United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

EPA/600/9-90/042
September 1990

EPA

ORD Ground Water Research Plan: Strategy for 1991 and Beyond

Foreword

Ground water is a vital natural resource in the United States. Its quality is of foremost concern for the future of human health and the environment. The importance of ground water for consumption and other uses, as well as the interaction of ground water with the rest of the hydrologic cycle and other aspects of the environment has become increasingly apparent in a number of EPA programs. The Agency has therefore established standards and undertaken various activities to protect and remediate this resource. To underscore the importance of these activities, the Deputy Administrator convened an EPA-wide Ground Water Task Force to coordinate and direct future efforts.

There are three essential and inter-related requirements for EPA's ground water efforts: legislative authority, administrative framework, and scientific and technological know-how. This document addresses the third requirement, particularly the role of research in building a scientific understanding of how to prevent, predict, and remediate ground water contamination. This Plan presents the Office of Research and Development's strategy for conducting subsurface and related research in support of EPA's programs.

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Preface

This document describes a ground water research plan for EPA's Office of Research and Development (ORD). The ground water research program is carried out by ORD's Office of Environmental Processes and Effects Research (OEPER), the Office of Modeling, Monitoring Systems, and Quality Assurance (OMMSQA), the Office of Environmental Engineering and Technology Demonstration (OEEDT), and the Office of Exploratory Research (OER). Four ORD laboratories have lead responsibilities in ground water research: OEPER's Environmental Research Laboratories in Ada, OK and in Athens, GA, OMMSQA's Environmental Monitoring Systems Laboratory in Las Vegas, NV, and OEEDT's Risk Reduction Engineering Laboratory in Cincinnati, OH. 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, Peter W. Preuss, Director of ORD's Office of Technology Transfer and Regulatory Support. This Plan was prepared by Peter W. Preuss and Amy L. Mills for the Assistant Administrator for Research and Development. The Plan reflects the review and contributions of the ORD Ground Water Matrix Management Work Group and the Deputy Administrator's Ground Water Task Force.

Abstract

Ground water research at EPA encompasses several different ORD programs which are contributing to the body of knowledge in this emerging science. Efforts are focused on serving EPA programs which are requiring an increasingly sophisticated knowledge base and greater technical assistance in order to develop and implement environmental programs. Two major themes or objectives for future research are prevention and remediation of ground water contamination. These objectives can continue to be met through focused research products for EPA program clients, supported by basic research on subsurface processes, monitoring and remediation methods, while evaluating and refining research results based on field experience. Of primary importance are coordination with other research agencies and organizations, and dissemination of research expertise through technology transfer and technical assistance. Several ground water research initiatives are highlighted in this Plan which would serve these goals. Two significant research initiatives proposed for consideration concern improving the performance of remedial technologies, and basic process research on the behavior and effects of agricultural chemicals in ground water and surface water. Enhanced funding for ground water research should be considered in order to sustain its ability to serve the Agency's needs.

Contents

Foreword i
Preface ii
Abstract iii

I. Introduction 1

II. Background 1
- A. Subsurface Monitoring 1
- B. Transport and Transformation 2
- C. In Situ Subsurface Remediation 2
- D. Underground Source Control 3
- E. Technical Assistance and Technology Transfer 3

III. General Approaches for Future Ground Water Research 3
- A. Staying at the Forefront of an Emerging Scientific Field 3
- B. Preserving Continuity 3
- C. Meeting Users' Needs 3
- D. External Coordination 4
- E. Dissemination of Research Results 4
- F. Science Advisory Board Recommendations 4
- G. Ground Water Research Legislation 5

IV. Growth Themes for ORD Ground Water Research 5
- A. Prevention 5
- B. Remediation 5

V. Emerging Research Topics 6
- A. Monitoring 6
- B. Transport and Transformation 6
- C. Subsurface Remediation 7

VI. Future Needs and Support of Ground Water Research 7

VII. New and Proposed Research 8
- A. New Research for FY 1990 and 1991 8
  - 1. Wellhead Protection 8
  - 2. Prevention of Ground Water Contamination from Pesticides: Information Systems for State Use 8
  - 3. Subsurface Cleanup and Mobilization Processes (SCAMP) 8
- B. Proposed Initiatives for FY 1992 and Beyond 9
  - 1. Improving Performance of Remedial Technologies (IMPORT) 9
  - 2. Mid-West Agrichemical Subsurface/Surface Transport and Effects Research (MASTER) 9
  - 3. Other Initiatives to Consider for the 1990s 10
- C. Future Funding for ORD Ground Water Research 10

ORD Ground Water Research Plan: Strategy for FY 1991 and Beyond

I. Introduction

The Science Advisory Board's, "Review of the EPA Ground Water Research Program" (July, 1985) concluded, among other things, that ORD should establish centralized direction and management for its ground water research program through a Ground Water Research Manager. They recommended that this Manager develop an integrated, comprehensive ground water research plan. The plan would address research needs and activities spanning the various EPA programs having ground water components.

ORD has responded to these recommendations by appointing a Ground Water Matrix Manager, who coordinates with other ORD Offices to analyze ground water needs and promote new initiatives. This Ground Water Research Plan summarizes the status of ground water research at EPA, and proposes areas for growth for fiscal year 1991 and beyond.

II. Background

ORD supports an active, diverse ground water research program dedicated to provide the scientific basis for protecting current and potential drinking water aquifers, and interconnected surface water resources, from contamination. The interrelated scientific fields of hydrogeology, hydrology, geochemistry, geophysics, biochemistry, microbiology, statistics, soil science, and physical chemistry are components of ground water research. Each field provides a perspective on what can collectively be called ground water science. Research areas span source control, detection, monitoring, prediction, and remediation of ground water contamination. Five EPA programs and their statutory missions are served: CERCLA, RCRA, CWA, SDWA, and FIFRA.

EPA's role is some what unique in the Federal ground water research community, due to our regulatory missions and timetables. For example, EPA's need to monitor ground water quality and remediate contamination to drinking water concentrations has generated research into areas sometimes untested by other organizations. Technology transfer and technical assistance to those implementing environmental programs depends upon a strong in-house knowledge base, responsive research agenda, and assertive outreach program. EPA's research effort in support of environmental programs is therefore distinctive in purpose, direction, and timing. Other agencies cannot be expected to fulfill this role. Our challenge in working with other agencies and organizations is to identify areas of common and separate interest, so that research is complementary but not duplicative or lacking.

To carry out its functions in supporting ground water activities at EPA, ORD conducts research in five broad areas. These areas, and some of ORD's significant contributions, are summarized below:

A. Subsurface Monitoring

The goal of this research program is to produce techniques and methodologies for detecting and quantifying changes in hydrogeology, and in subsurface water quality. Both direct sampling and remote sensing approaches are generated. This program includes research on locating and installing monitoring wells; sample collection and preservation; quality assurance and quality control; geophysical and geochemical detection and mapping of shallow contaminant plumes with both surface and downhole methods; mapping deeply buried plumes associated with injection wells, determining chemical indicators of ground water contamination; developing monitoring methodologies for the unsaturated zone; advanced monitoring techniques such as real-time, in situ monitoring of ground water with fiber optic sensor and fluorescence spectroscopy; and external leak detection devices for underground storage tanks.

Most of ORD's subsurface monitoring research has been undertaken in response to the needs of the CERCLA and RCRA hazardous waste programs, where immediate needs to accurately sample and analyze ground water have challenged the state of the science to develop appropriate laboratory and field techniques. ORD's monitoring research and development has advanced EPA's ability to meet environmental needs and statutory requirements.

Some of ORD's most significant contributions have been in:

- fiber optic and x-ray fluorescence remote sensing;
- unsaturated zone monitoring for hazardous waste facilities and underground storage tanks;
- well construction techniques to minimize sample contamination;
- identification of indicator parameters for ground water contaminants;
- methods for collection of uncontaminated aquifer core material;
- quality assurance of field investigations;

- application of standard geophysical techniques to hazardous waste site investigations;
- development of geographical information systems (GIS); and
- methods for statistical comparisons of ground water monitoring data.

As these methods and technologies are developed, they are transferred to EPA Regions, States, and the public through guidance manuals, training, reports, and professional journals. Case-by-case technical support to program offices in these areas is also a major effort.

B. Transport and Transformation

In order to predict the movement of contaminants in the subsurface, and thereby predict potential human and ecological exposure, ORD maintains a research program in transport and transformation of contaminants. Predicting contaminant behavior in the subsurface requires understanding the mechanisms and rates of transport, and chemical, physical, and biological transformations of contaminants. Transport is often assumed to occur in the dissolved, aqueous phase, but may also occur in separate, dissolved phases such as in immiscible oils, or sorbed to fine, colloidal particles. The subsurface environment affects the oxidation state, and the rates and types of chemical transformations. These transformations in turn affect the solubility and mobility of the contaminants. Transformation and transport are therefore intimately related processes. ORD's research studies these processes for various contaminants in different settings, and develops models for predicting time of travel and exposure concentrations.

Recent developments in transport and transformation research include advances in understanding the processes that control these phenomena, and integrating these processes into mathematical models for describing and predicting the behavior of contaminants in the subsurface.

At the process level, there have been recent advances in:

- understanding the kinetics of the partitioning of contaminants between ground water and aquifer solids;
- the behavior of multiphase fluid systems of water, oil, and air;
- the movement of metal ions in response to chemical conditions;
- abiotic transformation pathways and rates;
- vapor phase transport phenomena important in the vadose zone;
- facilitated transport resulting from the presence of colloidal materials, or cosolvents such as alcohols;
- the movement of contaminants through fractured rocks;
- aerobic and anaerobic biotransformation;
- re-examination of the capacity of pollution-degrading bacteria to move through soils and geological material, which has improved our understanding of the partitioning of organic compounds between ground water and residual oily material,
- understanding higher order transformation reactions;
- understanding hydrodynamic dispersion in relation to heterogeneity in the hydrodynamic domain;
- a more definitive description of the metals sorption processes;
- mathematical descriptions of the reduction of organic pollutants in ground water.

Recent advances in integrating process level information into predictive tools include:

- the development and dissemination of the metal speciation model MINTEQA2;
- the pesticide soils leaching model PRZM;
- the pesticide ground water leaching model RUSTIC;
- the screening model for vulnerable soils DBAPE, and development of databases for access through DBAPE;
- development of the multimedia model MULTIMED for predicting the exposure from landfilled solid and hazardous wastes;
- development and application of the CEEPES comprehensive environmental management model to agricultural chemicals.

Most of the transport and transformation research in ORD is performed in support of the hazardous waste programs, and their needs in predicting the off-site effects of ground water contamination from waste disposal sites. Some is also done to support the Office of Pesticide Programs to predict the leaching behavior of agricultural chemicals. A new effort is underway to support the Office of Water in determining the sorptive properties of soils as a factor in protecting wellheads from contaminant migration.

C. In situ Subsurface Remediation

ORD's ground water research in the area of subsurface remediation is developing effective, reliable methods for restoring contaminated soils and ground water as close as possible to their original quality. This includes methods for recovering contaminants from aquifers for further treatment, reducing the volume or toxicity of contaminants in situ, monitoring and modeling remediation projects, and examining past remediation and source control efforts to identify subsurface factors contributing to their success or failure.

Significant research advances have included the initiation of applied bioremediation to the subsurface, the development of design tools for remediation (i.e., the BIOPLUME model), and methods for performance evaluation of pump-and-treat technology. Other areas of investigation include steam stripping

and soil vacuum extraction of contaminants, with an emphasis on understanding the subsurface processes governing the results of remedial measures.

ORD's research in the subsurface remediation area has been performed in support of EPA's drinking water and hazardous waste programs.

D. Underground Source Control

EPA's Underground Injection Control program regulates the injection of hazardous wastes into the subsurface. ORD has a research effort to develop protocols for injection well practices, injection well integrity testing methods, and to understand the interaction of injected material with subsurface materials.

E. Technical Assistance and Technology Transfer

Technical assistance generally refers to one-on-one assistance by ORD on site-specific or problem-specific Regional, State, or National regulatory matters. Technology transfer generally refers to printed documents, software packages, and focused training that are initiated and budgeted by ORD. Both are carried out by ORD laboratories primarily for Superfund staff in the Regional Offices. This effort is largely funded by OSWER through the Superfund Technical Support Project, which provides support on ground water as well as other aspects of Superfund site investigations and remedies.

For example, the RSKERL provides assistance on subsurface remediation problems through the Subsurface Remediation Technology Support Core Team, operates an information clearinghouse on this subject, and transfers technology from the National Center for Ground Water Research, a consortium of Rice, Oklahoma, and Oklahoma State Universities. Areas of expertise include hydrogeological aspects of pump-and-treat aquifer remediation, in situ bioremediation of soils and ground water, geochemistry, fluid and contaminant transport, transformation, and mathematical modeling.

EMSL-LV provides assistance in detecting, monitoring, site characterization, data interpretation, and geophysical techniques. This includes saturated and unsaturated zone monitoring, remote sensing, mapping, geostatistics, analytical methods and quality assurance, borehole and surface geophysics, and x-ray fluorescence field survey methods. A hotline and on-site field training facility are important features of the technology support program at EMSL-LV.

At ERL-Athens, the emphasis is on multimedia (i.e., ground water, surface water, and soil) exposure and risk assessment modeling of remedial action alternatives. Through the Agency's Center for Exposure Assessment Modeling (CEAM), support is provided on applying models to assist in risk-based decisions. This includes information on models and databases that link ground water transport and transformation to human and ecological exposure scenarios. Workshops and an electronic bulletin board serve to enhance technology transfer and assistance.

RREL operates the largest of the technical support centers in ORD. Support is provided on engineering problems related to but not specific to ground water, such as soil and above-ground water treatment alternatives, remedial construction processes and materials, source control, and geotechnical methods.

Technical assistance and technical support continue to be a highly important part of the ground water research program. In the future, the services described above could be further expanded to others in need of scientific and engineering expertise for technical decision-making.

III. General Approaches for Future Ground Water Research

A. Staying at the Forefront of an Emerging Scientific Field

Hydrogeology and contaminant behavior is an emerging field, and EPA's scientific research is at the forefront. EPA's contribution to the state of knowledge is evidenced by our contributions to the literature, our sponsorship of cutting-edge research by universities such as Stanford, Yale, Louisiana State, Carnegie-Mellon, and the consortium of Rice, Oklahoma, and Oklahoma State Universities, and our participation in international conferences (such as the International Geological Congress, and others). Implementation of EPA's environmental programs need the best available technologies and methods. These needs demand that supporting research be innovative, state-of-the-science, and timely. It is essential therefore that ground water research be supported so that it may remain at the forefront.

B. Preserving Continuity

Another essential aspect of the research program is continuity. Research projects studying flow, sorption, transformation, or model development often require years of steady effort. Field studies in particular require multiple years of observation. A successful ground water research program must maintain stability over time in order to generate useful, tested products. Ground water research should therefore be part of the Agency's long-term research agenda. Two examples of on-going research areas related to ground water which have successfully adopted 5-year plans are the Biosystems Technology Development Program and the Wellhead Protection Research Program.

C. Meeting Users' Needs

There are several categories of users of EPA's ground water research. A primary user of research is EPA Headquarters program offices, that develop regulations, guidance, and strategies for national implementation. The scientific underpinnings of these documents are based on ground water research. For instance, the Office of Solid Waste, the major supporting office for ground water research funding, uses research results from fate and transport modeling to formulate hazardous waste characteristic criteria.

A second primary category of users is the Regional, State, local government staff, and consulting community who implement environmental regulations, guidance, and strategies. Technical field manuals and technical assistance activities are generally geared to this group. They represent the largest segment of the user community, and are increasingly receiving more of the research focus through technology transfer, technical assistance, and training. Some examples are technical assistance on developing remediation plans at Superfund sites, or providing training on sampling procedures. This user group is also a valuable source of information on the application of ground water methods and techniques, and can provide essential feedback to research.

Third, basic research projects feed into other, more advanced research projects which can eventually lead to products or predictions. For instance, basic research in methods development is necessary in order to conduct quantitative field or laboratory studies. Research to develop scientific principles of sorption, transformation, and migration provides the basis for much of the research on technological controls for specific sources of ground water contamination. Therefore, one of the primary users of research is researchers, who work through iterative, experimental processes to develop products of use to environmental programs.

Fourth, EPA contributes to extramural knowledge and applications in ground water science. Through interagency agreements, publications, participation in conferences, and membership in professional organizations, EPA ground water research is shared among users in the scientific community for the betterment of all. Clearly, the research plan should emphasize environmental program support, while seeking the best balance among the various user groups.

The future trend will be toward greater and more innovative technology transfer and technical assistance to Regions and their contractors, as well as delegated States because these groups are increasingly responsible for carrying out environmental programs and are in need of technical knowledge. This effort cannot occur in the absence of continued basic research and development. Basic research to maintain and build our knowledge base must be sustained so that there will continue to be technology to transfer.

D. External Coordination

Coordination plays a major role in prevention and remediation research. ORD coordinates with other federal agencies as well as State governments and private and public institutions to promote information exchange and produce better research products. Some examples are: current coordination on the preparation of an interagency research plan with the USGS and USDA on agricultural chemicals and their effects on water resources; ongoing coordination with these agencies at field test sites for validating pesticide leaching models and performing site investigations; participation in the EPA/USGS Coordinating Committee; recently co-sponsoring a conference on hazardous waste ground water research with the Electric Power Research Institute; and participation in the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), which has recently published a synopsis of all ground water research supported by Federal agencies. These types of alliances, and coordinated research plans and projects will continue to be fostered in the future.

Particular attention should be paid to the special expertise and perspective various organizations can bring to a research problem. EPA's needs and expertise are somewhat unique in the research community due to our regulatory missions and timetables. Subsurface processes that attenuate, transport, or transform synthetic chemicals and metals, and sampling strategies for point and non-point sources, are examples of areas where EPA specializes. Our Agency's mandates to protect and remediate ground water quality have generated research into some areas other organizations have not explored. We must continue to work with other agencies to identify areas of common and separate interest, so that important research is conducted but not duplicated.

E. Dissemination of Research Results

Technology transfer and technical assistance are important applications of ground water research. This mechanism provides a direct link between the researchers' expertise and EPA's program implementation at the Headquarters, Regional, and State levels. Various efforts are underway, including seminars and publications disseminated from ORD's Center for Environmental Research Information (CERI). These efforts also support EPA's Ground Water Protection Strategy (1984), which calls for strengthening State ground water programs through technical assistance and a strong research program.

ORD's major technical assistance activities in ground water are supported by and directed at Superfund programs. However, other programs such as RCRA are equally in need of hazardous waste remediation expertise, and an institutional mechanism for accessing all appropriate laboratories for short-term, intensive, site-specific project support should be considered.

F. Science Advisory Board Recommendations

The Science Advisory Board's "Review of the EPA Ground Water Research Program" (1985) identified a number of needed refinements, including the need for increased resources and the need for increased technology transfer and training. They indicated 16 specific recommendations for filling research gaps among monitoring, source control, fate and transport, and remediation. Some of those recommendations have been partially implemented, such as CERCLA funding for ground water research, increased funding for monitoring, source control, source minimization research, and technology transfer. Many, however, have not been fully implemented due to resource limitations and competing priorities for research funding. This includes research on contaminant sources not addressed by specific Congressional mandates, field validation of predictive techniques, assessment of field applications of

containment techniques (caps, liners, walls, hydrodynamic controls), remedial actions in fractured formations and in karst topography.

The SAB also emphasized the general need for sustained, long-term research and emphasis on environmental protection at EPA in "Future Risk: Research Strategies for the 1990's" (1988). The SAB's "Resolution on Use of Mathematical Models for EPA for Regulatory Assessment and Decision-Making" (1989) recommended, among other things, that EPA increase its model validation program. To the extent practicable, EPA should incorporate these recommendations into plans for future research.

G. Ground Water Research Legislation

Several bills have been introduced in Congress over the past several years calling for additional ground water research and related activities in the Federal government. This legislation would give EPA specific authority and direction to perform ground water research. Currently, EPA derives this authority from a number of different statutes, such as the Safe Drinking Water Act.

Major provisions of these bills that affect EPA include a new interagency research oversight committee and an education committee, a research demonstration program, environmental profiles and research on significant ground water contaminants, technical assistance, training, and technology transfer, establishment of a ground water information clearinghouse, establishment of research institutes, and grants to States to develop and implement ground water strategies. Most of these provisions are consistent with parts of the existing program, however the research demonstrations, environmental profiles, and clearinghouse would entail significant added emphasis in EPA's research program.

The attention that Congress has given to new legislation in this area underscores the importance of existing work at EPA, and reinforces the need for additional research to serve the needs of the Nation.

IV. Growth Themes for ORD Ground Water Research

Subject areas where ground water research should seek to expand can be broadly characterized by two themes: prevention and remediation.

A. Prevention

Prevention encompasses the identification of threats to ground water from point and non-point sources, and mitigating these threats through a combination of source control, management practices, land use changes, and institutional measures. Prevention requires an understanding of fate and transport processes, use of predictive techniques, and monitoring to delineate the threats to ground water.

One aspect of prevention is wellhead protection, which involves focused land and source management practices aimed at preventing contamination of aquifers which supply drinking water wells. By characterizing the vulnerability of aquifer systems, local sources of contamination, and likely pathways and rates of transport and transformation to such wells, State and local governments can develop plans for protecting their drinking water supplies. Wellhead protection research includes methods for delineating wellhead protection areas, and managing point-source/non-point source contamination threats.

Other aspects of the prevention theme are predictive tools, such as models for flow, fate and transport. Predictive models can be used to support management decisions to prevent the introduction of contaminants to the subsurface or to prevent exposure above a health-based concentration at a specified location. The correct use of these models depends upon the underlying field and contaminant data and assumptions that are incorporated in the models. Research into rate constants and physical properties such as hydraulic conductivity and effective porosity can therefore all be looked upon as part of the prevention goal.

Monitoring the subsurface for early detection of leaks from underground storage tanks or waste impoundments, or seepage from pesticide applications, can also be considered an integral part of prevention. By employing various sampling and remote sensing methodologies near the source of contamination, actions can be taken to prevent the spread of contamination to ground water.

B. Remediation

The success of ground water remediation efforts depends largely upon understanding subsurface processes in order to design effective remedies. For example, the success of remediation may be governed by mutiphase behavior of contaminants, partitioning among solid and fluid media, biotic and abiotic transformations, and transport in fractured media. In order to remediate ground water at a waste site, knowledge of these processes and how they are likely to operate under given site-specific environmental conditions is essential.

Predictive tools such as models are also part of designing and tracking remedial actions. For example, the BIOPLUME model predicts contaminant migration affected by oxygen-limited biodegradation, and can be used to help plan a bioremediation project. Monitoring is also integral to remedial actions, both for detecting contaminants and monitoring the progress of ground water cleanup. For example, assessing whether health-based concentrations have been reached at a site depends heavily on the monitoring techniques and strategy utilized.

Knowledge of subsurface conditions also interfaces with the design of engineering methods and technologies for remediation. For example, ground water pumping systems and practices must be compatible with the local hydrogeology and contaminant properties. Because subsurface remediation is relatively new and much remains unknown about the subsurface precesses and long-term results of various remedies, development and evaluation of remedies must continue to be a focus for research.

V. Emerging Research Topics

Within the prevention and remediation themes, ORD has identified a number of emerging topics and research needs in ground water.

A. Monitoring

Advanced monitoring techniques that rely upon non-intrusive, in situ, or microelectronic techniques hold promise for the future, and may supplement or possibly replace conventional laboratory "wet chemistry" for ground water monitoring. Development of fiber optics and x-ray fluorescence (XRF) have been successful for in-situ, real time monitoring of some organics and metal compounds, respectively. For example, in XRF, an x-ray is directed at a sample, and in response the sample emits induced fluorescence in the x-ray spectrum. A detector analyzes the fluorescence for both type and concentration of inorganics. With further refinement, it may be possible to do at least preliminary screenings for a range of specific contaminants at waste sites or USTs with these methods. The advantages in time and cost savings, holding times, chain of custody, and laboratory requirements are significant.

Other emerging topics include monitoring strategies for non-point sources of contamination, long-term monitoring strategies for closed hazardous waste sites, problems monitoring in wet environments, remote sensing methods for fracture characterization, unsaturated zone processes and monitoring techniques, monitoring strategies for karst terrain, and new applications for problem solving with GIS.

B. Transport and Transformation

The roles of organic carbon, redox potential (eH), pH, and solubility in aqueous phase transport need better understanding in order to develop and rely upon predictions of contaminant transport. Facilitated transport, a phenomenon that refers to various mechanisms whereby contaminants move through the subsurface at velocities greater than expected by considering solubility and primary permeability alone, merits greater understanding. For example, sorption of contaminants on colloidal particles, and flow through macropores facilitate transport, and must be accounted for in our predictions of time of travel and exposure. Although anecdotal evidence exists that this phenomenon occurs, it is not fully understood and is not accounted for in operational transport models.

Another research topic in the area of contaminant transport is complex wastes, or wastes with several components, densities, or behavioral characteristics. The separation of leachates into water-soluble and immiscible fractions can result in plume stratification, with light non-aqueous phase liquids (LNAPLS) floating above dense non-aqueous phase liquids (DNAPLS). A portion of the former sometimes can be removed from the subsurface, while the latter settle in residual masses which are not currently amenable to conventional removal methods. Another complexity to this situation is the chemical alterations which take place in the subsurface, sometimes producing plumes of degradation products more toxic than the original waste.

The kinetics of adsorption and desorption, collectively referred to as sorption, must be better understood to predict transport reliably and design remedies. This is particularly applicable to understanding the slow desorption of residual contaminants in the deep subsurface. Remedies that enhance desorption may be necessary in some settings.

Most transport models assume homogeneous hydrogeology, while in fact this is more the exception rather than the rule. Accelerated flow through fractured media is one important example of the effects of heterogeneity on transport. This phenomenon needs to be better understood and integrated into transport models.

Transport, transformation, and environmental fate of non-point sources, particularly agricultural chemicals is of special interest to EPA. For example, much remains to be learned in the areas of nitrate and pesticide behavior in the subsurface in order to predict fate and effects with confidence.

Abiotic transformation processes have been studied for some time, but much remains to be done, given the large number of organic pollutants. Recent discoveries, for example, show that certain halogenated hydrocarbon solvents may be hydrolyzed or reduced over a period of days or months to other compounds having different properties.

The mobility and bioavailability of toxic metals and metalloids depend on the species of the metal, which in turn is a function of metal/metalloid chemical properties and the characteristics of the subsurface. Improving our understanding in these areas is providing a better basis for predicting exposures to these toxic substances.

Little is known about the fate of pollutants disposed of in underground injection wells. The conditions of temperature and pressure in this environment may greatly accelerate the transformation and transport of pollutants.

Ground Water Modeling

The National Research Council, Water Science and Technology Board, Committee on Ground Water Modeling Assessment's report "Ground Water Models: Scientific and Regulatory Applications" (September, 1989) contained a number of recommendations applicable to EPA ground water research. In summary, the report recommends: (1) continued validation and refinement of ground water models, particularly those for flow through the unsaturated zone, fractured rock, multiphase flow, and codes linking mass transport and chemical reactions; (2) the role of bacteria in transport and removal of contaminants; (3) improving the presentation of uncertainty in model predictions, and improving our ability to estimate the reliability of model results; (5) continued efforts at characterizing subsurface processes through field and laboratory studies; and (6) developing approaches for parameter estimation and measurement techniques.

The Science Advisory Board gave similar recommendations in their July, 1985 report, "Review of the EPA Ground

Water Research Program" and their January, 1989 report, "Resolution on Use of Mathematical Models for EPA for Regulatory Assessment and Decision-Making", particularly points (1) and (3) above. Clearly, future research in transport and transformation should address improvements in the development, application, and validation (i.e., laboratory or field evaluation) of predictive models that EPA uses.

C. Subsurface Remediation

Identification of information requirements for remedy selection, and methods for subsurface remediation continue to be crucial areas for research. Low and variable permeability influence the transport of contaminants, as well as the dispersion of surfactants used in clean up, and pumping rates in pump-and-treat operations. Other important relationships between subsurface conditions and application of remedial technology must continue to be explored, in order to maximize the success of costly and time-consuming remedial efforts.

Enhanced in situ methods for biotic and abiotic contaminant degradation is an active research area that merits greater attention. The permanent solutions possible through this approach (as opposed to moving contaminants to treatment systems, concentrating them, and moving the residuals to still other locations), and the important alternatives these methods provide to unproven extraction methods, render in situ methods one of the most important growth areas for research. Processes for transforming contaminants in the subsurface to simpler, less toxic compounds are being explored for application to remediation of hazardous waste sites and pesticide use.

Topics include in situ bioremediation, where microbes are stimulated to degrade organic contaminants in place. Use of naturally occurring, indigenous species is showing promise for some contaminants and settings, while engineered microbes are being developed for others. It has been shown in the laboratory and field that certain organic wastes can be converted into biomass and harmless by-products of microbial metabolism. This has begun to be demonstrated in the field for indigenous species with hydrocarbon components of gasoline and for chlorinated compounds such as vinyl chloride and DCE, which can be cometabolized with methane. More highly chlorinated compounds tend to be more recalcitrant to these methods, and may require addition of microbes with special biodegradative functions. White rot fungus has also shown to be effective on a number of contaminants including DDT, PCBs, PAHs, chlorinated phenols and chlorinated dioxins.

The major limiting factor in successful field application of bioremediation, however, appears to be transporting oxygen or other electron acceptor and nutrients to the microbial populations so that they may flourish and metabolize the contaminants rapidly. This transport factor is a function of the heterogeneity and hydraulic conductivity of the site's geologic media and distance from the remedial application to the contaminant plume. In addition, in certain anaerobic conditions, reductive dechlorination can be an effective bioremediation method. In all circumstances, the importance of reliable site investigations, monitoring systems, and predictive tools are evident.

Ahead in bioremediation research is identification of breakdown mechanisms for a range of contaminants, identification of alternative electron acceptors (other than oxygen), aerobic degradation of solvents, and the feasibility of adding micro-organisms with special metabolic capabilities. Of equal importance is overcoming hydrogeological obstacles to employing bioremediation in the field, and developing methods for enhancing transport of nutrients to microbial populations. This research must be built upon methods development and controlled studies of biological transformation processes. Some of this research is incorporated in ORD's Biosystems research program.

In the future, EPA may be able to estimate and enhance the rate and extent of natural degradation processes of many contaminants of concern in soils and ground water. A major emphasis should be to approximate the extent of contaminant reduction that can be attained with bioremediation to determine whether the technology can be used to meet EPA's regulatory standards for remediation and closure.

Abiotic remediation is another topic that has an unexplored potential. EPA investigators are in the process of isolating the natural compounds responsible for the observed abiotic reduction of several classes of pollutants. These compounds may be useful in enhancement of degradation processes.

VI. Future Needs and Support of ORD Ground Water Research

While significant strides have been made in understanding various aspects of ground water science and technology, ground water research is still in its infancy in many respects. Unlike surface water, ground water is very difficult to observe and measure in the field, it moves slowly, and is strongly influenced by the medium through which it flows. Further, contamination results in different flow characteristics as well as a range of chemical interactions and transformations, most of which cannot be quantitatively predicted at this time.

The scope of research needs has been broadened by greater concern for ground water quality, new legislation and regulations, better problem identification, and a tendency for investigations to uncover ever greater variability in the chemistry, physics, and biology of the subsurface. Research must strive for but may never attain solutions to every contamination problem in every hydrogeologic setting.

EPA programs require increasingly sophisticated knowledge on which to base complex, costly contamination prevention and remediation decisions. The importance of continued and expanded supporting research is paramount. The value to EPA programs in supporting ORD research has been demonstrated by such advances as in ground water monitoring practices, site characterizations, tools for risk assessments, remedy selections

at hazardous waste sites, and pesticide leaching models. Continued sustenance of these and other program office activities will depend in part on future research in the high priority areas identified below.

VII. New and Proposed Research

A. New Research for FY 1990 and 1991

Three research initiatives have been approved within the last two fiscal years which will address some of the emerging topics presented in this Plan.

1. Wellhead Protection

In September, 1988, ORD and EPA's Office of Water entered into a 5-year research and technology transfer agreement to support State Wellhead Protection (WHP) Programs. States are currently implementing WHP programs in accordance with the 1986 Amendments to the SDWA. The purpose of the research is to advance fundamental understanding and transfer information regarding how to protect ground water supplies which flow to drinking water wells in various physical and institutional settings across the nation. ORD begins research and development activities for WHP in FY 1990.

Four research priorities are envisioned. First, field testing and verification for WHP area delineation methods will be undertaken, including the refinement of current modeling approaches. Second, ORD will evaluate the ability of the subsurface to assimilate certain amounts of contamination without impact to drinking water supplies, and apply this information to the delineation of WHP areas. Third, ORD will evaluate and apply knowledge of agricultural chemical behavior, including the use of pesticide leaching models, for delineating WHP areas. Fourth, ORD will develop WHP area ground water monitoring strategies, including definition of optimal sampling and monitoring designs.

The WHP research is consistent with the prevention theme for ground water research, as well as ORD's approaches to long-term basic research, service to EPA client offices, and technology transfer to the States. It also will use results from several emerging topics identified in this Plan, such as sorption, model validation, transport of agricultural chemicals, and monitoring strategies.

2. Preventing Ground Water Contamination from Pesticides: Information Systems for State Use

The problem of pesticides in ground water is national in scope, but locally variable, therefore accurate predictions of pesticide transport and transformation requires specific information at the local level. Evaluation of all likely combinations of pesticides, environmental settings, and management practices is virtually impossible using random, large-scale monitoring studies or limited site-specific investigations. However, tools are available to locate problem areas, and develop strategies for regulation and use of pesticides on a local level. These tools include models which have been developed to predict the leaching of pesticides to ground water, data which has been collected on soil properties and other relevant environmental factors, and geographic information systems (GIS) for displaying and analyzing spatial information. To date, these types of tools have not been systematically integrated into a workstation framework for State and local risk management.

The main purpose of this initiative is to provide such a framework for States upon which they can develop locally meaningful pesticide management plans. The work will also include field evaluation of monitoring and modeling schemes. The project will be carefully coordinated with related research on the effects of agricultural chemicals on water quality at the USGS and USDA, in order to ensure integration of information and dissemination of results.

3. Subsurface Cleanup and Mobilization Processes (SCAMP)

The potential effectiveness of "pump and treat" technology to remediate contaminated ground water and soils is largely unknown, but widely practiced. Further, the technology sometimes fails to accomplish the mandates of the Superfund Amendments and Reauthorization Act of 1986 (SARA) which states that cost-effective technologies be utilized for the permanent remediation of contaminated sites. The successful application of this technology in site remediation requires an understanding of site characterization methods and the processes controlling contaminant transport and mobilization in the subsurface. Poor understanding of these processes and inadequate site characterization are the most common reasons that pump and treat does not perform as a cost-effective, permanent remedy. This does not mean that pump and treat should be abandoned, but that a research program should be carried out to significantly improve its efficacy, and current guidelines for the implementation of this technology should be reexamined with new recommendations for its use.

The overall objective of the research is to acquire process and characterization information that will allow development of a decision-making framework for predicting the appropriateness and potential efficacy of "pump and treat" for site remediation. This research will support the goals of the Superfund and RCRA programs by providing information necessary to improve remedial actions at hazardous waste sites.

The effort will consist of up to seven phases or activities: 1) consolidation of existing information, and development of a 5-year plan for research and development projects and outputs; 2) development of improved methods for site characterization; 3) research on immiscible fluid flow and residual saturation, and their effects on pump and treat methods; 4) research on mass transport in heterogeneous media, and its effect on pump and treat methods; 5) research on contaminant sorption to geologic materials, and its effect on pump and treat methods; 6) research and development of accelerated remediation methods, such as combination of pump and treat with use of surfactants or micro-organisms; and 7) technical assistance and technology transfer to Superfund personnel.

The SCAMP research is a fundamental part of the ground water remediation theme of this Plan, and several emerging topics including site characterization, behavior of immiscible substances, sorption, bioremediation, effects of heterogeneous media, and model refinement. It also strongly supports the CERCLA and RCRA programs in site remedy decisions, and responds to several Regional research priorities expressed in a recent survey of Regional Superfund offices. In addition, it addresses several research activities recommended by the SAB, as noted in Chapter 2 of this Plan.

B. Proposed Initiatives for FY 1992 and Beyond

Of the many remaining research needs in ground water, two high-priority research areas have been identified for special consideration in FY 1992 planning and beyond. With consideration of limited funding availability, the following two initiatives address many, although not all, of the emerging topics discussed earlier in this Plan.

1. Improving Performance of Remedial Technologies (IMPORT)

The Superfund Research Plan for FY92 identified the evaluation of contaminant fate and transport mechanisms as a major Regional need. Without adequate information about the subsurface behavior of contaminants, remedial goals for soils cannot be set and the performance of remedial technologies for soils and ground water cannot be predicted. Contaminated soils frequently act as a source of pollutants to ground water, either by direct contact with the water table or as recharge water percolates through the vadose zone to the water table aquifer. Soil cleanup goals for Superfund sites do not emerge from a standardized methodology and frequently do not reflect risk associated with alternative pathways, such as exposure to contaminated water. Given the relationship between groundwater quality and contaminated soil, it should be possible to establish soil cleanup goals at Superfund sites that are quantitatively related to drinking water standards. To accomplish this, the Superfund program needs to understand subsurface contaminant fate and transport. Basic research that focuses on the physical and chemical parameters of subsurface contaminant transport will provide a firm technical basis for setting remedial goals for soils at Superfund sites. In addition, such research provides the basis for evaluating and predicting the effectiveness of existing and potential in situ remedial technologies.

The purpose of IMPORT is two-fold: (1) to develop a systematic approach to determining remedial goals at Superfund sites; and (2) to improve the knowledge base for selecting and implementing in situ remedial technologies. This initiative would complement the FY91 SCAMP initiative, which will include some subsurface process studies as an integral part of predicting the length of time required for pump-and-treat systems to remediate ground water. A joint ORD/OSWER five-year research plan would be developed to coordinate IMPORT research on subsurface assessment, characterization, monitoring, and prediction for remedial planning .

These integrated efforts would result in improved guidance on site-specific remedial planning for Superfund sites in the areas of cleanup goals for contaminated soils and the selection of remedial technologies for contaminated soils and ground water. A critical component of this initiative would be an aggressive technology transfer and technical support program to synthesize information, transfer it to field personnel, and assist in its application to ongoing remedial projects. The necessary resources will be anticipated and reserved during development of the comprehensive research plan to ensure the rapid transfer of this information.

The IMPORT initiative would address the remediation theme of this Plan, and the emerging topics of information for remedy selection and post-closure monitoring strategies. This research would also strongly support EPA and State CERCLA and RCRA decisions on remedy selection, and was strongly suggested by Regional Superfund offices in a recent survey of research needs. It also addresses several recommendations made by the SAB, as discussed in Chapter 2 of this Plan.

2. Mid-West Agrichemical Subsurface/Surface Transport and Effects Research (MASTER)

EPA, USGS, and especially USDA have various research projects in progress studying the effects of agriculture on the quality of ground water and surface water. Although each agency has its unique responsibilities and areas of expertise and concentration, there is mutual concern about the fate of agricultural chemicals as they move through the environment that could best be addressed through a coordinated plan of study. Such a plan was drafted in February, 1989, and selected the mid-continent soybean and corn-growing region to determine the regional factors affecting the distribution of atrazine, an herbicide of long-standing use, through the environment.

It is expected that methodologies developed through this interagency research could be used by the agricultural community and others to predict the effects of various soil, hydrogeological, and climatic factors and management practices on the distribution of agricultural chemicals on ground and surface waters in other parts of the U.S. This interagency effort will, among other things, generate basic and applied research into the transport and transformation of agricultural chemicals in midwest farmland. The information afforded from this research will provide a better basis for predicting and controlling the leaching of agricultural chemicals into drinking water aquifers.

Currently, ORD's role in the interagency effort is mainly as an advisory body. However, EPA's concerns with environmental impacts of pesticides, wellhead protection, and non-point source pollution suggest that basic knowledge in this area is of primary importance. The interagency initiative presents an excellent opportunity to share and contribute to an important research effort. An interagency work group has met and agreed on several proposed research areas for EPA, should funding become available.

Of particular benefit to EPA would be the addition of research components to this interagency effort for studying

subsurface degradation processes of agricultural chemicals, behavior of nitrates in surface and ground waters, macropore flow in the subsurface, testing and improving EPA-developed pesticide leaching models, real time monitoring methods, non-point source monitoring strategies, interaction of pesticide runoff with wetlands and potential recharge to ground water, and ecosystem effects.

This initiative would address the prevention theme of this Plan, and the emerging topics of monitoring strategies for non-point sources, subsurface behavior of agricultural chemicals, and model validation. MASTER is not entirely a ground water initiative, however much of the investigation is within the scope of this Plan. Several recommendations of the SAB would be addressed by this research, as discussed in Chapter 2. The goals of this initiative are also consistent with the President's Water Quality Initiative, EPA's Agricultural Chemicals in Ground Water Strategy, and the Agency's support for interagency coordination in research.

3. Other Initiatives to Consider for the 1990s

Other research initiatives to consider for the future, in line with the themes, emerging topics, and approaches discussed earlier include:

- Further development of bioremediation methods, including continuation of such essential efforts as characterizing subsurface controls on implementing bioremediation in situ for contaminated ground water, and developing methods for evaluating and augmenting bioremediation processes in the subsurface.
- Enhancement of wellhead protection research, such as assessing the relative impacts of multiple sources of contamination to underground water supplies, as well as identifying and preventing "unaddressed" sources of contamination, e.g., from Class V injection wells.
- RCRA Technical Support Centers. Expand the existing infrastructure for Superfund technical support at ORD laboratories to address similar problems at RCRA sites.
- Enhancement of technology transfer to State and local users. New and innovative means of transmitting research results can be developed.
- Further development of in situ , real-time monitoring devices, to provide faster, less costly results for planning, regulatory compliance, and remedial actions.
- Characterization of subsurface heterogeneity, and quantifying the dispersion term in different settings. This impacts the results of virtually all of the transport models EPA uses.
- Abiotic transformations of contaminants. Non-biological transformations in the subsurface are not well understood for many compounds, and have significant effects on mobility and toxicity.
- Methods for measuring redox potential in ground water samples. This property is essential for understanding certain reactions and modeling the subsurface, yet current methods may be inadequate for measuring it.
- Develop chemical-specific reference documents, or environmental profiles, containing physical/chemical properties, environmental transport and fate information, remedial methods and treatability information for significant ground water contaminants.
- Analysis of water quality trends in ground water used for drinking water supplies. There are various approaches to analyzing the growing body of information on ground water quality to better understand national and regional trends.
- Subsurface transport of pathogens. Much remains to be known about the public health risk of viruses and bacteria transported via ground water to water supplies.
- Potential effects of alternative fuels use and storage on ground water quality. While the use of certain fuels may improve ambient air quality, potential leakage of highly mobile fuel products from storage tanks may endanger ground water quality.
- Effects of global warming on ground water. Global warming may have significant impacts on ground water quality and quantity, for example through water table lowering of major aquifers and changes in recharge patterns.

C. Future Funding of ORD Ground Water Research

At the current funding level of approximately $23 million/year, ORD can respond to some but not all of the research needs expressed by programs. To respond to a range of needs, both on the generic and site-specific scale, on-going research and new initiatives must be better supported.

An increase in the ground water research budget could potentially support within five years a significant improvement in the development and evaluation of databases, codes, and field methodologies to respond to many of the outstanding needs of EPA programs. For example, an increase of funds in transport and transformation (currently funded at approximately $9M/yr.) could advance current research efforts to the stage where we might understand and begin to predict with some accuracy: a) the behavior of major classes of organic compounds in major hydrogeologic settings, b) the transport of contaminants in certain complex environments, such as fractured rock, c) abiotic transformations of certain common compounds, and d) biotransformation in the subsurface, particularly under anaerobic conditions.

With an increase in the monitoring budget (currently at approximately $7M/yr.) we could move forward in developing advanced, low cost screening and monitoring techniques for major contaminants. In aquifer remediation (currently at ap-

proximately 5M/yr.) we could be much farther along in developing, evaluating, and predicting the time and cost involved with a number of subsurface remedies. In underground source control (currently at approximately 1M/yr.) we could significantly advance our knowledge of the impact of injection wells on the subsurface and consequent effects on ground water.

In technology transfer and technical assistance (currently at approximately 1M/yr.) we could provide much needed support for information clearinghouses, technology transfer to States, and greater support for EPA enforcement cases and other site-specific ground water activities. We could make major progress toward improving data management systems for storing and accessing the vast amount of information available for site characterization.

A larger budget in general would also improve our ability to provide seed money for promising external projects, and leverage other agencies and organizations for cooperative research efforts.

Congress has considered new legislation for ground water research over the past several years, including authorization for additional appropriations. The potential impact on current research activities is not clear, however significant new funds might be appropriated to carry out the legislative provisions, such as research demonstrations, environmental profiles of significant ground water contaminants, and grants to States.

The potential results of not advancing ground water research through some mechanism (legislative or otherwise) are, (1) early contaminant detection and ground water protection limited by untested monitoring approaches, (2) uneven predictability of contaminant transport and subsequent human and ecological exposure, (3) poor source control planning where based on crude predictions of contaminant fate and transport, and (4) inefficient or ineffective remedial actions at hazardous waste sites and other ground water corrective actions.

Aside from these impacts on implementation of EPA and State programs, there are potential impacts of a lagging knowledge base for future rulemaking and national policy development. A strong, current knowledge base in ground water has benefits for many aspects of environmental programs.

★U.S. GOVERNMENT PRINTING OFFICE: 1990 - 748-159/20467

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