposure from ground-water contamination, controlling contamination from numerous possible sources, and restoring contaminated aquifers to a point where human health and the environment are no longer at risk. Research into predicting the distribution, movement, and fate of man-made contaminants in ground water is the cutting edge of ground-water protection and sets the pace for progress in controlling contamination sources and remedial action. To ensure that the latest science and technology advances are applied to ground-water problems by government and private sector decision makers, ORD manages proactive technology transfer and technical assistance programs.

EPA Program Office Responsibilities

This section summarizes the responsibilities of EPA Program Offices, Regional Offices, and the states and the resulting information needs to which ORD's ground-water research program responds. Although research results have broader applicability than just to the programs to which they are directed, in practice, research activities are supported by, and performed in support of, individual EPA programs. Research needs are, therefore, described here in the context of the supporting programs—RCRA Hazardous Waste, Superfund, Drinking Water, and Pesticides. ORD ground-water research resources supported by these programs and by ORD's exploratory (fundamental) research program are shown in figure 1.

RCRA Hazardous Waste

The management of regulatory programs under RCRA and the Hazardous and Solid Waste Amendments of 1984 (HSWA) is the responsibility of OSW, OUST, and OWPE. RCRA and its amendments allow states to take over responsibility for program implementation and enforcement and provides for oversight by EPA's Regions. Because the hazardous waste program is the program most people think of when RCRA is mentioned, the terms "hazardous waste" and "RCRA" are used interchangeably to refer to research in support of hazardous waste (RCRA Subtitle C), municipal waste (RCRA subtitle D), and underground storage tank (RCRA Subtitle I) regulatory programs.

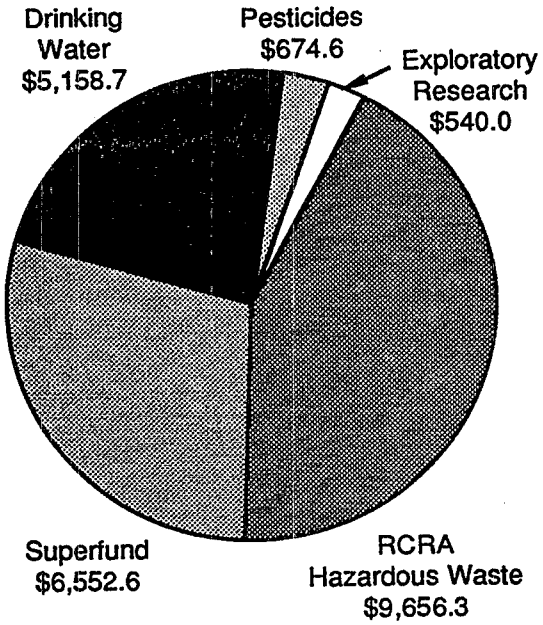

Figure 1. ORD ground-water research resources for FY89 (in thousands).

Subtitle C of RCRA established a program to manage hazardous wastes from "cradle to grave," including the generation, transportation, treatment, storage, and disposal of hazardous wastes. Facilities regulated by OSW under RCRA include containers, tanks, surface impoundments, waste piles, land treatment units, landfills, incinerators, underground injection wells, and chemical, physical, and biological treatment processes. RCRA also authorizes corrective action cleanups at facilities from which hazardous wastes have been released into the subsurface. Regional and state permitters and enforcement personnel need methods to establish ground-water monitoring programs at disposal facilities to detect pollutants migrating from facilities and to monitor compliance with permit conditions. Information on the transport and transformation of contaminants in ground water is needed to assess health and environmental impacts of various regulatory options and clean up ground water contaminated by improper hazardous waste disposal.

Subtitle D of RCRA established a program to assist states who voluntarily develop and implement municipal waste management plans. It also required OSW to issue minimum technical standards to which all municipal waste disposal facilities must comply in order to accept solid wastes. These minimum standards are outside

the voluntary state program and cover ground-water monitoring, siting of facilities, and corrective actions. EPA municipal waste activities declined in the early 1980s, but now are on the increase because of many reported instances of ground-water contamination from municipal waste dumps. The 1984 amendments to RCRA require EPA to revise, if necessary, the criteria for municipal waste facilities, incinerator ash monofills, and land application units. To support environmentally safe municipal waste management, the states need information on suitable monitoring strategies, methods to predict the transport and transformation of contaminants in ground water, and remediation methods for cleaning up contaminated soils and ground water.

Subtitle I of RCRA established a program to regulate over 1.5 million underground storage tanks (USTs), hundreds of thousands of which are suspected to be leaking petroleum products. OUST has developed performance standards for new tanks and regulations for leak detection, prevention, and corrective action at all underground tank sites. Because of the number of tanks, OUST has designed a program in which the states have responsibility, after approval of their programs by EPA, for controlling leakage from underground tanks. The 1986 amendments to CERCLA provided for a Leaking Underground Storage Tank Trust Fund to finance corrective actions necessitated by leaking underground tanks. OUST and the states need information on methods to monitor the subsurface around USTs and clean up contaminated aquifers and soils.

Superfund

OERR is responsible for mitigating threats from abandoned, high-priority, hazardous waste sites under CERCLA and its amendments. The Hazardous Substance Response Trust Fund (Superfund) was established to finance EPA-lead remedial actions at CERCLA sites, short-term removal actions to lessen imminent threats, emergency responses to accidental spills, and research. EPA policies and procedures for implementing Superfund responses are contained in the National Contingency Plan (NCP), which delineates criteria for when—and to what extent—a removal or remedial response should be undertaken.

Preliminary assessments must be conducted at sites reported as possible sources of contamination or illegal dumping (now over 31,000 sites). If the preliminary assessment shows that there is an immediate need for action, a removal action may be initiated to stabilize or eliminate the release. EPA on-scene coordinators (OSCs) in the Regions direct Superfund-financed removal activities. When a preliminary assessment shows that the site may threaten human health or the environment, the site is inspected to collect sufficient information to rank its hazard potential, including risks to ground water. If a long-term remedial response is required, a lead organization is determined, which may be OERR, the state, or the responsible party; the latter under supervision of OWPE. The site remedial response is managed by a Regional remedial project manager (RPM) when OERR has the lead.

Sites are subjected to a remedial investigation to gather data necessary to determine the type and extent of soil, ground-water, and other contamination at each site and a feasibility study to analyze cleanup needs and evaluate alternative approaches. After completing these studies, a remedial design is developed, including detailed engineering plans, drawings, and specifications. The remedial response process at a Superfund site may take four years or more to complete and may cost millions of dollars.

OSCs, RPMs, and their state counterparts need monitoring procedures and analytical protocols that can quickly and effectively assess the degree of hazard posed at waste sites. They need methods to determine the transport and transformation of contaminants in the subsurface and innovative remedial technologies to clean up contaminated sites. Although microbial degradation of contaminants in the subsurface has great potential to cost-effectively clean up some Superfund sites, a great deal of research is required to determine which contaminants are amenable to *in situ* microbial remediation and how to evaluate controlling processes, design criteria, costs, by-products, and site-specific effects.

Enforcement powers have been granted to EPA to gain the compliance of recalcitrant RCRA facility and underground storage tank owners, oversee Superfund site cleanups, and recover the costs of site cleanups financed by Superfund. These enforcement powers are employed by OWPE and its counterparts in the Regions and states. Enforcement personnel need ground-water information similar to that needed by RCRA, Superfund, and UST regulatory, permitting, and response personnel in order to defend the scientific and technical merit underlying decisions in

these programs.

Drinking Water

Under the authority of SDWA, ODW publishes maximum contaminant level goals and promulgates national primary drinking water regulations for all contaminants that may have an adverse effect on human health and are known or anticipated to occur in public water systems serving over 25 people. The list of potential contaminants must be updated every three years. ODW is also required to promulgate regulations by 1991 requiring the disinfection of all ground water used for drinking water. Variances may be granted if it can be shown that the water is likely to be free from viral contamination. The Clean Water Act also contains provisions affecting ground-water quality, including provisions for areawide waste treatment management plans and protection of ground-water quality from non-point sources of pollution.

Approximately 40% of the chemical waste generated in the United States is disposed of by injection into the subsurface. Both SDWA and HSWA contain provisions to protect ground-water quality from the injection of waste into the subsurface by means of deep wells. Regulations for underground injection control have been based on ensuring that the use of injection wells for the disposal of waste will not endanger human health or the environment.

OGWP is responsible for the wellhead protection program mandated by SDWA. SDWA requires each state to develop a wellhead protection program to protect public water wells from contaminants that may enter wellhead areas. More than 30 states are now actively developing such programs. This entails consideration of a number of technical elements, including the hydrogeologic delineation of protection areas and assessment of potential contaminating sources.

To carry out their ground-water protection responsibilities, ODW, OGWP, and the states must develop approaches to assess the risk to human health of contamination from various categories of sources, determine the likelihood that a chemical will persist in the subsurface, and develop management strategies including criteria for site selection. To support these activities, research is needed to improve methods for detecting and monitoring ground-water contamination, predicting the transport and transformation of pollutants in ground water, and using *in situ* technologies to remediate ground-water contamination.

Pesticides

FIFRA established a program that bans the use of all pesticides unless they are registered with OPP. OPP has set forth guidelines specifying the kinds of information required to support the registration of a pesticide, including data on the anticipated extent of use, pattern of use, and level and degree of potential exposure of humans and the environment. When used in accordance with commonly recognized practice, pesticides must not cause unreasonable adverse effects to the environment. Although the extent of exposure to human populations through drinking water is not certain, EPA will complete a National Pesticide Survey (NPS) in 1990 that will help evaluate the degree of pesticide contamination in drinking water wells. The Agency's proposed *Agricultural Chemicals in Ground-Water Strategy* stresses a localized approach to protecting ground-water from pesticide contamination by building Regional and state capabilities and encouraging the states to develop site-specific management plans.

Techniques are needed to predict the fate of pesticides in the subsurface on a site-specific basis and measure environmental exposures of pesticides that threaten human health, impair important environmental functions, and endanger desirable biota.

RESEARCH PROGRAM OVERVIEW

Three laboratories have lead responsibilities for ground-water research—the Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma (RSKERL-Ada), Environmental Research Laboratory in Athens, Georgia (ERL-Athens), and Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV) (Figure 2). The Risk Reduction Engineering Laboratory in Cincinnati, Ohio (RREL-Cin), also conducts ground-water research, but concentrates primarily on water and soil treatment technologies.

ORD's ground-water research program to address the primary needs of environmental protection programs can be organized into five areas—monitoring; transport and transformation; *in situ* aquifer remediation; underground source control; and technology transfer and technical assistance.

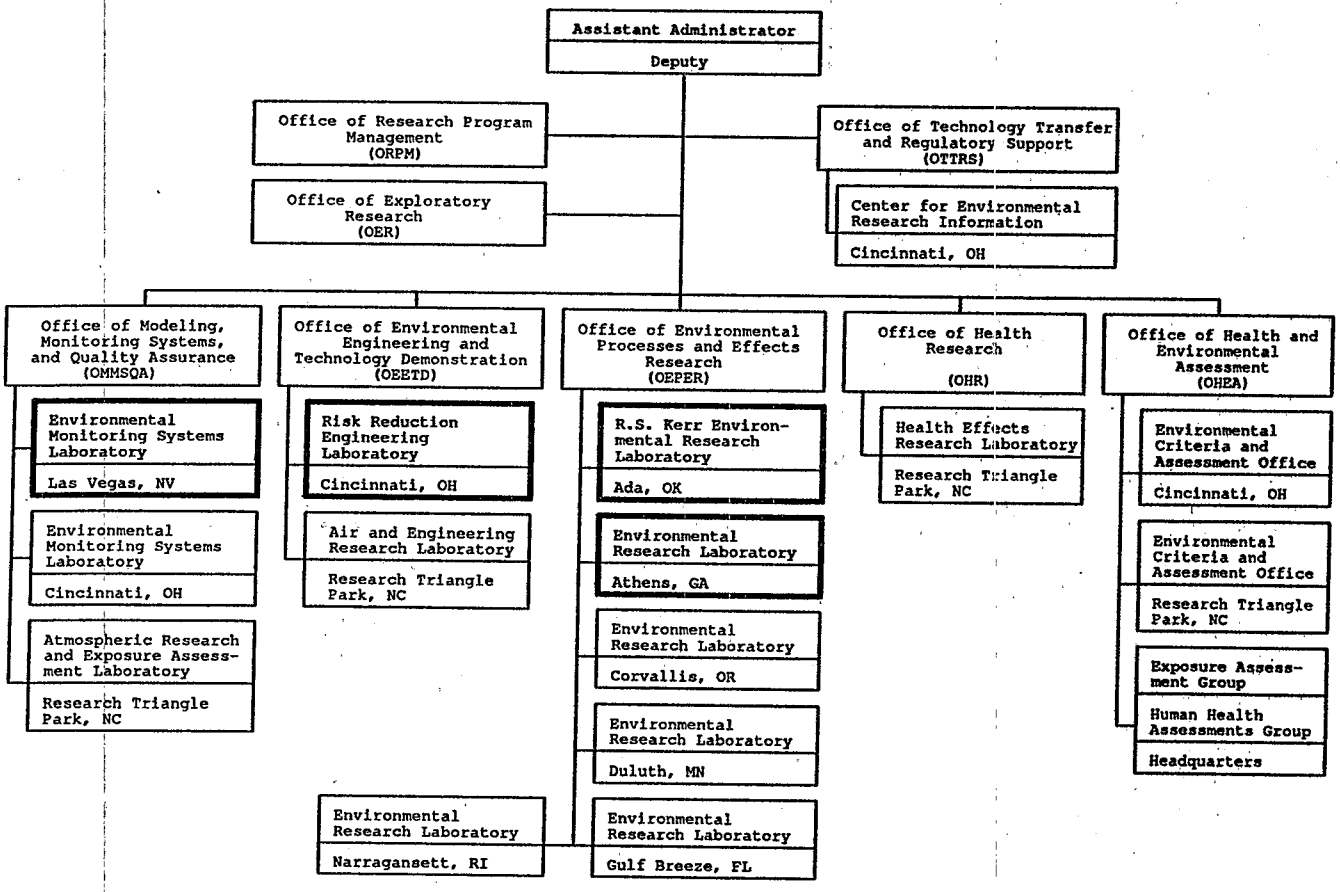

Figure 2. Office of Research and Development organization with laboratories conducting ground-water research highlighted.

Ground-Water Research Areas

Monitoring

The placement and spacing of monitoring wells, procedures for sample collection and preservation, and quality assurance and quality control (QA/QC) are fundamental requirements for credible decisions in 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 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.

Transport and Transformation

Predicting contaminant behavior in the subsurface is one of the most difficult tasks for ground-water protection programs. Transport research considers the physical movement of water and contaminants in the subsurface. Transformation research considers biotic and abiotic processes in the saturated and unsaturated zones that change the form, species (for example, of metals and ionizable organics), or composition of ground-water contaminants. The knowledge gained about transport, transformation, and speciation phenomena is incorporated into predictive models to enable the estimation of contaminant behavior in the subsurface and potential exposures to humans and the environment. The lead laboratories involved in fate and transport research are RSKERL-Ada and ERL-Athens.

In Situ Aquifer Remediation

Cleaning up a polluted aquifer is a technically difficult process, if it can be done at all. Effective cleanup methods are needed to remove contaminants from many different hydrogeologic settings. ORD's aquifer remediation research is

developing methods to recover contaminants from aquifers for on-site treatment, make *in situ* remediation techniques more effective and less expensive, and identify factors that contribute to the success or failure of existing cleanup techniques. Advances in aquifer remediation methods are highly dependent on advances in the understanding of subsurface processes affecting the behavior of contaminants in the subsurface; aquifer remediation research projects are often conducted in conjunction with transport and transformation research. RSKERL-Ada is the lead laboratory in this area.

Underground Source Control

A major potential source of ground-water contamination is the improper injection of hazardous wastes into the subsurface. Leaking well casings, abandoned wells that have not been properly sealed, injection of drainage waters containing agricultural and industrial chemicals and urban wastes into shallow aquifers, and upward migration of hazardous wastes from deep injection into drinking water supplies all need to be evaluated to determine safe underground injection practices. ORD's research program in underground source control addresses protocols for injection well practices, injection well testing methods, and the interaction of injected material with subsurface materials. The lead laboratory for underground source control research is RSKERL-Ada.

Technology Transfer and Technical Assistance

Field personnel in EPA Regions, states, and local government agencies must deal with an extremely broad and complex range of data and information, and require close support from scientists and engineers in ORD laboratories. Ground-water issues are becoming a major focus of technical requests from client offices. To be effective, research results must be disseminated to targeted operational personnel, program managers, and decision makers in a timely manner and in an effective format. ORD's lead in technology transfer is the Center for Environmental Research Information (CERI). In addition, all laboratories routinely conduct technology transfer and offer technical assistance.

Related Research Areas

ORD conducts ground-water research in the areas of health effects, on-site treatment technologies, and surface source control. Although closely related to ground-water research, they are not considered components of the ground-water research program for the purpose of this research description.

Health Effects

The major route of human exposure to ground-water contaminants is through drinking water. Illnesses attributed to ground-water contamination account 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 decision makers to establish credible standards for safe drinking water, demonstrate to the public that the standards are based on sound data, and design health-based cleanups of hazardous substances in the environment. ORD's Office of Health and Environmental Assessment (OHEA) conducts a research program to develop methods for predicting human exposure risks from hazardous materials, emphasizing the estimation of exposure to contaminants found in drinking-water supplies. Since health effects caused by contaminant exposure are the same regardless of whether through ground or surface water, research on health effects is not considered part of the ground-water research program.

On-Site Treatment Technology

EPA has a major research, development, and demonstration program investigating technologies for treating hazardous substances on site (above ground) to reduce or eliminate their volume, toxicity, or mobility. This program provides performance and cost data on available technologies for treating volatile and non-volatile organics, inorganics, metals, and microbes. Information on treatment technologies is being developed for the drinking water, Superfund, hazardous waste, and pesticides programs. On-site treatment technologies are often used for treating ground-water contaminants after they are pumped to the surface, however, on-site treatment technologies are not included in this description because they are not specific to ground water. Technologies for bringing subsurface contaminants to the surface for on-site treatment are discussed in the section on *in situ* aquifer remediation. RREL-Cin is the lead laboratory for the on-site treatment research program.

Surface Source Control

The surface source control research program primarily addresses the development of technologies to prevent ground-water contamination from RCRA facilities and underground storage tanks. Engineering research activities include improving land-disposal containment systems, such as landfill covers, leachate collection systems, and soil and flexible-membrane liners. ORD also develops guidance and procedures for siting, designing, closing, and detecting leaks from hazardous and municipal facilities, underground storage tanks, and other waste management facilities. The objective of this research is to reduce the risk of contaminant migration to ground water. RREL-Cin is the lead laboratory for this research.

CURRENT RESEARCH PROGRAM

The FY89-FY90 ground-water research program budget is presented in Appendix A. The FY89 research budget consists of $22.6 million and 95.6 work years (Figure 3). About 30% of the FY89 budget is in monitoring, 39% in transport and transformation, 21% in aquifer remediation, 4% in underground source control, and 6% in technology transfer and technical assistance.

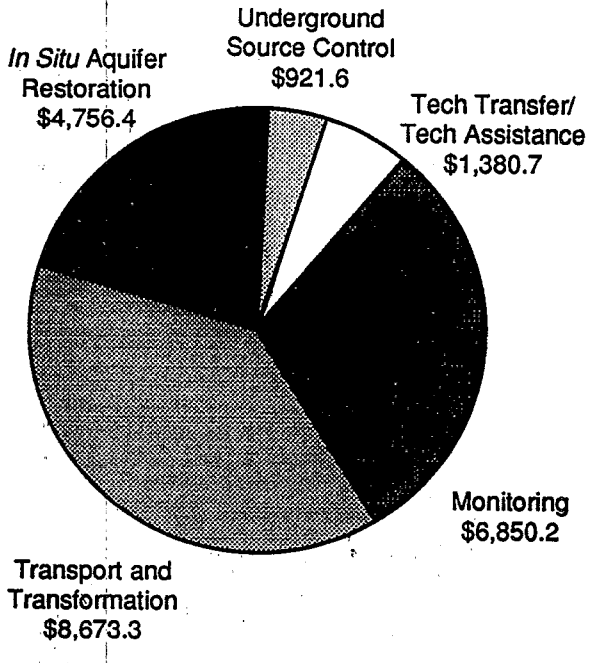

Figure 3. ORD FY89 ground-water research resources for each research area (in thousands).

The FY90 ground-water research budget is proposed to be the same as the FY89 budget, with the exceptions of an increase of $810 thousand for wellhead protection research and a disinvestment of $220 thousand from hazardous waste exposure assessment research, which will be redirected to the Agency's new pollution prevention initiative.

ORD deliverables, outputs, and other accomplishments expected to be completed in FY89, FY90, and beyond are listed in Appendix B. Although these products are listed only under the programs they support, they are often applicable to problems in more than one program area because of the many common ground-water technical information needs.

Monitoring Research

EPA Regions and states need faster and more cost-effective methods for the detection, mapping, and monitoring of contaminants in the ground-water and vadose (unsaturated) zones of the subsurface. A number of advanced geophysical and geochemical methods for monitoring subsurface contamination show great promise for saving time and expense in monitoring the subsurface. These methods are being evaluated under laboratory and field conditions. Additional monitoring research is being conducted to improve methods for interpreting large data sets and characterizing the hydrological, physical, and chemical properties of contaminated sites. Monitoring research is conducted for the RCRA hazardous waste, Superfund, and drinking water programs (Figure 4).

RCRA Hazardous Waste Monitoring Research

High-priority monitoring research under the RCRA program emphasizes the evaluation of methods and equipment for monitoring contamination of the unsaturated zone and ground water around RCRA hazardous waste facilities. Other priority research is the development of methods for characterizing underground storage tank environments to enable the determination of the boundaries of contamination and background levels of contaminants. Closely related to this is the evaluation of remediation methods for cleaning up contamination from leaking underground storage tanks. Research areas with less emphasis are the development of geostatistical data interpretation methods, evaluation of special monitoring problems for municipal waste facilities, standardi-

zation of monitoring methods, and evaluating underground storage tank external leak detection methods.

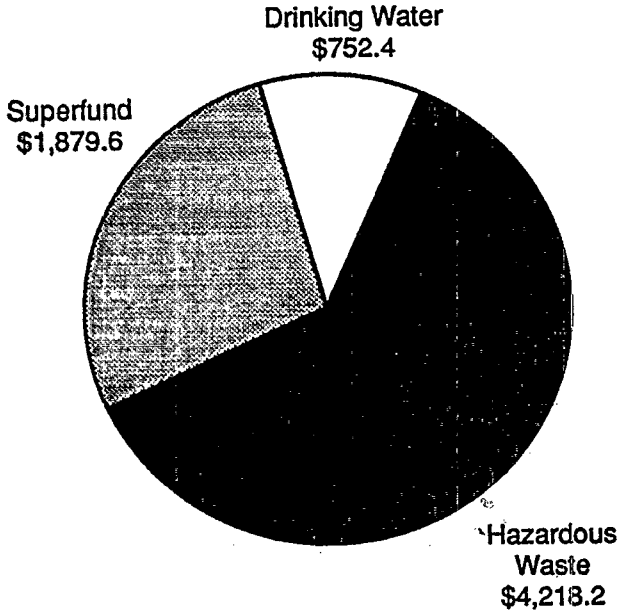

Figure 4. ORD FY89 monitoring research resources (in thousands).

RCRA Hazardous Waste Facility Methods

To support permitting and compliance at RCRA hazardous waste storage, treatment, and disposal facilities, EMSL-LV develops advanced field monitoring and geophysical screening technologies for detecting contaminants and their concentrations, measuring ground-water movements, and determining subsurface physical and chemical characteristics. EMSL-LV is investigating operational characteristics, performance standards, and siting criteria for commercially developed technologies as well as developing promising technologies not commercially available. The objective is to provide methods to collect better and lower-cost hydrogeologic information.

Monitoring of the unsaturated zone is designed to detect leaching and percolation of pollutants from waste sites before they reach ground water. EMSL-LV is evaluating the performance and efficiency of unsaturated zone monitoring equipment, determining limits for their application, and establishing installation procedures for monitoring at RCRA facilities (in conjunction with a larger Superfund research effort). Standard procedures for the operation of selected equipment will be prepared that meet *American Society for Testing and Materials* (ASTM) guidelines. Draft standard procedures are being developed for using sampling and analysis equipment for monitoring unsaturated zone liquids trapped in soil pores and soil gases that may contain volatile organic contaminants.

Conventional monitoring of ground water involves drilling monitoring wells, using various devices for collecting samples (bailing, pumping, *in situ* samplers), and sending the samples to a laboratory for analysis. A great deal of research in the past few years has provided monitoring well construction methods and sampling techniques that produce samples truly representative of the source. EMSL-LV is continuing its efforts to improve ground-water monitoring methods through the development of guidance on sampling frequency, well casing materials, and monitoring well network design. The seasonal and temporal variability of volatile organics in ground water in arid and humid climates is being investigated to determine optimal sampling intervals in these situations. A historical database including RCRA, Superfund, Department of Defense, and other monitoring data has been compiled and is being studied to determine chemicals that may be used as indicators of contamination from specific industries. A longer term project being initiated is the development of standard test procedures to guide field personnel in evaluating ground-water sampling devices under specific conditions.

Geophysical monitoring methods are remote sensing methods for determining subsurface characteristics and contaminant locations. They include use of electromagnetics, electrical resistivity, seismic methods, magnetics, ground-penetrating radar, and various borehole methods. By remotely measuring anomalies in electrical currents, reflected or refracted shock waves, reflected radar, and other target aspects, subsurface conditions can be inferred. The advantages of geophysical methods are that they do not require laboratory sample analysis and can generate extensive, low-cost information. The disadvantages are that their resolution is low and more than one interpretation of the data can often be made. Direct sampling of the subsurface in conjunction with geophysical measurements can greatly reduce these limitations.

The effectiveness of geophysical methods has been demonstrated for delineating subsurface pro-

perties and contamination. Research into the application of these methods for Superfund and RCRA field use is a major priority. RCRA geophysical research is smaller than, and coordinated with, the Superfund geophysical research program, concentrating on adapting borehole technologies to lower the cost of RCRA hazardous waste facility monitoring. Theoretical model studies are used by EMSL-LV to select methods that can be applied to RCRA needs, followed by field and laboratory evaluations of the various methods. EMSL-LV is now field testing a surface-to-borehole resistivity method, where an electrical current is applied to the surface and resistivity measurements down a borehole, combined with the known resistivities of subsurface materials, can be used to increase the vertical resolution of geophysically detecting subsurface contamination.

Two other advanced field technologies that are being adapted to RCRA needs (in conjunction with a larger Superfund research effort) are X-ray fluorescence spectrometry methods for detecting metal contaminants and fiber-optic technologies for *in situ* monitoring of organic contaminants in ground water. The application of these techniques will provide operators of hazardous waste facilities with the means to rapidly screen for hazardous constituents migrating from a site. Field testing of a prototype, portable X-ray fluorescence system is about to be completed. EMSL-LV has recently begun development of a portable, ultraviolet fiber-optic analytical system that can detect aromatic hydrocarbons in ground water. These technologies are described further in the Superfund monitoring research description.

While there is an established EPA program to ensure the quality of analytical chemical data, there is no equivalent program to ensure that samples are collected correctly or that field data collection is performed according to set protocols. EMSL-LV has established a research project to provide standardized EPA procedures for subsurface monitoring in conformance with guidelines of the ASTM. Protocols are being completed for the design and installation of ground-water monitoring wells and for determining critical aquifer properties. Other standards are being developed for measuring hydraulic conductivity in the unsaturated zone and for sampling in ground-water wells.

Site Characterization Methods

Because ground-water monitoring data are often scarce and inappropriate for classical statistical analysis, new geostatistical designs and data interpretation tools are needed to more efficiently use available data. Geostatistical analyses and simulations of aquifer parameters are being used to evaluate the effects of spatial variability on ground-water monitoring network design and data interpretation. Statistical and geostatistical methods are being developed or acquired and incorporated into appropriate software packages.

Municipal Waste Facilities

To ensure safe disposal of the large volumes of municipal wastes, monitoring systems must account for site-specific conditions and the materials being disposed. EMSL-LV evaluates hydrogeologic environments, existing monitoring network effectiveness, and types of contaminants to improve monitoring methods for specific disposal problems. A guidance document has recently been completed in cooperation with the National Park Service for monitoring in karst terrains (limestone bedrock where ground water can flow very rapidly through underground conduits and caves). Guidance on monitoring landfills located in fractured bedrock environments is almost completed, and work is in progress on guidance for monitoring landfills containing municipal waste incineration ash.

Underground Storage Tank Methods

To support the implementation of underground storage tank regulations, EMSL-LV is emphasizing the development of protocols for installing external leak detection systems, site characterization procedures for determining the boundaries of active leaks, and methods to monitor cleanups.

Installers of underground storage tank monitoring systems need guidance on the design and performance characteristics of external monitoring systems. To provide this guidance, EMSL-LV is evaluating external leak detection monitoring systems and the impacts of site-specific conditions and monitoring systems on the effectiveness of monitoring network designs. Performance criteria are being established to aid instrument manufacturers in their development and testing of external leak detection monitoring methods. Standard test protocols are also being developed so that leak

detection instruments can be evaluated on a common basis. Standard operating procedures for external leak detection systems are being developed to help installers select and install effective systems. Data from these studies and mathematical models are being used to develop a guidance manual on the design of external leak detection systems.

Improved methods for characterizing site-specific effects on contaminants leaking from underground storage tanks are needed to help determine active leaks, the boundaries for cleanup actions, and the success of cleanups. Controlled laboratory experiments in physical models are being conducted to characterize hydrocarbon liquid and vapor movement through soils and into ground water. The effects of fuel type, leak rate, moisture, temperature, backfill, and other chemical, physical, and biological processes that control hydrocarbon concentrations around underground storage tanks are being studied. EMSL-LV is also conducting field studies at selected service stations and examining existing soil-gas and meteorological monitoring networks to determine soil-gas concentration baselines and the influence of seasonal variables on soil-gas hydrocarbon concentrations. In the longer term, EMSL-LV has begun development of miniaturized electronic (microelectrode) vapor sensors that will be capable of inexpensively detecting specific hydrocarbon vapors released from leaking underground storage tanks.

Closely related to site characterization research, EMSL-LV is comparing the effectiveness of various physical, chemical, and biological methods for cleaning up leaks and is developing an inexpensive on-site analysis method for monitoring cleanup activities. Information on the success and failure of past cleanup actions is being generated through the soil-gas monitoring network and physical models described above. In addition, a database is being compiled from industries and other organizations regarding their monitoring and remediation activities. This information will be used as a basis for developing guidance on monitoring and remediation of underground storage tank sites.

Superfund Monitoring Research

Superfund monitoring research emphasizes the development of improved geophysical technologies to characterize hydrogeology and advanced field monitoring methods to detect contaminants at Superfund sites. The priority of these research activities is the development of technologies that will allow more rapid and less expensive assessment of the hazards posed by Superfund sites. To help make these technologies available to field personnel, demonstrations of prototype technologies are being demonstrated in the field to encourage their commercialization.

Geophysical Site Assessment Procedures

Further research is needed to improve the resolution of various geophysical techniques, data interpretation procedures, and guidance to field staff. Geophysical methods being studied include seismic, electrical resistivity, and ground-penetrating radar methods.

A study on the application of seismic reflection techniques for determining near-surface geologic features at a hazardous waste site has recently been completed. Seismic techniques utilize a mechanical or explosive device to set up a subsurface compression wave. Measurements of the time it takes for the compression wave to reach various distances from the source and the amplitude of resulting ground motion are used to develop a rough profile of the subsurface. This method can, for example, delineate the boundaries of subsurface trenches containing wastes and the depth of landfills.

Controlled field tests of a number of electrical resistivity methods for the direct detection of organic contaminants are near completion. EMSL-LV is particularly interested in examining the effects of the interaction between organic chemicals and clay minerals, which can affect the response of resistivity surveys.

The investigation of appropriate uses for new ground-penetrating radar equipment has also been initiated. This technology makes use of the fact that radar pulses directed into the ground are reflected back toward the surface where there is a contrast in the electrical properties of subsurface materials. Generally, good electrical conductors, such as metal drums, saturated clays, and salt water, reflect back more of the radar signal than poor conductors, such as unsaturated sands. A major drawback to this technology is its relative lack of resolution.

Guidance documents will be prepared on the use of these rapid and inexpensive field site characterization methods. In addition, a geophysics

expert system is updated annually to assist field personnel in choosing geophysical methods at Superfund sites. The updates incorporate the latest information on geophysical methods applicable to Superfund site characterization.

Advanced Field Monitoring Techniques

New technologies capable of rapid data generation in the field are greatly reducing the amount of time required to assess contaminants at Superfund sites. EMSL-LV has established an advanced field monitoring methods research program to identify, evaluate, and accelerate the development of promising on-site monitoring technologies. Technologies currently being emphasized in this program are fiber optic-based sensing, immunoassay detection methods, and portable X-ray fluorescence systems.

Fiber optic-based sensors for *in situ* monitoring of subsurface contaminants rely on the ability of optical fibers to transmit light of various wavelengths to the subsurface and back again. The interaction of a chemical sensor at the end of the optical fiber and the chemical it is contacting can result in fluorescence (re-emitting the light at a lower frequency), reflection, or absorption. A spectrometer at the other end of the optical fiber then can analyze the spectra of returning fluoresced light, which will differ depending on the chemical. This research emphasizes the development of sensors that are sensitive to particular chemicals or classes of compounds, developing advanced spectroscopic equipment that can be used in the field, and combining various chemical sensors and analytical equipment into systems that can be used in the field to rapidly and remotely detect contaminants. Since volatile organic compounds are among the most common contaminants at Superfund sites, initial analytical and sampling efforts will focus on these compounds.

Immunoassay methods for detecting contaminants rely on the ability of organisms to produce antigens that are highly sensitive to particular chemicals. Immunoassay techniques have been applied to the analysis of many hazardous substances and have several attributes that make them particularly suitable for field screening—they are applicable to a wide range of compounds, sensitive, fast, and accurate. A list of target compounds for immunoassay development has been developed, including various classes of pesticides and chlorinated hydrocarbons. EMSL-LV is evaluating existing immunoassay systems and adapting them to EPA needs. An important aspect of this research is coordination with the fiber optics research project to develop hybrid technologies that are highly specific and sensitive.

A prototype portable X-ray fluorescence unit has been jointly developed by EPA and the National Aeronautics and Space Administration for delineating subsurface inorganic metal contamination at Superfund sites. This version includes a telemetry system to feed data into a personal computer to analyze data on-site and immediately locate the position of detected metal contaminants. Field testing of this unit is being completed and a final project report on its capabilities is about to be published. EMSL-LV is also redesigning the X-ray fluorescence system to fit down monitoring wells for detecting subsurface metal contaminants.

Cooperative agreements with the private sector will be used to accelerate the development and commercialization of advanced field monitoring techniques. Field systems that fill voids in existing capabilities will be recommended for field demonstration under the Superfund Innovative Technology Evaluation (SITE) program.

Monitoring System Demonstrations

Establishment of the SITE program was required by the Superfund amendments of 1986 to speed up the commercialization of promising new technologies and their application to Superfund problems. Under the SITE program, the performance of monitoring technologies are demonstrated at Superfund sites by their developers while EPA provides quality assurance oversight and analysis of the demonstration results.

SITE demonstrations are emphasizing simple, rapid, and inexpensive field deployable monitoring instruments that utilize fiber-optic, immunoassay, X-ray fluorescence, and other technologies. Procedures for proper operation of these technologies to detect and quantify toxicants at sites are being developed as systems are demonstrated. When appropriate, data management and analysis for these evaluations will use geographical information system (GIS) technology. It is expected that field demonstrations of monitoring technologies will concentrate on technologies that have been carefully selected for their usefulness at Superfund sites. The expense of field work limits the number of technologies that can be demon-

strated.

Drinking Water Monitoring Research

Priorities for drinking water monitoring research are the development of methods to monitor the migration of contaminants from underground injection wells and toward drinking water wellhead areas.

Ground-Water Quality Monitoring Methods

To support the implementation of SDWA provisions concerning underground injection control (UIC) and wellhead protection, EMSL-LV is testing ground-water monitoring technologies and designs for protecting ground-water sources of drinking water. The depth at which hazardous wastes are injected makes it difficult and expensive to monitor the migration of contaminant plumes for movement into drinking water supplies. EMSL-LV is examining the resolution and detection limits of surface-to-borehole electrical resistivity methods for the mapping and monitoring of fluid movement from underground injection wells. If successful, this geophysical method would allow monitoring with far fewer monitoring wells and sample analyses. Geophysical methods are also being investigated for detecting near-surface contamination caused by movement up abandoned wells and fracture zones. Unlike RCRA monitoring needs, where contaminants are monitored to detect migration from a facility, wellhead protection monitoring designs must provide warning of contaminants migrating toward a water supply well or wellfield. In addition, the wellhead protection area to be monitored can be very large, requiring many wells or monitoring points. EMSL-LV is developing guidance on cost-effective monitoring strategies for wellhead protection areas to warn of contaminants nearing drinking water wells.

EMSL-LV is also developing indicator parameters for cost-effective detection of point and non-point sources of contamination in ground water, preparing suggestions on the construction of ground-water monitoring wells, and identifying sources of spatial and temporal variability in ground-water monitoring data.

Transport and Transformation Research

Lack of understanding of how contaminants move in the subsurface and are degraded by natural environmental processes severely restricts the Agency's ability to protect ground-water quality or to design effective systems to clean up contaminated ground water. The impacts of the Agency's regulatory options can be understood based on predictions of contaminant concentrations at some point of exposure, and such predictions are dependent on a qualitative and quantitative understanding of subsurface processes. Research into the transport and transformation of contaminants in the subsurface is fundamental to advances in monitoring, aquifer remediation, and underground source control research.

Transport research is generally divided into two areas—processes affecting organic contaminants and processes affecting inorganic (metal) contaminants. Research into the transformation of contaminants into by-products with different health and environmental effects is similarly divided into two areas—physical and chemical (abiotic) transformation processes and microbiological degradation (biotic) processes.

ORD conducts transport and transformation research for the RCRA hazardous waste, drinking water, and pesticides programs. In addition, EPA's exploratory research program funds basic research to improve understanding of subsurface processes affecting contaminants (Figure 5).

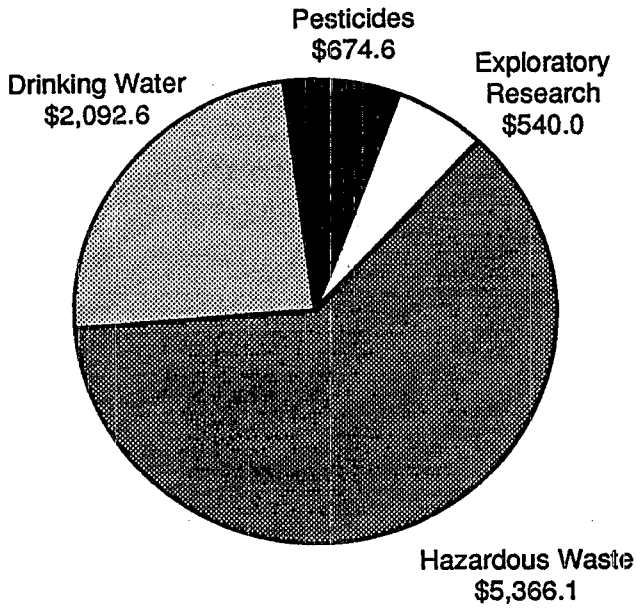

Figure 5. ORD FY89 transport and transformation research resources (in thousands).

RCRA Hazardous Waste Transport and Transformation Research

RCRA hazardous waste transport and transformation research is conducted by RSKERL-Ada and ERL-Athens.

RSKERL-Ada's highest priority research is the investigation of complex subsurface properties and processes that facilitate or retard the transport of organic contaminants. Closely related to this is mathematical modeling of these processes. RSKERL-Ada also conducts smaller research efforts on the spatial variability of subsurface properties, transport of metals attached to colloids, safety of hazardous waste land treatment, fate of residual hazardous wastes left in the subsurface when a RCRA facility is closed, and fate of dioxins in the subsurface.

ERL-Athens' transport and transformation research under the RCRA program emphasizes the development of exposure assessment modeling packages that link together transport and transformation models to allow predictions of metal and organic contaminant concentrations in ground water and the unsaturated zone. ERL-Athens conducts laboratory and field research projects to determine processes controlling the transport of metals in the subsurface and to estimate biotic and abiotic organic chemical transformation rates based on molecular structure. This information is incorporated into exposure models for OSW use in evaluating land disposal and facility closure options.

RCRA Hazardous Waste Concentration Predictions

Although the flow of water through uncontaminated, homogeneous aquifers is reasonably well understood, the processes affecting the transport of contaminants by ground water, particularly in heterogeneous aquifers, is poorly understood. This RSKERL-Ada research concentrates on developing an understanding of processes that either retard or facilitate the movement of organic contaminants in the subsurface and using this information is used to improve the capability of predicting contaminant concentrations.

"Facilitated transport" is a generic term encompassing processes that increase contaminant mobility, which often results in ground-water contamination in unexpected locations. Because contaminants leaking from RCRA facilities are usually complex mixtures of organic compounds, RSKERL-Ada is investigating the effects of multiple solvents within these mixtures in facilitating organic chemical transport. Although many contaminants do not dissolve in water, they can be dissolved by organic solvents in complex mixtures and may travel faster in this dissolved phase. RSKERL-Ada is studying the effects of miscible (capable of being dissolved in water) and immiscible (not capable of being dissolved in water) solvents on the transport of contaminants in soils and aquifers. Studies are also being conducted to evaluate the impact of solvent composition varying over time on the transport of immiscible organic solutes. Data from these experiments are used to develop and evaluate mathematical approaches to describe the phenomenon.

Laboratory tests have shown that significant amounts of immiscible contaminants, such as gasoline, can be trapped in soil pore spaces, retarding their movement and making them difficult to remove from the subsurface. These trapped contaminants can be a long-term source of ground-water contamination. RSKERL-Ada is studying how these contaminants are released from pore spaces, the effect of trapped immiscible contaminants on transport of dissolved contaminants, and the possible use of solvents to enhance their release from pore spaces. Algorithms describing these processes are being developed and refined.

The data and mathematical descriptions developed in these and other research projects are used to develop and test models for predicting the concentrations of hazardous wastes released from RCRA facilities. The ultimate goal of RSKERL-Ada's ground-water modeling research is to provide field-evaluated models to predict the concentrations of contaminants in the subsurface at some point of discharge or use. RSKERL-Ada's efforts include the development of high-quality field databases for retrospective ground-water pollutant model testing; improvement of predictive models by incorporating into models abiotic and biotic processes that are not normally included, such as multi-phase flow, particle transport, and second-order microbial transformations; compiling and evaluating existing models and solutions that can by used for predicting contaminant transport and transformation in the subsurface as well as for testing the validity of the algorithms in numerical models; and increasing the useability of models such as RITZ and BIOPLUME through the development of user-friendly software and the use of geostatistical

models and expert systems for providing input data for models.

Current models that describe contaminant transport are largely derived from laboratory data and observations. Although many of these can be useful in certain applications, there is a need to evaluate a model's performance by comparison to a physical model of the same system. This is being done by RSKERL-Ada through the use of its two large physical models that simulate ground-water flow. The models are instrumented to track transport and fate of contaminants introduced into the systems and evaluate model predictions. Although these physical model tests are conducted under simplified conditions, they provide a cost-effective transition from laboratory verification of model predictions to expensive, full-scale field testing.

Most subsurface formations are heterogeneous, but the impact of variability in important subsurface properties that control pollutant transport and fate is not well understood. RSKERL-Ada is developing methods for characterizing the variability of subsurface properties on a site-specific basis and evaluating the impact of spatial variability on transport processes and chemical and biological reactions at selected sites. Statistically valid and field-tested methods are being developed for use by field personnel in characterizing the spatial variability of subsurface properties at waste sites in a cost-effective manner.

The movement of contaminants through fractured bedrock systems is one of the most difficult conditions to predict. The predominant flow, which can be very rapid, is through cracks and fracture zones in the bedrock. Movement also can occur through the rock matrix, depending on its porosity. Laboratory studies are developing data on the basic properties and processes of porosity, diffusion, sorption, and ion-exchange that control transport in fractured systems. These data are being used to develop and test models that predict transport of contaminants in fractured bedrock.

RSKERL-Ada also conducts research of a more applied nature under the RCRA program. By statute, the land treatment of hazardous wastes (including residual wastes at closed RCRA facilities) must be limited to those wastes that either can be treated to performance standards or that have been demonstrated to show no migration from the soil treatment zone for as long as the waste remains hazardous. RSKERL-Ada is conducting land treatability studies at wood preserving, food processing, paint stripping, and oil refinery industry sites. This involves collecting waste and soil samples from specific sites and conducting laboratory evaluations of the movement and natural degradation of the wastes. This research also provides EPA with the opportunity to test the Regulatory Investigative Treatment Zone (RITZ) model developed at RSKERL-Ada for predicting long-term transport and fate of organic contaminants. A limited number of sites will be monitored over time to evaluate RITZ predictions.

RSKERL-Ada is completing a research program to provide techniques and data for predicting the rate of movement and transformation of 2,3,7,8-tetrachlorodibenzo-P-dioxin in soils and ground water in the presence and absence of solvents. These data are needed to assess the potential for human exposure to dioxin and to make rational decisions regarding the removal and disposition of dioxin-containing soils.

Exposure Assessment Methods

The objective of ERL-Athens' transport and transformation research under the RCRA program is to develop and refine exposure assessment models for use by OSW in evaluating land disposal and facility closure options. The development of data on metal and organic contaminant reaction rates for use in these models is an important aspect of ERL-Athens research.

ERL-Athens is refining MINTEQA2, a major metals transport model being used by OSW to determine the potential human health and environmental impacts of RCRA regulatory options. The original version of MINTEQ was distributed in FY86 essentially as a metals equilibrium model able to estimate dissolved and precipitated metal fractions. The model has undergone continual refinement to improve its accuracy and usefulness. The current research supporting MINTEQA2 involves the development of databases on metal reaction rate constants needed to provide more accurate transport and transformation input data for the model. Sorption of metals to iron, manganese, and organic oxides is an especially important process affecting the mobility of metals in the subsurface. ERL-Athens is conducting laboratory experiments to determine sorption rate constants for the sorption of 13 metals regulated under RCRA. The complexation of

metals to naturally occurring organic material (humics) is another important process affecting metals transport that ERL-Athens is studying. Sorption and complexation of metals render them less mobile, but other processes may increase the mobility of metals in the subsurface. Such processes under investigation include the effect of redox potential and other properties on metal speciation, sorption to simple organic compounds, and colloidal transport. This research receives significant funds directly from OSW, which are not shown in the ground-water research budget presented in Appendix A.

ERL-Athens is about to release another major exposure assessment model, called MultiMed, for predicting the transport of organic contaminants from RCRA landfills. The model links together components for ground water, surface water, and air into a multimedia exposure assessment modeling package for use by OSW in making regulatory decisions. The ground-water component of MultiMed is the EPA Composite Landfill Model (EPACML), which is itself comprised of two components for estimating organic contaminant attenuation and transport through the unsaturated zone and ground water.

A project to link the metals transport model, MINTEQA2, with the organic transport models RUSTIC (discussed in the pesticides transport and transformation section) and EPACML is in the conceptual stage. The results of MINTEQ would feed into the organic transport models to predict the transport of dissolved metals and those attached to simple organic compounds that have an affinity to metals.

ERL-Athens also conducts research to estimate organic contaminant reaction rates that are important to the transport and transformation of organics in the unsaturated zone and ground water. This data is needed to improve the input data for EPACML and other organic transport models. This research complements RSKERL-Ada research to improve fundamental understanding of these phenomena. Instead of conducting laboratory experiments on every possible organic contaminant, ERL-Athens has developed an approach for estimating microbial and abiotic rate constants based on mathematical modeling of molecular structure. Detailed laboratory studies are being conducted to describe hydrolysis and redox transformation reactions as a function of key environmental parameters (*p*H and redox potential) and molecular structure. Molecular structure is determined by spectroscopic analysis (which is much less expensive than laboratory rate constant measurements) and correlated to the transformation rates of similarly structured compounds determined in the laboratory experiments.

A range of organic contaminants have been subjected to laboratory assays to examine how their chemical structure and key environmental parameters influence microbial degradation. Models are being refined that describe the rate and extent of microbial degradation of benchmark chemicals. Degradation rates for additional organic contaminants are then estimated in a model by relating their structure to the benchmark chemical degradation rates. Laboratory experiments are conducted to determine the effects of important environmental variables and to verify selected estimated rate constants.

In addition to determining rate constants, ERL-Athens is developing 'transformation pathway profiles,' which show the chemical changes that a contaminant can pass through during transformation. Mathematical modeling then permits determination of the concentration of each transformation by-product under various environmental conditions.

Drinking Water Transport and Transformation Research

RSKERL-Ada transport and transformation research under the drinking water program emphasizes investigations of organic contaminant transport. This organic contaminant transport research complements similar research conducted under the RCRA program—RCRA research concentrates on facilitated transport by contaminants that act as solvents for other contaminants and transport retarded by the trapping of immiscible contaminants in soil pore spaces; drinking water research concentrates on facilitated transport by the movement of macromolecules and transport retarded by sorption processes.

Other high-priority research areas are studies of subsurface transformation of organic compounds by indigenous microorganisms and the development of wellhead protection methods that can be used to protect sources of subsurface drinking water. RSKERL-Ada conducts smaller research projects to study abiotic transformations of organic compounds and the transport of viruses and bacteria through the subsurface.

Contaminant Concentration Predictions

The ability to predict the concentration of contaminants at a selected future point of time is needed to conduct exposure and risk assessments and to control specific contaminant sources. This research is intended to provide the fundamental data on subsurface processes that are most significant in affecting contaminant transport and transformation in order to enable accurate predictions of contaminant persistence, movement, and concentrations.

RSKERL-Ada's research into transport phenomena under the drinking water program concentrates on sorption processes affecting organic contaminants. Past research with organic contaminants has indicated a number of important sorption processes that need study. While sorption can retard the spread of contaminants in ground water, it can also make contaminant removal very difficult and time consuming. A series of RSKERL-Ada research projects will investigate the processes that control the sorption of miscible and immiscible organic contaminants to subsurface materials. The sorption of organic cations to clay minerals, soils containing low levels of organic material, and soils containing high levels of organic material is being studied and compared. In addition, the effect of dissolved natural organic carbons on the partitioning of immiscible organic contaminants between the water, dissolved organic carbons, and sorbed to soils is being investigated. Algorithms that can describe these subsurface processes quantitatively are being developed, validated through laboratory and field experiments, and included in predictive models.

Vapor-phase transport is important in the movement and dissipation of volatile organic contaminants in the unsaturated zone. This transport is influenced by the soil moisture content, the distribution of organic vapors between the condensed and vapor phases, and the amount of organic vapor present in soil pore spaces. RSKERL-Ada is conducting laboratory research to quantify the influence of soil moisture content on the sorption and transport of a number of selected organic vapors. The collected data will be used to test existing models for soil vapor transport.

Facilitated transport research for the drinking water program investigates the transport of immiscible organic contaminants attached to very large molecules (macromolecules). RSKERL-Ada is studying whether the velocities of different organic macromolecules of the same apparent molecular weight are constant in a given soil, the range of pore sizes from which the macromolecules are being excluded, and if movement of the immiscible organics can be predicted by existing transport equations. The significance of size exclusion for selected soils is being studied to determine if this can be calculated using common soil characteristics. In addition, synthetic macromolecules are being studied to determine if they can be used to simulate transport by naturally occurring macromolecules.

Considerable information indicates that subsurface biological processes have a significant impact on the transformations of ground-water contaminants. RSKERL-Ada is conducting laboratory microcosm experiments to develop an information base on the degradation of classes of organic contaminants and pesticides by microorganisms native to different subsurface environments. The study includes important physical and chemical subsurface soil characteristics, microbial activity in different soils, enzymes involved in the degradation processes, and predominant chemical reactions. Correlations between microbial type, sediment type, and biodegradation potential are being sought to determine processes that limit or stimulate biodegradation. It is known that biodegradation occurs faster in aerobic (oxygenated) soils than in anaerobic (absence of oxygen) soils. Therefore, studies of anaerobic biodegradation of organic contaminants are being emphasized to find ways to improve biodegradation potential in anaerobic environments. Models for predicting the biodegradation of contaminants in the subsurface are being developed and their performance evaluated using field and laboratory data.

Although the natural microbial degradation of organic contaminants in the subsurface is recognized as a significant process and is being used to clean up contaminated sites, the movement of microorganisms in the subsurface in order to colonize areas of contamination is not well understood. Remediation techniques presume that contaminated aquifers already harbor organisms that are capable of degrading the contaminant. Site-specific information is needed that can be used to evaluate the prospects for colonization of a contaminated aquifer or the unsaturated zone by microorganisms. RSKERL-Ada is working with Cornell University to develop an understanding of

the properties of microorganisms and subsurface materials that determine the transportability of bacterial strains through geologic material and whether a particular site will be colonized by microorganisms capable of degrading wastes.

Most of RSKERL-Ada's transformation research is investigating process affecting organic contaminants, but the laboratory is also investigating a natural chemical (abiotic) process that can significantly affect organic contamination in certain subsurface environments. The role of subsurface soils containing iron and sulfur minerals on the transformation of halogenated organic compounds is being studied. The surface area, elemental composition, sorption, and other parameters that are expected to affect reactivity are being studied to determine the properties that control these reactions. Reaction rates are being measured to enable the development of a mathematical model describing this process.

In addition to protecting drinking water from organic, pesticide, metal and other hazardous contaminants, public water supplies need to be protected from disease-causing viral contaminants. An existing model of virus transport in soils and ground water is very simple in that it only considers horizontal movement of viruses under regional ground-water flow conditions. Improvements are needed to consider the transport of viruses through the unsaturated zone and the influence of pumping wells on the movement characteristics. The final model will have the capability of delineating zones around drinking water wells within which sources of contamination should not be placed if contamination by viruses is to be avoided. It will be developed for personal computers and data requirements will be limited to information available from local water utilities.

In support of United States' policy of scientific and technological cooperation with the People's Republic of China (PRC), the EPA and PRC entered into an agreement in 1980 known as the US-PRC Environmental Protection Protocol. The agreement provides for the establishment of a cooperative research program based on equal participation, information exchange, and mutual benefit. A joint research program has been established between PRC scientists and RSKERL-Ada to determine the impact of the land treatment of municipal and industrial wastewater on ground-water quality. Researchers from both countries will visit each other to exchange information on related topics involving land treatment and the control of ground-water contamination.

Wellhead Protection Methods

RSKERL-Ada is providing assistance to OGWP through the joint development of a five-year research strategy to aid states in the implementation of the SDWA amendments and a joint research program with the U.S. Geological Survey (USGS) to identify potential sources of contamination to wellhead protection areas. In addition, EMSL-LV is assisting several local agencies in designing and implementing pilot wellhead protection area monitoring systems. The FY89 EPA-sponsored USGS research is developing information for identifying sources of contamination in wellhead protection areas (WHPAs). Existing ground-water quality data is being collected to create a database for the development of models relating multiple sources of contaminants within WHPAs to shallow ground-water quality. The study includes statistical evaluations to determine the significance of hydrogeologic factors such as depth to ground-water, surface geology, ground-water flow direction, and recharge. Statistical relationships between human activities and ground-water quality will be used to determine areas where there is high potential for ground-water contamination. A geographical information system will be developed to allow easy management and interpretation of Regional information.

An FY90 initiative will significantly expand wellhead protection research. RSKERL-Ada will work to improve the scientific basis of, and clarify assumptions inherent in, wellhead protection delineation methods. Another research project to be started as part of the initiative will be on the capacity of the subsurface to assimilate contaminants and reduce their concentrations to acceptably low levels before they reach drinking water wells. This long-term research project is an opportunity to synthesize much of the information being developed on subsurface transport and transformation processes affecting contaminant concentrations. RSKERL-Ada will also conduct contaminant source assessment research to develop methods for determining the relative risks of different potential sources of contamination. Research into wellhead protection methods for agricultural regions will be conducted by ERL-Athens. The RUSTIC model developed for pesticides will be adapted to account for point and nonpoint contamination in delineating WHPAs in agricultural regions. In addition, EMSL-LV will

develop monitoring strategies applicable to wellhead protection areas, including using geographic information systems to manage data in a wellhead protection program and optimal sampling and monitoring network designs for wellhead protection programs.

Pesticides Transport and Transformation Research

ERL-Athens research under the pesticides transport and transformation program has two major components—the development of a modeling package to predict the fate of pesticides in the subsurface and major field projects to test the models and collect data on subsurface processes that control pesticide fate. Limited laboratory research is also conducted to fill gaps in parameters necessary for pesticide exposure modeling.

Pesticide Exposure Assessment Methods

ERL-Athens has developed a pesticide exposure model called RUSTIC (Risk of Unsaturated/Saturated Transport/transformation of Interactions for Chemical/concentration model). RUSTIC is comprised of three linked models—the Pesticide Root Zone Model (PRZM) for predicting transport and transformation of pesticides in surface soils (root zone), the VADOFT model for predicting transport in the unsaturated zone, and the SAFTMOD model for predicting transport in ground water. RUSTIC and its components are undergoing a series of field validations. A final report on the results of the Dougherty Plains Field Project is about to be released. The Dougherty Plains project evaluated the PRZM component of RUSTIC and provided information on the spatial variability of subsurface soils needed to evaluate pesticide leaching characteristics. ERL-Athens has begun work on another large field experiment at Plains, Georgia, in order to test the unsaturated and ground-water components of RUSTIC. ERL-Athens plans to collect field data on pesticide transformation processes in the unsaturated zone at the Plains, Georgia site. ERL-Athens is also working to improve the soils and meteorological databases included with the RUSTIC modeling package. As part of the wellhead protection research program, ERL-Athens will be enhancing RUSTIC for application to wellhead protection area delineation. Planned enhancements include the capability of handling multiple land segments, addition of a macropore flow component, and addition of a user-friendly interface to guide state and local personnel in its use.

ERL-Athens is developing a multimedia model for determining pesticide exposures to birds, animals, soil insects, and terrestrial ecosystems. The Terrestrial Ecosystem Exposure Assessment Model (TEEAM) includes PRZM and components for spray application, runoff, plant transport, and wildlife. Other components to be added include surface ponding and volatilization. A test version is planned for completion in about a year. The model is not inherently limited to pesticide exposure and may be adapted for use in estimating exposures from hazardous wastes. In addition, there is a possibility that TEEAM may be linked to RUSTIC in the future.

Laboratory studies are being conducted to relate pesticide molecular structure to the sorption of pesticides to solids in anaerobic aquifers and determine the key parameters that influence sorption processes. This information is being used to estimate reaction rates and equilibrium constants for pesticides to improve pesticide exposure models.

Exploratory Aquifer Remediation Research

EPA established the National Center for Ground-Water Research (NCGWR) in September, 1979, as a consortium of Rice University, the University of Oklahoma, and Oklahoma State University. As part of the EPA's Centers of Excellence program, the NCGWR is charged with developing and conducting a long-range exploratory research program to help anticipate and solve emerging ground-water problems.

National Center for Ground-Water Research

The Office of Exploratory Research provides base funding for the NCGWR, and another $1.8 million of research is funded through agreements with RSKERL-Ada, universities, the private sector, and other governmental units. The Center's co-directors and investigators work with the management and staff of RSKERL-Ada and other EPA laboratories to ensure that the exploratory research program is cooperatively planned, responsive to national needs, and appropriately linked to the Agency's mission. Technical oversight is provided by an eight-member panel of external scientific peers.

The four major areas of responsibility for the

Center's research are development of methods for ground-water quality investigations; transport and fate of pollutants in the subsurface; characterization of the subsurface environment with respect to pollutant transport; and information transfer. The NCGWR conducts five research projects under cooperative agreements with RSKERL-Ada, including research into land treatment, anaerobic microbial degradation, unsaturated zone transport modeling, isolation of a bacteria for degrading TCE, and case studies of Superfund site remedial activities. OER supports three additional projects to study transport and transformation processes and apply new information to *in situ* aquifer remediation methods.

Numerous theories have been proposed to account for frequent observations of unexpectedly slow release of organic contaminants from soils. A research project has recently begun to study soils from contaminated sites in the laboratory to develop an understanding of the mechanism of this slow release and to develop effective cleanup methods. Parameters being studied include flow rate, mixed solvents, *p*H effects, surfactants, and pumping regimes.

Another subsurface phenomena that results in the slower than expected release of contaminants from the subsurface is found where residual oils occur just above or below the water table. Fluctuations in the water table in this situation cause variable contaminant loadings to the ground water. Simple laboratory and field experiments are being conducted to help define variable source contributions from residual oil near the water table. In addition, BIOPLUME II will be improved to handle a variable source module.

Knowledge of the mechanisms by which *in situ* remediation can be optimized is limited. Another NCGWR project will investigate microbial transport through the subsurface, the effects of hydrogen peroxide on microbial populations, and the significance of emulsifiers and surfactants produced by subsurface microorganisms during degradation of contaminants in the subsurface.

In Situ Aquifer Remediation Research

In situ aquifer remediation methods show great potential as an alternative remedial action when a site has large volumes of soils with low levels of contamination. In this case, the cost of excavation for off-site disposal or on-site treatment are high in relation to the risk. Aquifer remediation research is often conducted in coordinated projects with fate and transport research. Its priority is to evaluate and develop cost-effective methods for *in situ* aquifer cleanup. Aquifer remediation research is conducted under the RCRA hazardous waste, Superfund, and drinking water programs (Figure 6).

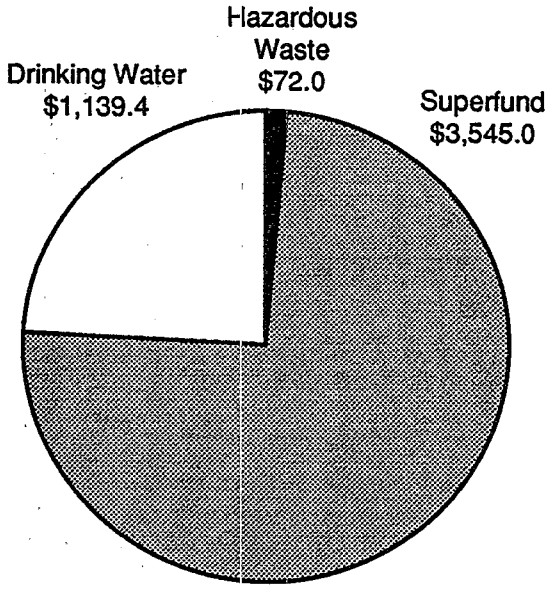

Figure 6. ORD FY89 *in situ* aquifer remediation research resources (in thousands).

RCRA Hazardous Waste Aquifer Remediation Research

RSKERL-Ada conducts a small in-house *in situ* aquifer remediation research program under the RCRA hazardous waste program. The research concentrates on determining the cost and effectiveness of selected techniques for cleaning up contaminants that have leaked from underground storage tanks.

Underground Storage Tank Corrective Action Methods

The state of the art in existing corrective action technologies for leaking underground storage tanks has been evaluated and a report was recently completed. Laboratory and modeling studies emphasized the determination of cost-effectiveness and applicability of techniques in various hydrogeological regimes.

RSKERL-Ada's current research program is investigating the effectiveness of purge-well pumping and forced-air-ventilation remediation techniques. An evaluation of contaminant response to purge-well pumping, including vapor-phase transport, sorption, partitioning, and biotransformation at an existing field site at Camp LaJeune, North Carolina is about to be completed. RSKERL-Ada has recently begun investigating the movement of volatile organic contaminants (VOCs) during forced air ventilation of the unsaturated zone. Physical properties of the soil, such as porosity, pore size distribution, and water content, are the primary limits to the transport of vapor-phase VOCs in the unsaturated zone. The impacts of these properties on vapor-phase movement of contaminants will be determined in laboratory studies and the results will be used in models for designing remediation processes.

Superfund Aquifer Remediation Research

In situ aquifer remediation research for the Superfund program emphasizes the development of *in situ* microbial degradation technologies, field demonstrations of these technologies, and modeling to help analyze remedial options. Another priority research area is the development of contaminant recovery techniques to more efficiently extract contaminants from the subsurface so that on-site treatment technologies can be applied.

Recovery Technologies

Recovery of contaminants without excavation of soils is an essential element of many treatment processes and remedial actions. RREL-Cin develops contaminant recovery technologies and evaluates their effectiveness, costs, and cross-media impacts. Technologies showing potential for commercial success are transferred to the SITE program for full-scale field evaluation. This program is characterized by research into technologies that do not currently offer a clear economic incentive to the commercial community. Two of the most promising techniques under investigation for improving *in situ* recovery processes are hydrofracturing and pulsed pumping.

Hydrofracturing is a technique where wells in low-permeability rock are pressurized with water to create cracks in the surrounding environment. Porous sand is then pumped into the wells to form long sand-filled lenses that open the system and increase recovery of contaminants. The cost and performance of this technology under site-specific conditions are being evaluated by RREL-Cin to provide guidance on its effective use.

A common means to recover contaminants from ground water is pumping the water to the surface where a variety of treatment technologies can be applied. A problem commonly encountered with this pump-and-treat technique is that, after an initial rapid decrease in the concentration of extracted contaminants, the last fraction of the contaminants takes a very long time, even decades, to extract. Pulsed pumping—the intermittent operation of a pump-and-treat system—is a technique that can avoid the expense of pumping and treating large volumes of water to remove low concentrations of contaminants. During periods when pumps are shut off, contaminants that are trapped in pore spaces or sorbed to subsurface materials can diffuse into more mobile ground-water zones until equilibrium is achieved. When the pumps are turned back on, the minimum volume of contaminated ground water can be removed at the maximum concentration. RREL-Cin is conducting research to improve understanding of the site-specific conditions that affect the performance of this extraction process. This information will be used to optimize pulsed-pumping systems and ensure uniform recovery.

Most contaminant recovery processes involve removal of contaminants through the water phase. However, particular classes of contaminants may be extracted more effectively through the vapor phase. RREL-Cin is examining data generated on major contaminant groupings to determine which contaminants can be recovered effectively based on removal from unsaturated zones in the vapor phase. Promising vapor-phase recovery technologies being evaluated include vacuum extraction for recovering VOCs and techniques that can be combined with vacuum extraction to recover less volatile organic contaminants. Two technologies being studied that can mobilize less volatile contaminants and increase subsurface air flow are radio frequency heating and steam injection.

Emerging Biosystems

Microbial degradation treatment systems (biosystems) are processes for the controlled use of microorganisms and their products for breaking down hazardous wastes to non-hazardous compounds. Biosystems offer the capability of using

the broad versatility of microorganisms for degrading mixed wastes; the ability to tailor treatment processes toward specific compounds or groups of compounds at specific sites; the potential to eliminate soil excavation and transportation costs; and the minimization of air emissions caused by the movement of contaminants.

ORD's Superfund biosystems research program includes the evaluation and development of systems for *in situ* aquifer remediation and on-site treatment applications. Biosystems research is a centrally coordinated, multi-laboratory program utilizing the combined capabilities of RREL-Cin, RSKERL-Ada, and ERL-Athens. Only *in situ* biosystem applications are included in this ground-water research description.

RREL-Cin conducts two projects to develop innovative *in situ* biosystem applications. In the first, laboratory and field testing is being conducted to determine the potential for the bacteria FM4100, genetically engineered by General Electric, to biodegrade polychlorinated biphenyls (PCBs) in Superfund soils. The comparison of this organism to the performance of *Pseudomonas putida* will enable the first analysis of a native versus a recombinant-DNA organism for degrading PCBs on soils. RREL-Cin's other project involves the design of an *in situ* soil contamination treatment technology using the white rot fungus, *Phanerochaeta chrysosporium.* Bench-scale studies will be designed to determine its ability to degrade pentachlorophenol (PCP) and selected major constituents of creosote through the use of carbon-labeled substrates and counting of evolved carbon dioxide concentrations.

RSKERL-Ada is completing combined laboratory, field, and modeling studies on the effect of enhancing natural microbial aerobic degradation processes through the addition of hydrogen peroxide to an area contaminated by a gasoline spill. This project is being conducted in cooperation with the U.S. Coast Guard at the Traverse City, Michigan, Coast Guard Station. Laboratory microcosm experiments were used to define the specific role of microorganisms and determine whether that role could be enhanced by adding hydrogen peroxide to the contaminated area as a source of oxygen needed for microbial metabolism of the contaminants. Laboratory results were used to design a field experiment to evaluate enhanced microbial remediation of a contaminated area by adding hydrogen peroxide and monitoring contaminant concentrations and movement. The data from this project were used to identify and evaluate the hydrological, chemical, and biological parameters that control *in situ* microbial remediation. The field study was also used to evaluate BIOPLUME II, a mathematical model of *in situ* microbial remediation used to estimate the time and cost of returning a site to a specific level of restoration.

RSKERL-Ada is conducting a similar series of studies in cooperation with the U.S. Coast Guard on the effectiveness of enhancing microbial denitrification processes for the remediation of soils contaminated by jet fuel at the Traverse City site. Laboratory microcosm experiments are being conducted to determine the specific role of microorganisms and whether that role can be enhanced through the addition of nitrate or nitrous oxide. The BIOPLUME II model is being modified to describe microbial degradation of jet fuel components. The modified model will be used to design an *in situ* perfusion cell to bathe the contaminated region of the aquifer with nitrate-amended water. Recovery wells will reclaim any nitrate that is not consumed by the bacteria to prevent regional contamination of the aquifer. The progress of the field demonstration will be followed, and the results of the demonstration will be compared with model projections.

ERL-Athens is conducting experiments to determine the extent to which sorption processes affect the degradation of specific classes of hazardous organic chemicals and to determine if the addition of emulsifying agents can enhance bioremediation. The sorption of chemicals to solid substrates inhibits the degradation of organic chemicals by lowering the concentration of available substrate. The degradation rate of sorbed or highly insoluble substrates can be increased by making the substrates more available to the microorganisms. Artificial emulsifiers have been used to enhance the degradation of PCB mixtures. ERL-Athens will examine the effects of adding emulsifiers on the degradation of other insoluble compounds, including 4-chlorophenol, chlorobenzenes, and polyaromatic hydrocarbons (PAHs). The results of these experiments will be used to develop mathematical models to predict the effects of emulsifying agents.

Drinking Water Aquifer Remediation Research

In situ aquifer remediation research under the drinking water program provides methods and data for decision-makers to evaluate aquifer reme-

diation options. Promising methods revealed through transport and transformation research are being tested for contaminant removal efficiency and cost-effectiveness. The research emphasizes microbial degradation of TCE and related compounds by methane-utilizing microorganisms. Another important project is the development of an expert system, OASIS, to assist field staff in evaluating possible aquifer remedial activities. Smaller projects include investigations of TCE removal from the unsaturated zone using ozone, chemical processes to degrade organic contaminants, and microbial degradation of PCB.

Aquifer Remediation Methods

The contamination of ground water with trichloroethylene (TCE) and other compounds within this class of chemicals continues to be one of the most pervasive environmental problems in the United States and other industrialized countries. Currently accepted techniques for the remediation of aquifers contaminated by this class of chemicals primarily involve pumping the water to the surface and removing contaminants by air stripping or carbon adsorption. These procedures are expensive and time consuming. Prior research by RSKERL-Ada and elsewhere has identified the use of native bacteria capable of metabolizing methane (methanotrophic) as a promising approach for *in situ* remediation of aquifers contaminated by TCE and related compounds. Under a cooperative agreement with Stanford University, a small, pilot-scale field demonstration has been conducted to determine the feasibility of using these microorganisms to remove TCE and related contaminants from ground water. Information on the range of conditions under which the treatment method was effective and criteria for *in situ* treatment of contaminants in the field have been developed.

A number of research projects are underway to improve the removal of TCE-related contaminants from ground water by methanotrophic bacteria. A field demonstration of a system using methane to support the growth of TCE-metabolizing organisms is being conducted in cooperation with the U.S. Air Force at the Tinker Air Force Base in Oklahoma. Information on design criteria for full-scale systems and cost evaluations are being developed. In addition, new strains of methanogenic microorganisms are being sought. Methanotrophic organisms capable of degrading TCE will be isolated or genetically engineered to develop strains that can grow in the absence of methane, allowing growth on TCE as a sole source of energy.

The feasibility of using ozone instead of air is being evaluated by RSKERL-Ada for *in situ* vapor stripping systems that are used to remove TCE, tetrachloroethylene (PCE), and related compounds from unsaturated soils. The study is assessing the reactivity of ozone in unsaturated soils, the role of humic acids in reactions with these contaminants, and rates of ozone and contaminant decomposition.

The feasibility of a chemically based *in situ* remediation process using free-radical reactions to degrade organic contaminants is being studied by RSKERL-Ada. The free radicals will be introduced into columns containing aquifer materials and several organic contaminants. At the end of the experiments, the aquifer material will be extracted to determine residual contaminant concentrations. Free radical effects on aquifer material will be evaluated through measurement of total organic carbon before and after the experiment.

RSKERL-Ada is also evaluating microbial degradation methods for the treatment of PCB and related compounds. Laboratory experiments of PCB degradation are being conducted using a mixed oily waste containing PCBs. A variety of treatment conditions are being evaluated, including aerobic, aerobic supplemented with nutrients, anaerobic, anaerobic supplemented with nutrients, and alternating aerobic and anaerobic treatments.

A major RSKERL-Ada research project under the drinking water research program is the development of an expert system that ties together microbial remediation models, databases, a reference library, and a user-friendly interface to assist field staff in the design of aquifer remediation activities. The expert system, called OASIS, is designed for use on a Macintosh personal computer and is just about ready for release. Documents in its reference library include descriptions of industrial generators and waste disposal systems and guidance on the principles of groundwater modeling. A hydrological database and summary statistics are included so that input parameters for models, including BIOPLUME II, can be estimated by the user. The DRASTIC index for estimating aquifer vulnerability to contamination can also be calculated by the system. Graphical outputs from the system allow easy manipulation of data and interpretation of modeling results.

Underground Source Control Research

Underground source control research focuses on the evaluation of methods to prevent toxic substances from entering aquifers that supply drinking water through subsurface sources of contamination. This research is conducted under the drinking water program, for which $921.6K were allocated in FY89.

Drinking Water Underground Source Control Research

Underground source control research under the drinking water program is conducted by RSKERL-Ada. The research program emphasizes techniques to protect ground water from underground injection of wastes through Class I and Class V injection wells. Class I injection wells are those where municipal and industrial wastes, including hazardous wastes, are injected deeply into the subsurface below ground water that can potentially be used for drinking water. Class V wells include a wide variety of injection wells where wastewaters are often injected into ground-water containing aquifers. Class V wells include agricultural, storm-water, and industrial drainage wells; septic systems; wastewater treatment plant effluent disposal wells; industrial process water wells; automobile service station disposal wells; aquifer recharge wells; and abandoned drinking water wells.

Hazardous Waste Injection Methods

There are a number of unresolved scientific questions regarding the risks involved with disposing of wastes through Class I underground injection wells. RSKERL-Ada has recently completed a research project to determine the movement of injected fluids and the integrity of confining layers of subsurface rocks. Research is being conducted on methods for determining the mechanical integrity of injection wells and the effectiveness of methods for plugging abandoned wells.

The mechanical integrity of injection wells constructed of various materials are being tested to develop methods for determining if wells are leaking into underground sources of drinking water. Two research wells have been constructed to provide a means for conducting field tests on specific mechanical integrity tests. Tests are being run on each well to evaluate the capability of various down-hole tools for determining the quality of the cement bond between the cement/casing and cement/hole, for detecting the movement of fluid behind the casing, and for developing methods for testing the integrity of the tubing, casing, and packers. The mechanical integrity of a third well, installed using fiber glass casing, is being evaluated by building channels into the well and determining the sensitivity of logging tools to these channels.

RSKERL-Ada is studying the effectiveness of plugging abandoned wells with drilling mud to prevent the migration of injected hazardous wastes through the wells to potable ground water supplies. An instrumented test well is being used to determine the effect of temperature, time, pressure, and composition on the strength of mud plugs and to evaluate techniques to enter previously plugged abandoned wells to determine the effectiveness of plugging materials used.

Class V Well Injection Methods

There are an estimated 170,000 Class V wells in the United States. Many of these are unregulated. RSKERL-Ada is conducting research to determine the impact of Class V wells on the environment and methods for improving Class V injection well practices. Background information on the impact of current Class V well design, use, and effects on ground-water quality is being compiled. Information is also being developed on the transport and fate of contaminants introduced into the subsurface via Class V injection wells, focusing on types presenting high potential for ground-water contamination. Methods and criteria for regulating Class V wells will be developed from this information.

Technology Transfer and Technical Assistance

Technology transfer and technical assistance are key elements of ORD's research program and are integral parts of all laboratory activities. Technology transfer is a cyclical process that incorporates the assessment of specific user needs, development of research results in a format keyed to specific audience needs, timely dissemination of the technical information, and evaluations of whether or not the technical information satisfied user needs. ORD ground-water technology transfer audiences include EPA headquarters, EPA Regional, state, and local regulatory, enforcement, and permitting staff, independent consultants, regulated industries, trade associations, and the general public. Technology transfer mechanisms in-

clude manuals and handbooks on the use of state-of-the-art technologies, journal articles, modeling packages and manuals for their proper use, training courses, seminars, video tapes, electronic bulletin boards, and technical information clearinghouses. ORD basic research on subsurface process does not always provide results that can be immediately used in the field. This information is transferred to the scientific community in federal and state agencies, academia, and industry through journal articles, research symposia, conferences, and training seminars. The transfer of research results is considered in each ORD research project.

Technical assistance is the direct, person-to person transmission of scientific and engineering information to help specific users apply state-of-art technologies and procedures to specific problems in the field. Technical assistance is provided upon request to EPA headquarters and Regional staff. Each of the four ORD laboratories involved in ground-water research have staff dedicated to providing technical assistance or directing requests to appropriate experts. Many researchers are contacted directly based on their publications and through the ORD *Ground-Water Research Technical Assistance Directory.*

Technology transfer and technical assistance ensure that RCRA, Superfund, drinking water, and pesticide regulatory approaches to protecting ground-water quality incorporate the latest scientific information on subsurface processes that control contaminant behavior in the subsurface and appropriate monitoring methods and equipment. It also ensures that permitting, remedial, and enforcement actions are scientifically credible and defensible. Technology transfer and technical assistance programs are conducted under the Superfund and drinking water programs (Figure 7). Technical assistance is also provided for the RCRA and pesticides programs as integral parts of research projects.

Superfund Technology Transfer and Technical Assistance

ORD's research laboratories constitute a pool of technical expertise and advanced capital equipment. Superfund remedial and enforcement staff need rapid access to such resources to characterize sites, assess hazards posed by specific problem sites, evaluate remedial options, design remedial actions, and provide best available evidence, testimony, and arguments in enforcement cases.

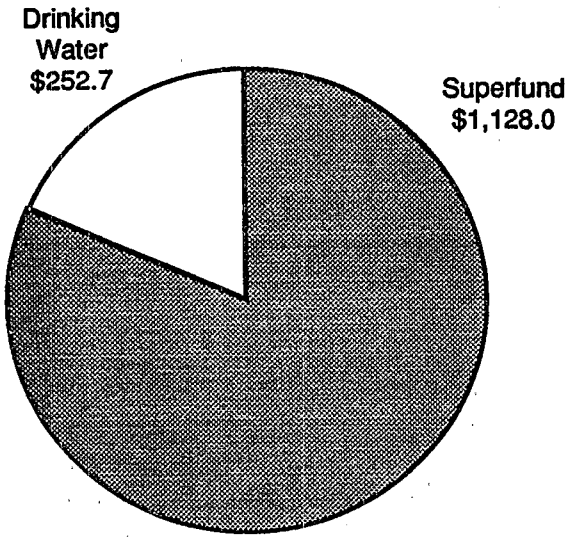

Figure 7. ORD FY89 technology transfer and technical assistance research resources (in thousands).

ORD and OSWER have jointly established Technical Support Centers (TSCs) at the four ORD laboratories involved in ground-water research—the Ground-Water Fate and Transport TSC at RSKERL-Ada; Monitoring and Site Characterization TSC at EMSL-LV; Exposure Monitoring and Ecological Risk Assessment TSC at ERL-Athens; and Engineering and Treatment TSC at RREL-Cin. The Technology Support Centers, in response to Regional requests for assistance, provide direct technical expertise in the field; review site technical reports; conduct workshops on emerging issues; and maintain technical information clearinghouses.

Geophysical Technical Support

EMSL-LV provides technical assistance for using geophysical techniques to characterize Superfund sites. Both field investigations and reviews of reports and work plans are provided. Geophysical support encompasses use of seismic, electromagnetic induction, resistivity, magnetometers, ground penetrating radar, and borehole electromagnetic induction techniques. Technical support on the use of additional methods can also be provided with the cooperation of the USGS and U.S. Army Corps of Engineers.

Transport and Transformation Technical Support

RSKERL-Ada has developed an interdisciplinary team of ground-water contamination experts who provide site- and case-specific technical assistance to Superfund Regional staff on a when-and-where-requested basis. Through the Ground-Water Fate and Transport TSC, RSKERL-Ada's team of experts helps field staff assess the extent of ground-water contamination, predict the transformations and movements of contaminants in the subsurface, and evaluate *in situ* aquifer remediation options. The team also develops training and seminar material in cooperation with CERI and serves as an interface between the ground-water research community and EPA, state, and local staff actively involved in dealing with contaminated sites.

In addition to direct technical support, RSKERL-Ada's technical assistance team participates in relevant research projects in order to present existing state-of-the-art technical information in a user-friendly format. RSKERL-Ada has recently completed consolidation of materials on the use of a USGS solute transport model (MOC) and is working on the development of a user-friendly software package to allow easy use and interpretation of an unsaturated zone organic phase contaminant transport model (ContPro). A report intended to provide new Superfund field staff with introductory information on ground-water modeling needs, responsibilities, and guidance is almost completed. Another manual is under development to provide guidance to field staff on site-specific field techniques for quantifying the physical and chemical properties of contaminated heterogeneous aquifers, including data needed for modeling contaminant behavior. The RSKERL-Ada team is also modifying existing geostatistical computer programs now being used by researchers so that they are useful to field staff who do not have extensive training in geostatistical methods. Finally, a manual that consolidates existing information on the use of pump-and-treat methods is under development, with particular emphasis on estimating the length of time a pump-and treat system may need to operate to remediate a contaminated site.

ERL-Athens established the Center for Exposure Assessment Modeling (CEAM) in 1987 to facilitate the use of state-of-the-art exposure assessment models that can account for contaminant exposure through ground-water and other sources. The Exposure Monitoring and Ecological Risk Assessment TSC is a part of CEAM and provides exposure assessment assistance to Superfund field staff. CEAM provides technical assistance to all EPA programs.

CEAM technical support activities concentrate on site-specific exposure assessment modeling and review of results. Modeling software, users manuals, databases, and procedural handbooks are developed, maintained, and distributed. CEAM operates an electronic bulletin board to facilitate the exchange of models and information on exposure modeling. The Center also conducts training courses on proper use of exposure assessment models. The current training emphasis is on the use of MINTEQA2 and RUSTIC.

Direct technical support is provided at specific sites, with emphasis on multimedia assessments and the uncertainties associated with model estimations. Sites for which direct support projects have recently been completed or are underway include the Clark Fork River, Montana; Lipari, New Jersey; California Gulch, California; and CSX Train Wreck, Georgia, Superfund sites. The results of the more intensive site support projects are developed into case studies for use as training aids and as technology transfer documents.

Aquifer Remediation Technical Support

RSKERL-Ada has established the Subsurface Remediation Information Clearinghouse (SRIC) to help transfer information on technologies for cleaning up contaminated ground water and soils to Superfund remediation field staff. The emphasis of the clearinghouse is on *in situ* technologies such as microbial remediation and specialized pumping techniques. The clearinghouse includes information on transport and transformation processes, remedial technology evaluations, guidance on the use of remedial technologies, case histories, and related research publications. Information to be included in the clearinghouse is evaluated for its value to users by RSKERL-Ada staff and experts in other agencies and universities. A protocol for evaluating the performance of ground-water remediation activities at Superfund sites is being developed for inclusion in the SRIC. Case studies of selected Superfund sites are being conducted to investigate the effectiveness of modeling and monitoring approaches. SRIC staff disseminates information in the clearinghouse, conducts literature reviews, and pro-

vides information services to EPA, other federal and state agencies, and researchers.

Drinking Water Technology Transfer and Technical Assistance

Technology transfer and technical assistance provided by RSKERL-Ada under the drinking water program emphasizes improving basic understanding of ground-water science and the use of transport and transformation models by field staff.

Training and Model Evaluation

RSKERL-Ada provides technical support and evaluations of models for the investigation, management, and protection of ground-water sources of drinking water. A series of 20-30 minute narrated slide presentations are under development that can be used as self-training aids to help field staff that may not have training in ground-water science keep abreast with new research findings and technologies. Modules that have been completed include basic geology, fundamental hydrogeology, monitoring well installation, and ground-water models. Modules near completion include ground-water contamination and ground-water sampling. Modules in the early stages of development include ground-water investigations, ground-water tracers, and ground-water restoration. Training courses are also provided periodically upon request. Recent two-day training course presentations included basic ground-water hydrology and the use of the DRASTIC index of ground-water vulnerability to contamination.

RSKERL-Ada has developed a close relationship with the International Ground-Water Modeling Center (IGWMC) at Butler University's Holcomb Research Institute. The IGWMC operates a clearinghouse for technical information on the use of mathematical transport and transformation models and software. The two major tasks of the clearinghouse are the dissemination of information on ground-water model application and the distribution and support of modeling software. The Center regularly offers short courses and seminars on the use of models and carries out a research program to evaluate the quality of the confusing array of existing ground-water transport and transformation models.

The IGWMC, under a cooperative agreement with RSKERL-Ada, is developing a ground-water transport model testing and evaluation methodology. Existing transport and transformation models are being subjected to careful scrutiny for quality in development and efficiency of operation. The models and evaluation methodology will be made available to the user community along with the results of the evaluation and other information developed during the project.

Relationship to Other Ground-Water Activities in EPA

In addition to ground-water research conducted by ORD and coordinated by EPA's research committees, EPA program offices sponsor a significant amount of research at ORD's laboratories, conduct research through program office contractors to support short-term data needs, and synthesize current knowledge into technical guidance documents. A major example of program offices co-sponsoring ORD research is OSW and OPP support for exposure assessment modeling at ERL-Athens. The program offices, particularly OGWP and OERR, also have increased activities to provide direct technical assistance to Regional and state staff.

OGWP develops new methods and transfers existing knowledge and methods to state and local agencies for protecting ground-water sources of drinking water. Because the states develop and implement their own ground-water protection programs under EPA leadership, OGWP has concentrated on providing policy, program management, and technical guidance to the states. Much of this work involves the collection of existing technical information on hydrogeologic assessment and pollutant source management tools that have already proven effective in other roles and putting this information into a format appropriate for various state and local audiences. OGWP also conducts applied scientific research by adapting existing hydrogeologic approaches to ground-water protection needs in problem subsurface environments. In addition, OGWP conducts pilot studies, workshops, and training programs with states and local governments.

OERR has established the Technical Support Project (TSP) to provide site-specific technical assistance to Superfund OSCs and RPMs on the application of the best available technologies for Superfund site assessment and remediation. A major component of the TSP are the four ORD laboratory Technical Support Centers jointly established by ORD and OERR. The TSP also includes two Regional Forums and OSWER's Environmental Response Team in Edison, New Jersey.

Regional Forums have been established in Ground-Water Fate and Transport and Engineering and Treatment. The Forums provide an important medium for improving communications and building consensus on technology transfer needs among the Regions, ORD, and OSWER headquarters. The Forums, TSCs, and OSWER's Technology Staff frequently discuss Superfund site problems and successes, useful technologies and procedures, technical needs, and current ORD research, development, and demonstration projects. The TSP improves communication of technical information and the consistency of Superfund site remedial actions.

Ground-Water Research in Other Federal Agencies

The Federal Coordinating Committee for Science, Engineering, and Technology (FCCSET) of the Office of Science and Technology Policy in the Executive Office of the President has completed its first report on federal ground-water research—*Federal Ground-Water Science and Technology Programs: The Role of Science and Technology in the Management of the Nation's Ground-Water Resources* (June, 1989). The report summarizes the status of federal ground-water science and technology activities directly related to ground water.

Federal agencies with significant ground-water research programs include the EPA, Departments of Agriculture (USDA), Commerce, Defense, Energy (DOE), and Interior (DOI), the National Science Foundation, National Aeronautical and Space Administration, and Nuclear Regulatory Commission. Table 1 presents the federal ground-water research resources of these agencies for FY89 and FY90 (EPA ground-water research resources in Table 1 differ from the total resources presented in Appendix A because they were accounted for using different research categories). The USGS (DOI), USDA, EPA, and DOE ground-water research programs have accounted for over 92 percent of the federal effort over the last five years.

The largest federal ground-water research program is managed by DOI, primarily by the USGS. The major portions of the USGS ground-water program are for ground-water quantity and quality resource assessments and computer systems for the storage and retrieval of water-resource data. The USGS also conducts research programs on the transport and fate of organic and inorganic chemicals, flow through fractured rock, hydrology of the unsaturated zone, borehole geophysical logging, and the effects of organic chemicals on soil and rock permeability.

Table 1. Federal Ground-Water Research Resources (dollars in millions).

Agency	FY89	FY90 Est
Department of the Interior	$90.7	$93.8
Department of Agriculture	$48.5	$69.1
Environmental Protection Agency	$18.6	$18.9
Department of Energy	$11.2	$23.0
Department of Defense	$8.1	$5.6
National Science Foundation	$5.5	$5.4
National Aeronautics and Space Adm.	$4.4	$5.4
Nuclear Regulatory Commission	$1.6	$2.3
Department of Commerce	$1.1	$1.1

The next largest ground-water research program is the USDA's, which concentrates on the transport and fate of agricultural chemicals in the subsurface and methods for the environmentally sound management of agricultural chemical use. The USDA has a major training and education program through the Soil Conservation Service and the Extension Service on how to reduce ground-water contamination through better agricultural practices. The USDA also conducts research on predicting ground-water recharge, evaluating water movement through soils, and the effects of agricultural practices on macropore development. USDA is projecting a significant FY90 increase in ground-water research to improve methods for the biodegradation of agricultural chemicals in the subsurface and to study the toxicological, economic, political, and social consequences of agricultural contaminants in public and private water supplies.

DOE programs include research on geochemical and microbiological processes controlling the fate and movement of energy-related organic chemicals with emphasis on the degradation, mobilization, and stabilization of organic-metal mixtures and organic-radionuclide mixtures. This includes research on organic and mineral colloids; coupled sorption-desorption and chemical degradation models; presence, abundance, and diversity of microorganisms in deep sediments and aquifers; transport and thermodynamic properties of aqueous electrolytes; and geochemistry of hydro-

thermal fluids. DOE is projecting a doubling of its ground-water research in FY90 to study the effects of the disposal of waste mixtures that include radionuclides, organic and inorganic chemicals, and immiscible liquids. This will require new advances in fundamental understanding of the combined effects of physical, chemical, and biological processes on co-contaminant behavior in the subsurface.

EPA Coordination with Other Federal Agencies

EPA and the other federal agencies involved in ground-water research employ a number of mechanisms to coordinate their research and technology transfer programs, including:

- Specific interagency delegations of authority to provide lead agency coordination;
- Memoranda of Understanding (MOUs) that set forth specific responsibilities and areas of cooperation;
- Standing and *ad hoc* committees and technical workshops to monitor agreements and share information; and
- Jointly conducted projects or programs that employ the combined expertise of several agencies.

EPA and USGS signed a 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. EPA and USGS regularly exchange visiting scientists and participate in each other's technical meetings on ground-water. In addition, the two agencies have established a bilateral committee to coordinate their respective research programs and prevent duplication of effort.

The USGS has been investigating the relationship between human land-use patterns and the occurrence of nonpoint source contaminants, particularly agricultural chemicals, in seven states for over five years. An Interagency Agreement between the USGS and RSKERL-Ada will expand this USGS research program into the development of methods for using easily available water quality and land-use data to identify sources of contamination in wellhead protection areas.

EPA and USDA signed an interim MOU in October, 1988, providing an umbrella agreement for coordination in surface and ground-water quality improvement and maintenance. Through the MOU, EPA's Office of Water will use the expertise of USDA's Soil Conservation Service to increase technical assistance to states in the development and implementation of state-wide water quality programs and projects. EPA and USDA have formed *ad hoc* committees to investigate the transport and fate of agricultural chemicals at Beltsville, Maryland, and Plains, Georgia. EPA also participates on an interagency committee to guide the water quality research of USDA's Cooperative State Research Service. In addition, RSKERL-Ada and USDA have entered into an Interagency Agreement to develop geostatistical methods for reducing variance in ground-water quality data by properly locating sampling wells at ground-water contamination sites.

EPA participated in a November, 1988, interagency workshop on the impact of agricultural practices on ground-water quality. The workshop, cosponsored by the USDA and University of Nebraska, addressed the state of knowledge and the agencies' research program priorities for field research at specific sites; development of sampling, sampling analysis, and data interpretation techniques; and technology transfer.

Interagency coordination between DOE's Office of Energy Research (OER), USGS, EPA, and other agencies is predominantly at the scientific planning level. Since 1983, OER has sponsored about 20 meetings to assist in setting scientific direction for its fundamental research programs. All federal agencies have participated in OER reviews, providing program coordination and information exchange.

In addition to coordinating research with other federal agencies through interagency agreements and coordinating committees, EPA conducts joint ground-water research projects with the USDA, USGS, U.S. Air Force, U.S. Army, U.S. Coast Guard, U.S. Navy, NRC, DOE, National Research Council, and the Tennessee Valley Authority.

EVOLUTION OF GROUND-WATER RESEARCH PROGRAM

In 1970, when U.S. EPA was established, federal ground-water research programs were con-

cerned primarily with developing methods for increasing the supply of ground water for drinking water, agriculture, and industrial processes. Until the mid-1970s it was principally the state and local governments that were concerned with protecting the quality of ground water—and most did not recognize ground-water contamination as a significant problem. Federal environmental programs of the early and mid-1970s focused on responding to landmark environmental statutes such as the Clean Air Act, Clean Water Act, Safe Drinking Water Act, and FIFRA.

In the late 1970s, significant threats to ground water by man-made contaminants became apparent and ground water emerged as an area of major public concern. States began looking to EPA to provide information on which to base their responses to ground-water contamination. In addition, the Toxic Substances Control Act, RCRA, and Superfund were enacted and EPA increased its research into controlling toxic substances in the environment.

By the end of FY84, EPA funding for ground-water research had grown to about $10 million, mostly for transport, transformation, and monitoring research (and not including RCRA hazardous waste source control engineering research). Since then, EPA's ground-water research program has grown into a comprehensive program to improve the understanding of basic subsurface processes and meet the nation's needs for protecting ground-water quality. This growth has been guided by many external and internal reviews of ground-water research needs.

External Research Reviews

Several major documents have emerged with recommendations for research needed to implement the Agency's multiple mandates for protecting ground-water resources. The Science Advisory Board distributed its *Review of the EPA Ground-Water Research Program* in July, 1985. The Hazardous Waste Ground-Water Task Force distributed an *Evaluation of the RCRA Subpart F Ground-Water Monitoring Program* in February, 1986 and its final report *Hazardous Waste Ground-Water Task Force: 1987 Status Report* in October, 1988. Two recent reports contain recommendations on the development and use of ground-water models—the Science Advisory Board's *Resolution on Use of Mathematical Models by EPA for Regulatory Assessment and Decision Making* (January, 1989) and the National Research Council's *Ground-Water Models: Scientific and Regulatory Applications* (November, 1989).

The Science Advisory Board's 1985 review of EPA's ground-water research program recommended the creation of a strong central direction for the research program, greatly increased resources for training and technology transfer, proactive research on ground-water contamination sources not addressed by specific mandates, and development of faster methods for ground-water sampling and analysis while maintaining data quality. Increases or initiatives were also recommended in specific ground-water research areas: monitoring; basic transport and fate; remedial methods for fractured geologic formations; and identification of suitable geologic environments for isolating hazardous wastes by means of deep injection wells.

The Hazardous Waste Ground-Water Task Force considered technical problems in ground-water monitoring technology as a component of their overall evaluation of the RCRA Ground-Water Monitoring Program. Six technological needs were identified: (1) improved understanding of the behavior of individual contaminants and contaminant classes, and defined sampling strategies for each class; (2) investigation of the use of plume dispersion as a basis for monitoring well horizontal spacing, screen depth, and length; (3) identification of sampling equipment and techniques best suited for specific hydrologic settings or monitoring needs; (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.

The Science Advisory Board's review of the use of mathematical models in EPA regulatory decision making contains recommendations relevant to ORD development and testing of ground-water transport, transformation, and exposure assessment models. The report recommends an increase in validation of models by laboratory and field studies, increased communication of the sensitivity and uncertainty of environmental model predictions, and more stringent peer review of models and expert systems. The National Research Council's report mentioned above discusses the scientific bases on which existing models are founded, approaches and philosophies routinely used in the application of models to regulatory

decision making, and guidelines on the development and use of models intended for application to the regulatory process.

ORD is addressing these external research review recommendations to the extent practicable within its available funding.

Internal Research Reviews

In addition to external reviews of the ground-water research program, ORD laboratories host technical program reviews each year in concert with the budget development cycle. The objectives of the reviews are to evaluate research progress and results, determine whether planned research projects and their resources are sufficient to meet the needs of Program and Regional Offices, decide whether additional projects are necessary, and determine whether the timing and substance of planned deliverables are suitable.

Participants at the FY88 ground-water research review, including representatives from OERR, OSW, OGWP, Office of Pesticides and Toxic Substances, Regional offices, and ORD, concluded that increased efforts are most needed in three general areas: technical assistance to the Regions, expert systems and automated decision trees that can run on personal computers, and site-specific methods for site characterization. Improved methods for rapid site characterizations were seen as critical to tailoring models to local geologic conditions. A number of other research needs were raised in the areas of subsurface viral transport, pump-and-treat remedial technology, wellhead protection methods, multiphase flow mechanisms, contaminant interaction, flow through fractured rock, geophysical data interpretation, contaminant transport modeling, chemical-specific data requirements, unsaturated zone monitoring, definition of hazardous waste using model-derived toxicity estimates, metal/organic complexation, and effects of solvents and immiscible organics on contaminant transport.

The FY89 ground-water research program review was attended by representatives from OERR, OPP, OGWP, Region VI, and ORD. Further research needs identified at the review included the effects of subsurface heterogeneity on field studies; site characterization using soil-core analyses and distribution coefficients; retrospective analyses of site remediations; impacts of pesticides, fertilizers, and other non-point sources on ground-water quality; residuals of waste minimization and their potential impacts; behavior of contaminants under pressure in deep formations; use of laser technology in monitoring; model performance evaluation; and subsurface cleanup and contaminant mobilization processes.

Many of the research needs expressed in these ground-water research program reviews have been fulfilled or research programs have been established to address them. Other needs have not yet been fully addressed due to funding constraints and competing priorities.

ORD has developed many innovative procedures, methods, and equipment for advancing research capabilities and the scientific basis of Program and Regional office regulatory, permitting, and enforcement programs. Numerous technical articles, handbooks, and technical resource documents have been published describing these accomplishments. Appendix C lists the major reports produced by ORD's ground-water research program over the last three years.

Within recent years, major research programs have been initiated in the areas of advanced site characterization and contaminant detection equipment, monitoring methods, controlled field studies of microbial degradation techniques, facilitated transport processes that enhance contaminant mobility, methods for incorporating uncertainty analyses within modeling packages, pump-and-treat technologies, and wellhead protection methods. In addition, ORD has significantly expanded its efforts to transfer technical information and provide direct, site-specific technical assistance to personnel in the field. Reports planned to be completed in FY89 and FY90 under these and other important research programs are listed in Appendix B.

Despite recent advances in understanding of fundamental subsurface processes and ground-water monitoring and remediation technologies, many difficult questions are just beginning to be answered. ORD's future ground-water research program will address the highest priority of these questions.

Future Program

The two areas that ORD's future ground-water research program will emphasize are the prevention and remediation of ground water contamination.

The prevention research program will encompass identification of threats to ground water from point and non-point sources and mitigation of those threats through improved management of the contaminant sources. The Office of Water's wellhead protection program offers an opportunity to integrate advances in ground-water research into a comprehensive program to protect drinking water aquifers. Improved site-specific methods will be needed to characterize local point and non-point sources of contamination and define vulnerable ground-water resources in order for state and local governments to develop plans for protecting wellheads. The delineation of wellhead protection areas will require improved predictive models to account for the effects of subsurface biological, chemical, and physical processes on the transport and transformations of contaminants in the subsurface. The correct use of these models will depend, in part, on the quality of input data that is used. ORD's research into rate constants and physical properties such as dispersivity, hydraulic conductivity, and effective porosity can therefore be expected to continue. Cost-effective monitoring methods will also be needed for early detection of contamination from a multitude of possible sources before they can percolate into ground-water resources.

The success of ground-water remediation depends largely upon understanding subsurface processes. Some of the more important processes for which research is needed include multiphase behavior of contaminants, partitioning among solid and liquid media, biotic and abiotic transformations, and transport in fractured media. Predictive tools, such as models, will need to better account for these processes. Cost-effective monitoring methods are also needed for detecting contaminants, characterizing local, site-specific subsurface conditions, and track changes in ground-water quality during remediation of contaminated ground water. Improved knowledge of subsurface conditions will also lead the way for improvements in the design of engineering methods and technologies for remediation such as innovative ground-water pumping systems.

ORD efforts to meet these prevention and remediation objectives in the future will continue to be approached through focused research projects in support of EPA's programs, with attention to coordination, technology transfer and technical assistance.

APPENDIX A. ORD GROUND-WATER RESEARCH BUDGET

EPA's ground-water research program can be organized into five major research areas—Monitoring, Transport and Transformation, *In Situ* Aquifer Remediation, Underground Source Control, and Technology Transfer and Technical Assistance. For budget tracking and research management purposes, ORD research is organized hierarchically, with the largest division called Budget Subactivities (BSAs). ORD ground-water research is supported by base funding in five BSAs—RCRA Hazardous Waste (D109), Superfund (Y105), Drinking Water (C104), Pesticides (E104), and Exploratory Research (H109). The BSAs are divided, in decreasing hierarchical order, into Issues, Planned Program Accomplishments, and Projects. This Appendix presents ORD research resources at the Project level, the laboratory conducting the research Project, and the percent of resources within each Project that is considered ground-water research. For each project, the FTEs, S&E resources (funds for salaries, expenses, and research conducted within the laboratory), and R&D resources (funds for research conducted outside of EPA) are presented. All budget dollars are in thousands. Totals by laboratory and BSA are presented on the last page of this Appendix.

Appendix A. ORD Ground-Water Research Budget (Continued)

Planned Program Accomplishment (PPA) Project	Lab	% GW	FY89 FTE	FY89 S&E	FY89 R&D	FY89 Total	FY90 (Proposed) FTE	FY90 (Proposed) S&E	FY90 (Proposed) R&D	FY90 (Proposed) Total
Monitoring										
RCRA Hazardous Waste (D109)										
I15 Field Methods for Surface and Subsurface Monitoring										
01 Vadose Zone Monitoring	EMSL-LV	100%	1.0	78.3	539.0	617.3	1.0	78.3	539.0	617.3
02 GW Monitoring	EMSL-LV	100%	1.8	158.8	388.0	546.8	1.8	158.8	388.0	546.8
03 Field Methods for Subsurface Monitoring	EMSL-LV	100%	1.0	78.4	243.6	322.0	1.0	78.4	243.6	322.0
04 X-Ray Fluores & Fiber Optics Screening Methods	EMSL-LV	100%	1.5	117.5	338.7	456.2	1.5	117.5	338.7	456.2
05 QA and Methods Standardization for GW Monitoring	EMSL-LV	100%	1.0	78.3	324.0	402.3	1.0	78.3	324.0	402.3
07 Geostatistics and Survey Design	EMSL-LV	30%	0.5	85.6	60.1	145.7	0.5	85.6	60.1	145.7
CERI Seminars	CERI	100%	0.0	0.0	150.0	150.0	0.0	0.0	150.0	150.0
			6.8	596.9	2043.4	2640.3	6.8	596.9	2043.4	2640.3
I16 Subtitle D Monitoring Research										
01 GW Monitoring Research for Subtitle D Facilities	EMSL-LV	100%	0.7	45.5	200.1	245.6	0.7	45.5	200.1	245.6
			0.7	45.5	200.1	245.6	0.7	45.5	200.1	245.6
R62 Methods for UST Leak Monitoring										
01 Monitoring of Cleanup Around USTs	EMSL-LV	100%	3.5	295.6	1036.7	1332.3	3.5	295.6	1036.7	1332.3
			3.5	295.6	1036.7	1332.3	3.5	295.6	1036.7	1332.3
Superfund (Y105)										
A04 Techniques for Site Assessment										
01 Geophysical Methods	EMSL-LV	100%	3.0	24.5	600.0	624.5	3.0	24.5	600.0	624.5
			3.0	24.5	600.0	624.5	3.0	24.5	600.0	624.5
H03 Field Screening Techniques for Assessment and Eval										
01 Advanced Field Monitoring Methods	EMSL-LV	100%	1.0	87.3	585.5	672.8	1.0	87.3	585.5	672.8
04 Vadose Zone Methods	EMSL-LV	100%	0.0	0.0	175.0	175.0	0.0	0.0	175.0	175.0
			1.0	87.3	760.5	847.8	1.0	87.3	760.5	847.8
S01 Monitoring Technology Development and Demonstration										
01 Advanced Field Monitoring Methods	EMSL-LV	100%	1.0	87.3	320.0	407.3	1.0	87.3	320.0	407.3
			1.0	87.3	320.0	407.3	1.0	87.3	320.0	407.3
Drinking Water (C104)										
F81 Ground Water--Drinking Water Quality Assurance										
01 Ground Water Monitoring	EMSL-LV	100%	4.5	281.9	470.5	752.4	4.5	281.9	470.5	752.4
			4.5	281.9	470.5	752.4	4.5	281.9	470.5	752.4
F89 Develop Methods for Wellhead Protection										
01 Wellhead Protection Monitoring Strategies	EMSL-LV	100%	0.0	0.0	0.0	0.0	0.0	0.0	250.0	250.0
			0.0	0.0	0.0	0.0	0.0	0.0	250.0	250.0
Subtotal			20.5	1419.0	5431.2	6850.2	20.5	1419.0	5681.2	7100.2

Appendix A. ORD Ground-Water Research Budget (Continued)

Planned Program Accomplishment (PPA) Project	Lab	% GW	FY89 FTE	FY89 S&E	FY89 R&D	FY89 Total	FY90 (Proposed) FTE	FY90 (Proposed) S&E	FY90 (Proposed) R&D	FY90 (Proposed) Total
Transport and Transformation										
RCRA Hazardous Waste (D109)										
C25 Prediction of Environ Concentrations of Haz Waste										
01 Field Eval of GW Contamination from Haz Wastes	Ada	100%	5.9	289.7	930.9	1220.6	5.9	289.7	930.9	1220.6
02 Prediction of Cont Behavior in the Subsurface	Ada	100%	15.2	948.9	523.6	1472.5	15.2	948.9	523.6	1472.5
03 Spatial Variability of Subsurface	Ada	100%	2.0	101.0	149.4	250.4	2.0	101.0	149.4	250.4
			23.1	1339.6	1603.9	2943.5	23.1	1339.6	1603.9	2943.5
C28 Land Disposal Assessment/Eval Other Mgmt Systems										
03 Chemical Transformation Pathways & Rates	Athens	100%	2.0	120.8	372.3	493.1	2.0	120.8	352.3	473.1
07 Environmental Process Characterization--Metals	Athens	100%	3.7	227.4	517.2	744.6	3.7	227.4	417.2	644.6
17 Environmental Process Characterization--Biologic	Athens	25%	0.4	22.5	77.6	100.1	0.4	22.5	77.6	100.1
21 Multimedia Modeling with Uncertainty Analysis	Athens	75%	3.4	215.0	623.6	838.6	3.4	215.0	523.6	738.6
38 Environmental Process Characterization--Organics	Athens	50%	0.5	27.3	219.1	246.3	0.5	27.3	219.1	246.3
			10.0	612.9	1809.7	2422.6	10.0	612.9	1589.7	2202.6
Drinking Water (C104)										
F83 Prediction of Contaminant Concentrations										
01 Subsurf Phys/Chem Processes Affecting Transport	Ada	100%	7.0	331.4	586.7	918.1	7.0	331.4	586.7	918.1
03 Predict Microbial Contaminant Concentrations	Ada	100%	0.2	9.4	100.0	109.4	0.2	9.4	100.0	109.4
04 Predict Biotransformation of Subsurface Cont	Ada	100%	5.5	260.4	400.0	660.4	5.5	260.4	400.0	660.4
			12.7	601.2	1086.7	1687.9	12.7	601.2	1086.7	1687.9
F87 Ground-Water Research with China										
01 GW Research with China	Ada	100%	0.0	105.0	20.0	125.0	0.0	105.0	20.0	125.0
			0.0	105.0	20.0	125.0	0.0	105.0	20.0	125.0
F89 Develop Methods for Wellhead Protection										
01 Develop Methods for Wellhead Protection	Ada	100%	2.5	119.7	160.0	279.7	5.0	257.7	590.0	847.7
02 Wellhead Protection in Agricultural Regions	Athens	100%	0.0	0.0	0.0	0.0	0.0	0.0	270.0	270.0
			2.5	119.7	160.0	279.7	5.0	257.7	860.0	1117.7
Pesticides (E104)										
D07 Ground Water--Pesticide Cont and Process Studies										
24 Validate Predictive Techniques for Env Exposure	Athens	100%	3.0	138.7	455.0	593.7	3.0	138.7	455.0	593.7
			3.0	138.7	455.0	593.7	3.0	138.7	455.0	593.7
D08 Predictive Techniques for Environmental Exposure										
14 Pesticide Process Characterization	Athens	50%	0.8	34.7	0.0	34.7	0.8	34.7	0.0	34.7
25 Predictive Techniques for Environmental Exposure	Athens	50%	1.0	46.2	0.0	46.2	1.0	46.2	0.0	46.2
			1.8	80.9	0.0	80.9	1.8	80.9	0.0	80.9
Exploratory Research (H109)										
C02 National Center for Ground-Water Research	OER	100%	0.0	0.0	540.0	540.0	0.0	0.0	540.0	540.0
			0.0	0.0	540.0	540.0	0.0	0.0	540.0	540.0
Subtotal			53.0	2998.0	5675.3	8673.3	55.5	3136.0	6155.3	9291.3

Appendix A. ORD Ground-Water Research Budget (Continued)

Planned Program Accomplishment (PPA) Project	Lab	% GW	FY89 FTE	FY89 S&E	FY89 R&D	FY89 Total	FY90 (Proposed) FTE	FY90 S&E	FY90 R&D	FY90 Total
In Situ Aquifer Remediation										
RCRA Hazardous Waste (D109)										
R64 Corrective Action and Models for USTs										
01 Corrective Action and Models for USTs	Ada	100%	1.4	72.0	0.0	72.0	1.4	72.0	0.0	72.0
			1.4	72.0	0.0	72.0	1.4	72.0	0.0	72.0
Superfund (Y105)										
B01 Control Technology Evaluation										
90 In Situ Control Technologies	RREL	85%	4.3	316.4	1345.8	1662.2	4.3	316.4	1345.8	1662.2
94 Emerging Biosystems Program	RREL	40%	1.2	89.1	1056.8	1145.9	1.2	89.1	1056.8	1145.9
			5.5	405.5	2402.6	2808.1	5.5	405.5	2402.6	2808.1
B02 Biodegradation Applications to Superfund Cleanups										
01 Enhanced Biorestoration of Contaminated GW	Ada	100%	2.0	128.5	488.0	616.5	2.0	128.5	488.0	616.5
33 Biodegradation Applications to SF Cleanups	Athens	20%	0.2	15.0	105.4	120.4	0.2	15.0	105.4	120.4
			2.2	143.5	593.4	736.9	2.2	143.5	593.4	736.9
Drinking Water (C104)										
F84 In Situ Aquifer Restoration										
01 In Situ Aquifer Restoration	Ada	100%	5.0	239.4	900.0	1139.4	5.0	239.4	900.0	1139.4
			5.0	239.4	900.0	1139.4	5.0	239.4	900.0	1139.4
Subtotal			14.1	860.4	3896.0	4756.4	14.1	860.4	3896.0	4756.4
Underground Source Control										
Drinking Water (C104)										
F88 Underground Injection Control Reg & Implementation										
01 Mechanical Integrity of Injection Wells	Ada	100%	2.0	95.8	252.0	347.8	2.0	95.8	252.0	347.8
02 Impact of Class I Wells on Subsurf Geol Material	Ada	100%	0.5	24.0	100.0	124.0	0.5	24.0	100.0	124.0
03 Class V Injection Well Practices	Ada	100%	1.5	71.8	378.0	449.8	1.5	71.8	378.0	449.8
			4.0	191.6	730.0	921.6	4.0	191.6	730.0	921.6
Subtotal			4.0	191.6	730.0	921.6	4.0	191.6	730.0	921.6

Appendix A. ORD Ground-Water Research Budget (Continued)

Planned Program Accomplishment (PPA) Project	Lab	% GW	FY89 FTE	FY89 S&E	FY89 R&D	FY89 Total	FY90 (Proposed) FTE	FY90 S&E	FY90 R&D	FY90 Total
Technology Transfer & Technical Assistance										
Superfund (Y105)										
F06 Monitoring for Enforcement & Other Tech Support										
02 Geophysical Support	EMSL-LV	100%	0.0	0.0	138.8	138.8	0.0	0.0	138.8	138.8
			0.0	0.0	138.8	138.8	0.0	0.0	138.8	138.8
F22 Enforcement and Other Technical Support										
01 Clearinghouse on GW Remedial Action Techs	Ada	100%	1.0	65.2	250.0	315.2	1.0	65.2	250.0	315.2
02 GW Technical Support	Ada	100%	1.9	124.0	450.0	574.0	1.9	124.0	450.0	574.0
23 Anaerobic Biotreatment Development	Athens	100%	0.0	0.0	25.0	25.0	0.0	0.0	25.0	25.0
29 Center for Exposure Assessment Modeling (CEAM)	Athens	20%	0.0	0.0	75.0	75.0	0.0	0.0	75.0	75.0
			2.9	189.2	800.0	989.2	2.9	189.2	800.0	989.2
Drinking Water (C104)										
F82 Ground-Water Methods, Info Transfer, & Applications										
01 Information Transfer	Ada	100%	1.1	52.7	200.0	252.7	1.1	52.7	200.0	252.7
			1.1	52.7	200.0	252.7	1.1	52.7	200.0	252.7
Subtotal			4.0	241.9	1138.8	1380.7	4.0	241.9	1138.8	1380.7
Total Ground-Water Research Resources:			95.6	5710.8	16871.4	22582.2	98.1	5848.8	17601.3	23450.1
Totals by Laboratory/Office:										
	RSKERL-Ada		54.7	3038.9	5988.6	9027.5	57.2	3176.9	6418.6	9595.5
	ERL-Athens		14.9	847.5	2370.1	3217.6	14.9	847.5	2420.1	3267.6
	EMSL-LV		20.5	1419.0	5420.0	6839.0	20.5	1419.0	5670.0	7089.0
	RREL-Cin		5.5	405.5	2402.6	2808.1	5.5	405.5	2402.6	2808.1
	CERI		0.0	0.0	150.0	150.0	0.0	0.0	150.0	150.0
	OER		0.0	0.0	540.0	540.0	0.0	0.0	540.0	540.0
			95.6	5710.8	16871.4	22582.2	98.1	5848.8	17601.3	23450.1
Totals by Program Area:										
	RCRA Haz Waste		45.5	2962.5	6693.8	9656.3	45.5	2962.5	6473.8	9436.3
	Superfund		15.6	937.3	5615.3	6552.6	15.6	937.3	5615.3	6552.6
	Drinking Water		29.8	1591.5	3567.2	5158.7	32.3	1729.5	4517.2	6246.7
	Pesticides		4.8	219.6	455.0	674.6	4.8	219.6	455.0	674.6
	Exploratory		0.0	0.0	540.0	540.0	0.0	0.0	540.0	540.0
			95.6	5710.8	16871.4	22582.2	98.1	5848.8	17601.3	23450.1

APPENDIX B.
SUMMARY OF OUTPUTS FROM GROUND-WATER RESEARCH PROJECTS

Appendix B presents the outputs of ORD's ground-water research program that are planned to be completed as a result of ground-water research conducted in FY89 and FY90. Some outputs are planned to be completed in FY91 and beyond (outyears) as a result of longer-term research projects. Parenthetical numbers following most of the outputs are output designators to allow easier tracking of progress toward completion of the output.

MONITORING

	FY89	FY90	Outyear
RCRA Hazardous Waste			
Develop and evaluate ground-water monitoring methods and strategies for RCRA hazardous waste facilities (PPA I15).			
Vadose Zone Monitoring (EMSL-LV)			
Draft ASTM Standard for Direct Pore-Liquid Vadose Zone Monitoring Equipment (0886A)		12/89	
Draft ASTM Standard for Indirect Pore-Liquid Vadose Zone Monitoring Equipment (0888A)		1/90	
Draft ASTM Standard for Soil Core Monitoring Equipment (0887A)		2/90	
User's Guide on Criteria for Selection of Equipment and Indicator Parameters for Direct Pore-Liquid Sampling Guidance Document (0889A)		7/90	
Ground-Water Monitoring (EMSL-LV)			
Report on Feasibility of Using Control Chart Strategies for Detecting Trends in Ground-Water Pollutants (0626A)	12/88		
Geostatistics for Ground-Water Monitoring (0861A)	12/88		
Internal Report on a Performance Evaluation of Interpolation Methods (0615A)	12/88		
Journal Article on Cost-Effective Screening Methodology for Monitoring Organics in Ground Water at Hazardous Waste Sites (0890A)	3/89		
Monitoring Strategies at Wood Preserving Sites	6/89		
Monitoring Strategies for Municipal Ash Monofills	6/89		
Software Package for Screening Methodology Applicable to Ground-Water Quality Monitoring at Hazardous Waste Sites (0892A)		12/89	
Annotated Bibliography of Hydrologic Publications (8071A)		6/90	
Project Report on Field Comparison of Six Ground-Water Sampling Methods at Hazardous Waste Sites (0442A)			10/90

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

	FY89	FY90	Outyear
Internal Report on a Protocol for Testing Ground-Water Samplers (0464A)			11/90
Develop Field Methods for Subsurface Monitoring (EMSL-LV)			
Project Report on Application of Borehole Geophysics to Waste Site Monitoring (0885A)			10/90
X-Ray Fluorescence and Fiber Optics Screening Methods (EMSL-LV)			
Final Project Report on Portable X-Ray Fluorescence for Characterization of Hazardous Waste Sites (0527A) (part of Y105-H03-01)		12/89	
Final Report on Portable Ultraviolet Remote Fiber Spectroscopy for In Situ Screening of Aromatic Compounds in Ground Water			12/91
Quality Assurance and Methods Standardization for Ground-Water Monitoring (EMSL-LV)			
Draft Recommended Practice for Design and Installation of Ground-Water Monitoring Wells in Aquifers (8072A)	2/89		
Draft Standard Test Method for Determining Transmissivity and Storativity of Confined Non-Leaky Aquifers Under Constant Flux (8073A)	3/89		
Draft Standard Guide for Measuring Hydraulic Conductivity in the Vadose Zone (8074A)		10/89	
Draft Standard Guide for Sampling Ground-Water Monitoring Wells (8075A)		2/90	
Geostatistics and Survey Design (EMSL-LV)			
Annual Report of Research in Statistics, Geostatistics, and Chemometrics (0821A)	12/88	12/89	12/90
Seminar (CERI)			
Seminar on Application of Geophysical Methods to Ground Water	FY89		
Develop and evaluate ground-water monitoring methods and strategies for RCRA Subtitle D facilities (PPA I16).			
Ground-Water Monitoring Research for Subtitle D Facilities (EMSL-LV)			
Special Problems of Ground-Water Monitoring in Karst Terrains (0632A)	12/88		
Report on Nature and Hydraulic Significance of Fracture Trace and Lineament Related Structures with Application to the Design of Ground-Water Monitoring Wells (0631A)	6/89		

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

	FY89	FY90	Outyear
Evaluation of Published and Unpublished Environmental Monitoring Data for Determining the Impact of Monofill and Co-Disposal Ash Disposal Facilities (0822A)	9/89		
Develop methods for external leak detection at underground storage tank sites (PPA R62).			
Characterization and Monitoring of Cleanup Around Storage Tanks (EMSL-LV)			
Guide to Ground-Water Monitoring Based on Physical Modeling (0835A)	1/89		
Report on Results of the Long-Term Monitoring Program at Three Underground Storage Tank Sites (0645A)	3/89		
Preliminary Report on Network Design for External Leak Detection (0646A)	3/89		
Report on Inexpensive Screening Techniques for Contaminated Sites (0836A)	3/89		
Report on Protocols for Ground-Water and Vapor Monitoring (0837A)	3/89		
Report on Remediation Processes within a Large Physical Model of an Underground Storage Tank	9/89		
Report on Collection of Existing Underground Storage Tank Monitoring and Remediation Data	9/89		
Annual Report on Field Studies of Monitoring Around Underground Storage Tanks	10/88	10/89	
Final Report on Microelectrodes for Subsurface Detection of Specific Hydrocarbon Vapor Compounds			10/91
Superfund			
Provide monitoring techniques and procedures for Superfund site and situation assessments (PPA A04).			
Geophysical Methods (EMSL-LV)			
Journal Article on Application of Near-Surface Seismic Reflection at Hazardous Waste Sites (1629A)	4/89		
Internal Report on Status of Complex Resistivity Survey	4/89		
Geophysics Advisor Expert System: Version 1 (8122A)	6/89		
Journal Article on the Application of Complex Resistivity and Induced Polarization		10/89	

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

	FY89	FY90	Outyear
Practical Guide to Aquifer-Test Analysis (0880A)		12/89	
Journal Article on Geophysical Field Measurements		2/90	
Journal Article on the Evaluation of an Improved Ground Penetrating Radar System (8123A)		3/90	
Geophysics Advisor Expert System: Version 2 (8121A)		6/90	
Develop and evaluate new field-monitoring techniques and systems that are rapid, inexpensive, and more sensitive (PPA H03).			
Advanced Field Monitoring Methods (EMSL-LV)			
Interim Report on Sampling Design Methodology (0845A)	12/88		
Report on Preliminary Evaluation of a High-Resolution FTIR for Environmental Monitoring (0846A)	12/88		
Proceedings of the First International Symposium of Field Screening Methods (0847A)	2/89		
Interim Report on Methods for XRF Field Analysis and Sample Preparation (0527C)	3/89		
Report on State-of-the-Art Ultraviolet Fluorescence Systems for Site Screening (8127A)		10/89	
Final Project Report on Portable XRF for Characterization of Hazardous Waste Sites (0527A)		12/89	
Annual Report on Development of Fiber-Optic Based Lead Sensor		1/90	1/91
Adaption of a Prototype Data Telemet/Locator System to Portable X-Ray Analyzer (0881A)			10/91
Final Report on Development of Fiber-Optic Based Lead Sensor System			1/92
Vadose Zone Methods (EMSL-LV)			
Survey of Soil-Gas Screening Instruments	8/89		
Draft ASTM Standard for Soil Core Monitoring Equipment (0887A) (part of D109-I15-01)		2/90	
Develop and evaluate advanced field monitoring methods for Superfund sites (PPA S01).			
Advanced Field Monitoring Methods (EMSL-LV)			
Fiber Optics Systems Development for In Situ Monitoring (0505A)	12/88		

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

	FY89	FY90	Outyear
Annual Report on the Development and Demonstration of Immunoassay Detection System for Rapid Screening at Superfund Sites (0853A)	1/89		
Guidelines for Immunoassay Evaluation/Demonstration (8133A)	2/89		
Annual Summary on Demonstration of Fieldable and Portable X-Ray Fluorescence Analyzer System (0882A)	9/89		
Drinking Water			
Provide the scientific database and methods for the protection of ground-water resources (PPA F81).			
Ground-Water Monitoring (EMSL-LV)			
Journal Article on Modeling Ground-Water Quality Sampling Decisions (0879A)	10/88		
Annual *Report on Fiber Optics for Monitoring Ground-Water Contamination* (0610A)	11/88		
Method for Locating Contaminant Plumes from Abandoned Wells within the Area of Review of Injection Wells (2064A)	12/88		
Journal Article on Use of Geophysical Methods to Determine the Movement of Contaminants from UIC Class I Injection Wells (2065A)	12/88		
Journal Article on Geophysical Survey to Detect Brine Contamination from Injection Wells (0876A)	3/89		
Journal Article on Spatial Characteristics of the Occurrence of Pesticides in Drinking Water (0877A)	6/89		
Journal Article on Spatial Characteristics of the Occurrence of Volatile Organics in Drinking Water (0878A)	6/89		
Project Report on Optimization of Sampling Frequency (8040A)	6/89		
Handbook of Suggested Practices for Design and Installation of Ground-Water Monitoring Wells (1669A)		12/89	
Monitoring Strategies for Wellhead Protection Areas (0875A)			10/91

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

	FY89	FY90	Outyear
TRANSPORT AND TRANSFORMATION			
RCRA Hazardous Waste			
Provide field-evaluated methods and data to predict the concentrations of wastes released from RCRA hazardous waste facilities (PPA C25).			
Field Evaluation of Ground-Water Contamination Risks from Hazardous Waste Disposal (Ada)			
Internal Report on Implementation of a Ground-Water Database Clearinghouse (7942A)	11/88		
Report on Impact of Sensitive RITZ Model Parameters (7366E)	12/88		
Interim Report on Field Evaluation of RITZ Models (7947B)	12/88		
Report on Evaluation of Multiphase Flow Models (7366B)	3/89		
Report on Field Validation of Solute Transport Model for Prediction of Waste Concentration in Ground Water (7067A)	4/89		
Inventory of Models for Flow and Transport in Fractured Rock	5/89		
Report on the Use of Ground-Water Models for Regulatory Purposes	6/89		
Report on Field Evaluation of Selected Unsaturated Zone Models (7947A)	6/89		
Inventory of Flow Models of Immiscible Fluids	8/89		
Journal Article on Transport of Inorganic Solutes in Structured Media	9/89		
Internal Report on Multiphase Flow Model Development and Comparison of Models	9/89		
Article on Developed Solutions to Second Order Transformations Including Advection and Dispersion Terms		10/89	
Article on Comparison of Steady-State Solutions for Transport of Contaminants in Leaky Aquifers (7939X)		10/89	
Internal Report Comparing Performance of Ground-Water Models (8071A)		10/89	
Journal Article on Transport of Organic Solutes in Structured Media		6/90	
Internal Report on Nitrate Contamination Studies (8072A)			10/90
Monograph on Quality Assurance/Quality Control in Ground-Water Modeling			2/91

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

	FY89	FY90	Outyear
Monograph on Status of Ground-Water Modeling			6/91
Report on Multiphase Chemical Transport in Porous Media			7/91
Prediction of Contaminant Behavior in the Subsurface (Ada)			
Internal Report on Enhanced Degradation of Dioxin Isomers (7357A)	10/88		
Report on Land Treatability of Selected Hazardous Wastes, Volume III (7409A)	2/89		
Paper on Relationship of Hydrodynamic Dispersion to Percent Saturation	2/89		
Report on Mobility of Dioxins in Soils (7543A)	3/89		
Paper on Kinetics of Hydrazine Sorption and Ion Exchange	4/89		
Paper on Modeling of Hydrazine Transport	6/89		
Article on Contaminant Transport in the Presence of Residually Saturated Non-Aqueous Phase Liquids (NAPL)	6/89		
Journal Article on Sorption/Desorption of Metals by Clay Minerals in the Presence of Organic Acids	6/89		
Report on Case Studies for Selected Subtitle D Wastes (7949X)	7/89		
Report on Fate and Transport of Residual Matrix Constituents in Soil (7948A)	9/89		
Internal Report on Assessment of Ground-Water Pollution Potentials from Treated Aircraft Paint Stripping Wastewaters	9/89		
Journal Article on Transport in Time-Variant Mobile Phases		12/89	
Article on Inorganic Colloid Consideration in Metals		1/90	
Journal Article on Sorption/Desorption of Metals by Hydrous Oxides in the Presence of Organic Acids		4/90	
Report on Field Evaluation of Treatability Potential of PCP and Creosote Wastes in Soil (7075X)		4/90	
Report on Facilitated Transport of Metal Contaminants in the Subsurface: Part I–Organic Interactions (8120A)		9/90	
Internal Report on Transport of VOCs in Multi-Solvent Systems (7944A)			12/90
Two-Dimensional Multiphase Transport Model with User's Manual (8075A)			4/91

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

	FY89	FY90	Outyear
Three-Day Training Course on Use of Multiphase Chemical Transport Model			4/91
Report on Comparisons of Two-Dimensional Model Projections and Experimental Measurements of Multiphase Chemical Transport in Porous Media (8074A)			7/91
Spatial Variability of Subsurface Properties and Processes (Ada)			
Report on Determining Hydrologic Properties of Subsurface Environment (7654A)			12/90
Report on Methods for Handling Spatial Variability of Subsurface Environments (8076A)			12/90
Provide integrated, multimedia methods and data to estimate potential exposures to hazardous wastes from RCRA facilities (PPA C28).			
Determine Chemical Transformation Pathways and Rates (Athens)			
Report on Hydrolysis Rate Constants for Evaluating Property-Reactivity Correlations (7950A)	6/89		
Report on Transformation Pathway Analysis for Chemicals in the Environment (8157B)		7/90	
Environmental Process Characterization—Metals (Athens)			
Report on Prediction of Sorption Based on Chemical Character and Distribution of Metal Reactive Phases (7691P)	11/88		
Article Describing Role of Competitive Ion Character on Metal Speciation (7350I)	11/88		
Final Report on MINTEQ Bench-Scale Testing (7691N)	12/88		
Journal Article Describing Metal-Microbial Interactions–Role of Microbial Species and Life Stage on Metals Sorption (7350G)	12/88		
Report Defining Specific Complexation/Chelation Sites in Humic and Fulvic Substances (7351D)	3/89		
Report Defining Metal Complexation/Chelation Sites in Humic Materials (8158A)	3/89		
Interim Report on Preliminary Leachate Analyses and Proposed List of Compounds for Detailed Analysis of Equilibrium Constants (7691J)	6/89		
Article on Kinetics of Sorption and Desorption of Metals in Subsurface Environments (7350Z)	7/89		

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

	FY89	FY90	Outyear
Article Describing Kinetics of Complexation Phenomenon for Metals in Aqueous Systems (7351Z)	7/89		
Comprehensive Report on Applying Electrostatic Adsorption Theory to Natural Systems (8157A)	8/89		
Journal Article on Tested Model for Predicting Metal Distribution Coefficients in Environmental Samples (7350H)		10/89	
Final Report on Mathematical Form of Proposed Sorption Model Incorporating Revisions Due to the Availability of New Data and Results of Public Comment (7691G)		12/89	
Final Report on Input Data Distributions for Implementing the Sorption Model in OSW Rule-Making Scenarios (7691H)		12/89	
Final Report on Database Constants for Reactions of all 13 OSW Metals with Compounds in the Generic Mixture with Complexing Ability (7691K)		6/90	
Environmental Process Characterization—Biological (Athens)			
Report Evaluating the Utility of Current Methods for Estimating Anaerobic Degradation Rates for Use in Evaluative Models (8163A)	4/89		
Journal Article on Determinations of Microbial Substrate Removal Rate Coefficients Relative to a Benchmark Chemical (7951C)	6/89		
Internal Report on Microbial Process Research (8150A)	8/89		
Report on the Potential Uses of Isolated Natural Organisms to Enhance Bioremediation of Hazardous Wastes (8238A)		10/89	
Internal Report on Equations for Predicting Anaerobic Transformations within the Saturated Zones (7690A)		11/89	
Role of Limiting Nutrients in Adaptation to Degradation (8163B)		8/90	
Multimedia Modeling with Uncertainty Analysis (Athens)			
Feasibility Report on Linked Transport Code (6951I)	10/88		
Project Report on Components of Multimedia Environmental and Human Exposure Modeling (6019D)	11/88		
Report on Procedures for Estimating Indoor-Outdoor Exposures (6019E)	11/88		
Report on MINTEQ Predictions for Part II (6951B)	11/88		
MINTEQ Tapes with Thermodynamic Databases (6951F)	11/88		
Documentation on the Antimony and Cyanide Databases (6951G)	11/88		

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

	FY89	FY90	Outyear
Project Report on Performance Tests of OSW Modeling Approach Using Field Data (7352Z)	11/88		
Report on the Impact of Uncertainty in Leachate Tests and ADI Data on Overall Uncertainty in OSW Evaluations (7353B)	11/88		
Internal Report to OSW on Summary of Activities Conducted by OSW On-Site Contract Personnel (7685D)	11/88		
Report on Risk Assessment Methodology for Hazardous Waste Management (6019C4)	2/89		
Report on Impact of Treated Waste Forms on Exposure/Risk from Land Disposal of Hazardous Waste (8046A)	6/89		
User's Manual for Site-Specific Multimedia Model for Ranking Closure Options at RCRA Land Disposal Operations (8159A)	7/89		
Report on Colloid-Metal Transport (6951K)		10/89	
Report on Linked Transport Code (6951J)		12/89	
User's Manual for Model Defining Metal Species Transport in Subsurface (8160A)		8/90	
Report on Results of MINTEQA1 Model Performance at Globe, Arizona Site (8196C)			6/91
Environmental Process Characterization—Organics (Athens)			
Article Describing the Role of Soil in Mediating the Hydrolysis of Organic Compounds (7349Z)	1/89		
Final Report on Selection of Redox Parameters and National-Scale Redox Potential Distribution (7952Z)	1/89		
Report Describing the Kinetics of Redox Reactions in Soil-Water Environments (7689A)	4/89		
Book Chapter on Abiotic Transformation Processes in Water, Sediment, and Soils (7809C)	6/89		
Internal Report on Photodegradation Evaluation of Dioxin (2,3,7,8-TCDD) in Soils (7355A)	7/89		
Journal Article on Octachlorodibenzodioxin Dechlorination on Soil Surfaces (7954Z)		11/89	

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

	FY89	FY90	Outyear
Drinking Water			
Develop methods to predict subsurface contaminant concentrations to support risk analysis and source control (PPA F83).			
Subsurface Physical/Chemical Processes Affecting Transport (Ada)			
Internal Report on Facilitated Transport of Hydrophobic Organic Pollutants by Dissolved and Colloidal Organic Macromolecules (8058A)	9/89		
Report on Sorption of Organic Cations on Soils and Subsurface Materials (8056A)		1/90	
Internal Report on Abiotic Transformation of Haloaliphatic Compounds (8057A)		4/90	
Report on Facilitated Transport of Metal Contamination in the Subsurface: Part 2–Colloidal Transport (8118A)			6/91
Prediction of Microbial Contaminant Concentrations (Ada)			
Internal Report on Fate of Rotaviruses in Soils and Ground Water (8059A)	12/88		
Internal Report on Transport and Survival of Hepatitis A Virus in Unsaturated Soils (8060A)	12/88		
Report on Predictive Model for Viruses in the Unsaturated Zone (7589A)		12/89	
Prediction of Biotransformation of Subsurface Contaminants (Ada)			
Internal Report on Anaerobic Metabolism of Halogenated Organic Compounds (8061A)	1/89		
Report on Anaerobic Biotransformation of Contaminants in the Subsurface (7307A)		10/89	
Conduct joint research projects with the People's Republic of China on the impact of wastewater land treatment (PPA F87).			
Ground-Water Research with the People's Republic of China (Ada)			
Internal Report on Chinese–EPA Cooperative Land Treatment Research Project–Overland Flow (8119A)		1/90	

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

	FY89	FY90	Outyear
Evaluate models and management strategies in support of State wellhead protection programs mandated by the Safe Drinking Water Act Amendments of 1986 (PPA F89).			
Develop Methods for Wellhead Protection (Ada)			
Report on Impacts of Unregulated Sources of Ground-Water Contamination within Wellhead Protection Areas (8068A)	10/88		
Report on Approaches for Risk Assessment in Wellhead Protection Areas (8069A)		12/89	
Pesticides			
Determine how pesticides contaminate ground waters and remedial actions to alleviate the problem (PPA D07).			
Validation of Predictive Techniques for Environmental Exposure (Athens)			
Report on Sensitivity Analysis and Testing, Temik Contamination Potential (6639B)	11/88		
Final Dougherty Plain Report Including Pesticide Ground-Water Threat Assessment Methodology Validation (7661A)	9/89		
Report of Soils Database for RUSTIC Model (7664A)		6/90	
Report on Testing RUSTIC Model Using Selected Databases (8196A)			12/90
Develop information and techniques to estimate potential pesticide exposures and provide direct technical support to OPP (PPA D08).			
Pesticide Process Characterization (Athens)			
Report on Sorption of Water Soluble Ionic Pesticides to Soils and Sediments (8197A)		6/90	
Predictive Techniques for Environmental Exposure (Athens)			
Report on Development of Macropore Flow Model for Incorporation into RUSTIC (7709C)		8/90	

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

	FY89	FY90	Outyear
***IN SITU* AQUIFER REMEDIATION**			
RCRA Hazardous Waste			
Determine the applicability and cost-effectiveness of *in situ* reclamation techniques for contamination from leaking underground storage tanks (PPA R64).			
Corrective Action and Models for Underground Storage Tanks (Ada)			
Report on Hydrogeological Approaches for Mobilizing Immiscible Wastes for Corrective Actions (7361A)	12/88		
Report on In Situ Treatment Process for Water Contaminated with Wastes from Underground Storage Tank Releases (7363A)	12/88		
Report on Processes Affecting Aquifer Remediation by Pumping (8077A)		12/89	
Superfund			
Provide response technologies to support cleanup actions for contaminated ground water and soils at Superfund sites (PPA B01).			
In Situ Control Technologies (RREL)			
Handbook on Innovative In Situ and Treatment Processes for Hazardous Wastes and Contaminated Soils (4190A)	9/89		
Report of Radio Frequency Heating Treatability of Soils Contaminated with Wood Treating Chemicals		9/90	
Technology Transfer Workshop on In Situ Treatment of Contaminated Soils		9/90	
Report on Optimizing Pulse Pumping Systems for Ground Water to Achieve Uniformity os Coverage and Maximum Contaminant Removal			8/91
Handbook on Innovative In Situ Treatment Processes for Hazardous Wastes and Contaminated Soils			9/91
Field Test of In Situ Vapor Phase Removal of Organic Contaminants from National Priority List Municipal Solid Waste Units			9/91
Emerging Biosystems Program (RREL)			
Report of White Rot Fungus Field Tests (4690A)		7/90	

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

	FY89	FY90	Outyear
Evaluate abilities of natural and enhanced microorganisms for biodegradation of hazardous substances in Superfund remedial actions (PPA B02).			
Enhanced Biorestoration of Contaminated Ground Water (Ada)			
Internal Report on Enhancing Biodegradation of a Gasoline Spill in Ground Water (8078A)	4/89		
Journal Article on Enhanced Biorestoration of Contaminated Ground Water (7765A)	7/89		
Internal Report on Efficacy and Environmental Safety of Using Nitrate to Bioremediate Hazardous Wastes–Preliminary Findings	8/89		
Report on TCE Biotreatment Demonstration Project	9/89		
Internal Report on Evaluation of Denitrification for Biorestoration of JP-4 Jet Fuel-Contaminated Aquifer		4/90	
Efficacy and Environmental Safety of Using Nitrate to Bioremediate Hazardous Wastes: Final Report of a Field Demonstration		9/90	
Biodegradation Applications to Superfund Site Cleanups (Athens)			
Report on Evaluating the Utility of Current Methods for Estimating Anaerobic Degradation Rates for Use in Evaluative Models (8136A)	4/89		
Internal Report on Microbial Process Research Highlights (8150A)	8/89		
Report on Subroutines for Determination of Volatilization Rates from Bio-Restoration Systems (7966B)	8/89		
Report on the Use of Emulsifiers in Bioremediation of Hazardous Organic Wastes (8238D)		10/89	
Report on Potential Uses of Isolated Natural Organisms to Enhance Bio-Restoration of Mixed Hazardous Wastes (8238A)		10/89	
Report on the Use of Microorganisms to Biodegrade Hazardous Waste Under Methanogenic Conditions (8238C)		6/90	
Report on the Use of Sulfate Reducing Organisms for Bioremediation of Hazardous Waste Components (8238B)			11/90

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

	FY89	FY90	Outyear
Drinking Water			
Develop new methods for the restoration of contaminated aquifers and provide cost and feasibility data (PPA F84).			
In Situ Aquifer Remediation (Ada)			
Report on Criteria for In Situ Restoration of an Aquifer Contaminated with Halogenated Organic Concentrations (7311A)	6/89		
Expert System and User's Manual for Estimation of Parameters for Operating Aquifer Restoration Models (8062A)		12/89	
Report on Use of Fixed-Film Bioreactors for Treatment of Contaminated Ground Waters (8063A)		12/89	

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

	FY89	FY90	Outyear
UNDERGROUND SOURCE CONTROL			
Drinking Water			
Develop methods to determine the fate of underground injected wastes and develop safer technologies for underground injection control (PPA F88).			
Methods of Determining the Mechanical Integrity of Injection Wells (Ada)			
Internal Report on Methods for Evaluating Cement Bonding Behind Steel and Fiberglass Casing (8064A)	1/89		
Internal Report on Methods for Determining the Mechanical Integrity of Injection Wells (8065A)		1/90	
Impact of Class I Wells on Subsurface Geological Materials (Ada)			
Report on Methods for Regional Evaluation of Confining Bed Integrity (7798A)	12/88		
Internal Report on Transport and Fate of Contaminants Injected Directly into Aquifers (8067A)	12/88		
Class V Injection Well Practices (Ada)			
Report on Options for Improving Class V Injection Well Practices (7318A)		10/89	
Report on Effectiveness of Drilling Mud as a Well Plug (8066A)		1/90	

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

	FY89	FY90	Outyear
TECHNOLOGY TRANSFER AND TECHNICAL ASSISTANCE			
Superfund			
Provide technical support on Superfund settlement agreements, especially to enforcement programs in Regions and states (PPA F06).			
Geophysical Support (EMSL-LV)			
Aerial Remote Sensing Program for Hazardous Waste Sites–FY88 Program Summary and FY89 Management Plan (0844A) (also in D109-I17-01)	1/89		
Provide Superfund enforcement and response programs with rapid access to the best available technical information, evidence, and testimony (PPA F22).			
Clearinghouse for Information on Ground-Water Remedial Action Technologies (Ada)			
Manual Describing the Services of EPA's Subsurface Remediation Support Program	12/88		
Provide Subsurface Remediation Technical Information to the Regions and States	Cont.		
Ground-Water Technical Support (Ada)			
Technology Transfer Seminar Publication on Transport and Fate of Contaminants in the Subsurface (7769A)	12/88		
Technology Transfer Document on Evaluation of Bioremediation as a Remedial Action Technology (7768A)	1/89		
Technology Transfer Document on the Use of Assessment Models for Remedial Action (7767A)	3/89		
Internal Report of Regional Ground-Water Modeling Information Needs and Assistance as Provided (7766B)	9/89		
Manual on Selected Field Methods for Measuring Hydrologic Properties of Contaminated Aquifers		10/89	
User's Manual on the Use of Geostatistical Models for Managing Soil and Water Contamination (8079A)		12/89	
Protocol for Evaluating Ground-Water Remediation at Superfund Sites		1/90	
Internal Report on Methods for Measuring Sorption and Desorption Kinetics of Neutral Hydrophobic Contaminants		9/90	

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

	FY89	FY90	Outyear
Center for Exposure Assessment Modeling (Athens)			
Report on Procedure for Relative Risk Assessment and Ranking for Action Among Listed Sites and RCRA Closure Activities (7966)	2/89		
Research Brief of Exposure and Ecorisk Assessments Performed by Center for Exposure Assessment Modeling (8168A)	7/89		
Training Courses for Regional Superfund Staff on Exposure Assessment Modeling (8167A)	8/89		
Research Brief of Exposure and Ecorisk Assessments Performed by Center for Exposure Assessment Modeling (8170A)		7/90	
Training Courses for Regional Superfund Staff on Exposure Assessment Modeling (8169A)		8/90	
Drinking Water			
Develop and transfer improved methods for measuring subsurface parameters that influence contaminant behavior (PPA F82).			
Information Transfer (Ada)			
Report on Existing Ground-Water Models (7580A)	10/88		
Report on Compilation and Evaluation of Ground-Water Models (8055A)			12/90

APPENDIX C: RECENT ORD GROUND-WATER PUBLICATIONS

EPA publications in the 600 and 625 series (ORD) may be obtained by calling EPA's Center for Environmental Research Information at FTS 684-7562 (513-569-7562). Publications referenced by a PB number are also available from NTIS.

General

Protection of Public Water Supplies from Ground-Water Contamination. EPA-625/4-85-016, PB 86-168358, September, 1985.

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